Low Temperature Injury to Apple Trees
A Study of the Effects of an Unusual Low Temperature
in October 1925

by
Harry Esmond Nichols

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INTRODUCTION

The vicissitudes of Iowa winters have long been a subject of deep concern to fruit growers. Early in the history of the state, in 1842 and 1843, many fruit trees were killed by extremely low winter temperatures. On several subsequent occasions, some combination of unfavorable weather conditions has caused injury and death to thousands of fruit trees in Iowa. After each such winter, many fruit growers gave up in despair, but a few of the more far-sighted, profiting by their experience, proceeded to plant again, leaving out the varieties which suffered most severely. The last of the more severe low temperature tests occurred in October 1925, and is the subject of the present study.

During the last three days of October 1925, a cold wave swept over the North Central states, sending the thermometer at Ames down to $-7^\circ$ on October 30. Temperatures ranging from $-15^\circ$ in northwestern Iowa to $+13^\circ$ at Keokuk were officially reported. Zero temperatures were experienced as far south as southern Iowa and northern Missouri. Temperatures as low as $-28^\circ$ were observed in Montana. Sub freezing weather was reported from every state of the country with the exception of Florida, where the minimum was $37^\circ$. 
In Iowa, moderate to heavy rains during July, August, September and early October, together with moderate temperatures to the 16th of October caused all perennial vegetation to extend its growing period much later than normal. The cold wave the last of October, therefore, found many trees and shrubs in an immature condition which apparently rendered them susceptible to unusually severe damage. Especially was this true of the more tender species and varieties of plants.

In the case of the apple, the damage occurred mostly on trees under 10 years of age. Vigorous growing trees showed the most severe injury. Among the most important varieties most severely damaged were Golden Delicious, Stayman, Jonathan, Grimes and Delicious. Certain hardy varieties including Duchess, Wealthy, Northwestern Greening, Tolman, Ben Davis, Fameuse and Yellow Transparent showed very little or no injury. Nursery stock, especially in southwestern Iowa suffered severely. More injury was reported from southern and central Iowa than from the northern part of the state.

The first kind of damage noted was a splitting of the bark at the ground line. From one to four or five longitudinal cracks from two to six inches in length were observed on many trees of the injured varieties. Where the bark at the ground line had been split, desiccation had caused it to loosen for
an inch or two back from the injury. Where there were several splits scattered around the trunk, the bark had entirely loosened from the wood. Such trees died during the summer of 1926.

In cutting into the bark of the trunk, the cambium was brown. This browning was observed soon after the low temperature of October. At that time, many growers thought their trees were killed. By spring, however, much of this browning had disappeared. Only on the trunk and in the main crotches of certain trees had the cambium been killed.

After growth started in the spring of 1926, it was observed that certain limbs had died while others were alive. Upon examining the bark at the base of these dead branches, it was found that irregular areas of the cambium had been killed entirely around them. In some cases, dead patches of bark of various sizes occurred on the trunks.

On trees planted in the orchard one to three years, and on many nursery trees, the terminal growth was killed and much of the remaining wood was black hearted.

It is estimated that about 5 percent of the trees of the affected varieties in young orchards throughout Iowa were killed, or so badly injured they had to be replaced. A remaining 30 percent were damaged to a greater or less extent while about 65 percent were uninjured.
This low temperature injury to apple trees, the second to cause widespread damage during the first thirty years of the twentieth century, and the ninth in the history of fruit growing in the state, is the chief subject of the present study. This study includes (1) a history of past damages caused to apple trees in Iowa by low temperatures, (2) a survey of the damage caused by the low temperature of October 1925 including, (a) varieties damaged, (b) geographic extent of the damage, (c) the nature of the injury on the tree, (d) some methods of treating the injuries, (e) the persistence of the injury in certain Iowa orchards, and (3) a study of the persistence of the damage in 1557 Delicious hybrids growing on the Horticultural Farm at Iowa State College.
REVIEW OF LITERATURE

The literature on the effect of weather on fruit trees is voluminous. No attempt will be made here to review the whole field, as it has been reviewed in detail by Murneek (43), Gardner, et al (32), Chandler (11), Dorsey (16), Hildreth (28), and many others.

In general the literature on this subject may be classed into three groups, as follows: (1) literature dealing with the occurrence of winter injury, usually describing the type of damage, its extent, and causal factors, (2) that dealing with the cause of various types of injury, and (3) literature describing various methods of determining the hardiness of seedling trees.

The most complete work on the occurrences of winter injury, the various types of weather conditions involved, and the economic loss sustained is that of Bradford and Cardinell (7) who describe the effect of eighty winters on Michigan orchards. Many writers have described the effects of certain test winters on fruit trees, among them, Beach and Close (4), Blake (5), Bradford and Cardinell (7), Craig (12), Eustace (20), Green and Ballou (23), Hansen (26), Macoun (38), Moore (41), Nelson (44), Oskamp (45), Overholser, et al (46), Paddock (47), Shelby (52), Wells (55), and Whipple (57).
Macleon (37) has classified ten different types of injury on fruit trees; root killing, bark splitting, trunk splitting, sun scald, crotch injury, killing back of branches, black heart, trunk injury, killing of dormant buds, and winter killing of swollen buds. All of these types of injury have been reported by the above mentioned workers and have been noted in Iowa.

**Root injury.** Howard (28), Potter (49) and Carrick (9) have studied the effect of low temperature on root injury. Potter (49) concludes the reason apple roots kill more readily in dry than wet soil is because the temperature falls more rapidly and usually lower in dry than moist soils. Carrick (9) found that the hardiness of roots depends mostly upon their maturity. Howard (28) noted that small, young roots were more susceptible to cold than large, older roots. Root killing is more prevalent in winters with little snow following a dry summer and fall.

**Bark splitting** was reported on Golden Delicious in 1925 by Wells (55). It is the most common external type of injury occurring on young trees and is caused by the expansion of the bark by freezing when in a very succulent condition. The splitting usually occurs near the ground line where the bark, according to Mix (39), is the least mature.
Trunk splitting is a rather common type of winter injury in Iowa. The wood of the trunk often splits to the center of the tree or beyond. Under Iowa conditions such cracks usually close with warm weather and are soon covered with callous tissue. Several theories have been advanced as to the cause of this phenomenon. Gardner, et al (22) states that the generally accepted theory "is that a rapid fall of temperature induces a considerable contraction of the bark and the outer wood while the inner wood, still at a much higher temperature, does not shrink equally; hence the splitting."

Sun scald is very commonly found in Iowa orchards, especially on high headed trees and those that have been blown over towards the northeast. Mix (39) found as much as 37\(^\circ\) F. difference in temperature between the northeast and the southwest sides of apple trees in March. He also observed a fall in temperature from 59\(^\circ\) to 27\(^\circ\) F. between 2:00 and 9:00 p.m. He believes sunscald to be due to actual freezing to death of the tissues caused by the rapid drop in temperature subsequent to warming up by the 2:00 p.m. sun.

Crotch injury was a very common type of injury noted on the apple in Iowa following the 1925 October freeze. Bark on the inside of crotches was killed. Often the dead area extended entirely around a main branch. Chandler (10) found
that the last places on a tree where the wood matures are at the ground line, and on the inside of upward growing branches or on the outside of downward growing branches. Hence due to immaturity in these parts of the tree the wood, cambium and live bark may be killed while no injury occurs elsewhere.

**Killing back of twigs.** This type of injury may be found practically every winter under Iowa conditions on less hardy varieties, especially where they have been grown under conditions that have stimulated a late growth as described by Macoun (37), Chandler (11), Gardner (32) and others. Several Iowa orchards planted one or two years before the time of the October 1925 freeze showed this type of injury. It was especially noticeable on apple trees growing in the nursery row.

**Black Heart.** Macoun (36) reports black heart as one of the most common types of winter injury in Canada. It is also very common in Iowa; only a few of the most hardy varieties not showing any discoloration of their wood. During many winters with low temperatures, the last formed wood is killed while the cambium and bark remain uninjured. This dead or injured wood assumes various shades of brown or black, depending upon the degree of injury. Later growth incases this browned area in healthy wood. Black heart was the most common type of winter injury persisting in Iowa as a result of the low temperatures of October 1925.
Crown rot, often called collar rot or collar injury, is a very common type of injury found in Iowa orchards, and was quite noticeable following the low temperatures of October 1925. Although it has not been definitely established whether or not all types of crown rot are caused by low temperatures, Mix (39) and Chandler (10) state that the tissue at this point matures more slowly than higher in the tree making it more susceptible to injury. Such injury is not only found at the crown of the tree but also higher on the trunk. This form of crown rot is very similar to crotch injury.

Fruit buds are often killed by low winter temperatures. Although such injury is much more common on the peach, as reported by Whitten (58) and Chandler (10), yet Whipple (57) found as high as 98% of the fruit buds killed in certain varieties of apples in Montana, following the winter of 1910-11. Bradford (6) in December of 1921 found Jonathan flower buds killed at Columbia, Missouri.

Factors Influencing the Occurrence of Injury.

Of the many factors causing injury to plant tissue, the two most self evident and important are temperature and maturity. During the growing season most plant tissue is injured by temperatures very little below freezing. When the wood is mature and the tree in a dormant condition, some species of
apple will withstand a very low temperature. Macoun (36) mentions a hybrid between Pyrus baccata and Pyrus malus withstand- ing a temperature of $-58^\circ$ to $-59^\circ$ F.

In the apple there is considerable variation in the sus- ceptibility of varieties to injury by low temperatures. Beach and Allen (3), Dorsey (14), Wilson (56), and many others have shown that this variation is due primarily to the time re- quired in the fall for the varieties to mature their tissues.

The amount of rainfall and the periods of drought and precipitation during the growing season play an important part in determining the susceptibility of trees to winter injury. Craig (12) and Hansen (36) have pointed out the effect of the dry season of 1898 upon root injury when coupled with the low temperatures of the ensuing winter. Wells (55), and Shelby (53) describe injuries caused by low temperatures following a wet fall; conditions that had prevented the maturing of the plant tissues.

Craig (12) noted more root injury occurring on apple trees growing in a light sandy soil than on trees growing in a heavier soil.

The effect of various cultural practices such as clean cultivation, sod, and cover crops are noted by Bradford and Cardinell (7), Hansen (36), and others. They have pointed out that any cultural practice favoring early maturity reduces the susceptibility of a given variety to winter injury.
Physical Methods of Determining the Degree of Injury to Woody Tissues.

Various investigators have for years been searching for some method by which the relative hardiness of apple varieties and seedlings may be measured. Correlations between many physical and chemical factors have been tried. As yet, no simple, clear cut method has been found.

Beach and Allen (3) unsuccessfully attempted to correlate hardness and density of wood with hardiness. They found, however, that earliness of maturity of wood was correlated directly with earliness of leaf fall and formation of the terminal buds. Hildreth (28) exposed terminal growth of several varieties to artificial low temperatures and found that there was a close correlation between the degree of injury resulting and the hardiness rating of the varieties as shown by field experience. Dorsey (14) examined the discoloration of the wood in the trunks of many varieties of apples and found that the degree of browning varied with the severity of the winter and the hardiness of the variety. He considers this degree of browning a "most sensitive index of winter injury". He classified the degree of browning in apple wood into four classes; no injury, slight brown, medium brown, and dark brown. Dorsey (14) also noted that the trunk of a tree shows more discoloration than the smaller branches or twigs. Wilson (56),
using a method devised by Beaumont and Hildreth in which the degree of browning in nine different areas of the terminal and lateral bud was used as a measure of winter hardiness, found a significant correlation between the time of leaf fall and hardiness. Twig elongation showed very little correlation.

In a study of the inheritance of winter hardiness in certain wheat crosses, Quisenberry (50) concludes that hardiness in wheat "although inheritable, is very complex and greatly influenced by environment". In measuring the amount of winter damage sustained by wheat he used an "hardiness index" which was computed as follows: "Before growth stopped in the fall, counts were made of the total number of plants in each row. In the spring, after growth was well started, the number of surviving plants was counted. The surviving plants were classified as 'strong' or 'weak', depending upon their vigor of growth. In obtaining a mathematical measure of survival for each row, the number of strong plants was multiplied by one and the number of weak plants by 0.5. The sum of these two calculations divided by the total number of plants in the row in the fall, gave a survival percentage which was weighted for the spring condition of the plants."

The Iowa State Horticultural Society Reports.

Most of the subject matter in the subsequent report on Iowa test winters has been secured from the sixty-four annual
reports issued by the Iowa State Horticultural Society. This Society was organized in 1867 and was the first branch organization of the State Agricultural Society. This latter society was organized in 1857. The older reports of the State Horticultural Society contain many articles and discussions on winter injury, but very little information about winter injury is to be found in the reports issued since 1900.
Iowa Test Winters

The history of Iowa Horticulture is closely associated with the various factors of Iowa's changeable climate. In fact, the damage caused by the various "test winters" together with the resultant changes in cultural practice and varieties make up a considerable part of the history of fruit growing in the state.

Nearly fifty years before Iowa was admitted to the Union, orchard planting was started. The first orchard was planted near the present town of Montrose in Lee County about 1796, by Louis Honore Tesson, a Frenchman. At that time, Iowa was Spanish territory and only a very few people had settled on the west side of the Mississippi river. After the Louisiana Purchase in 1803, settlers gradually increased in numbers, first settling in what is now southeastern Iowa and as far up the river as Dubuque. During the decade from 1830 to 1840, the eastern part of the state was fairly well settled. About that time, southwestern Iowa from Council Bluffs south was being rapidly filled with people emigrating from Missouri.

There was very little settlement north and west of Des Moines until after 1850. The first settlers reached Story County in 1854, while the extreme northwestern part of the state, the
last to be settled, had very few residents until the seventies.

Most of the people who first settled the eastern part of the state came originally from Illinois, Indiana, Ohio, New York and the New England states. Soon after establishing themselves in this new land, many of them sent back for nursery stock and planted orchards.

The first orchards in Scott County were planted about 1837. The first orchards in Sac County were set in 1862. The first orchard in Taylor County was planted in 1855.

Growers soon found, however, that many of the varieties they had planted would not stand the rigorous winters of their new home.

In 1843-43 came the first "test winter". Very little can be learned about the damage done at that time as contemporaneous information is lacking.

Old records show "that the summer of 1843 was very dry which was followed by one of the coldest winters on record. The Mississippi River froze solid north of the Des Moines rapids (Keokuk) in November 1843 and remained closed until April 8, 1843. In March of that year the thermometer was below zero every day of the month, the average range of the thermometer at Iowa City for March being as low as in January 1856*." Large trees were frozen solid to the center and long continued dry freezing caused many trees to split from the

limbs to the roots, so we could see through the trunk. This usage killed some, while others lived in an imperfect way and bore some fruit.\textsuperscript{6} Root killing was also reported. The loss caused by this first test winter, (of which there is any record) was negligible as very few orchards were growing in the state at that time. However, it made the more horticulturally inclined farmers realize that they could not grow many of the varieties that were successfully grown further east.

During the next fifteen years (1843-1858), large numbers of farm orchards were set out. The state was overrun with "tree peddlers", who represented eastern nurseries. However, their trees proved so unsatisfactory that many small nurseries sprang up throughout the eastern part of the state. By 1859, there were six nurseries in Lee County, some having been established twenty years prior to that date. The first orchard census of the state, taken in 1858, showed a total of 23,310 acres. The available figures do not show, however, what percent of these were of bearing age.

Iowa fruit growing received another setback during the severe winter of 1855-56. Meager reports give very few facts concerning this test winter. The previous summer had been quite dry and the unusually cold long winter killed the roots of many older trees. The effects of this disasterously cold

\textsuperscript{6}Trans. Iowa St. Hort. Soc. 18: 244. 1883.
winter were felt from Iowa and Minnesota to Tennessee and Delaware (?) Southern Michigan reported temperatures of \(-23^\circ\) and \(-34^\circ\). Unlike Iowa, Michigan experienced a very rainy summer, previous to the extremely low temperatures of the winter of 1855-56. Thousands of peach trees were entirely destroyed throughout southern Michigan with the exception of a small area along Lake Michigan in Van Buren County. Many orchards in this section produced a good crop of peaches in 1856. This marked the beginning of the extensive planting of fruit in this section of Michigan.

In Iowa, half or more of all the orchards around Oska-loosa were killed. A young orchard in Floyd County also was nearly killed. Samuel Murdock of Clayton County reports that he had about 275 trees out of 500 left in a good thrifty condition.

This second test winter in Iowa emphasized the fact that fruit growers should plant only the more hardy varieties.

In 1853, Henry and Robert Avery, who started in the orchard and nursery business at Burlington in 1835, reported (32) a list of apple varieties best suited to southeastern Iowa. This list of 25 varieties includes the best of nearly 300 tested during a period of over 25 years and gives a good idea of the sorts suggested for planting at that time:
1. Early Harvest
2. Red June
3. Red Astrachan
4. Sweet June
5. Early Pennock
6. Summer Pearmain
7. Lowell
8. Maiden's Blush
9. Fall Wine
10. Rambo
11. Fameuse
12. Striped Sweet Pippin

13. White Bellflower
14. Black Gilliflower
15. Yellow Bellflower
17. Romanstem
18. Peck's Pleasant
19. White Pippin
20. Rome Beauty
21. Sweet Romanite
22. White Winter Pearmain
23. Roule's Jannet
24. Winesap
25. Winter Limbertwig

After this second test winter, many farmers lost faith in Iowa as a fruit growing region. An often repeated Eastern idea that "Iowa's climate is too severe to grow fruit" was heard once more on all sides. But not for long! In 1858 and 1859, many new orchards were set out. It is interesting to note, incidentally, that during the fall of 1859, many dwarf apple trees were imported from Rochester, New York, into Lucas County and, no doubt, into other sections of the state.

The opening of the Civil War checked orchard planting. With the close of the Rebellion, however, and the return of thousands of soldiers to the pursuits of peace, interest in fruit growing reached the point where, thru the efforts of Mark Miller, a meeting was held in Iowa City on June 26, 1866, and the Iowa State Horticultural Society was formed with 28 charter members*. The first annual report of this Society


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was issued in 1867.

It is interesting to note that one of the essays in the first report is entitled "Fruit and Fruit Trees - Destruction in the Winter of 1865-66 - Causes and Prevention" by W. W. Beebee of Dubuque, the second secretary of the Society. Mr. Beebee sounded the keynote of a subject that has filled hundreds of pages in subsequent reports.

The Test Winter of 1865-66

Considerable precipitation during the fall of 1865 caused a late growth of fruit trees. The first frost of the season occurred (in Fremont County) about October 26th and this was soon followed by a hard freeze. The cold weather persisted for six weeks with no snow. Due to the fact that the soil was so saturated with moisture, no root damage occurred but the tops were injured or killed. Most of this damage occurred in central and southern Iowa with very little reported from the northern part of the state. No report has been preserved as to the nature of the injury on the tree.

Reverend John Todd of Tabor (Fremont County) reports that two thirds of all apple trees were totally destroyed. Trees as old as 12 to 14 years were killed. In one fifty-tree orchard, two years old, four-fifths of the trees were killed. Some in blue grass sod suffered heavily while other sod orchards
escaped injury. Damage was severe in those orchards where cultivation had been extended late into the season.*

As a precaution for preventing the winter damage, Mr. Beebee of Dubuque suggested manuring the trees early in the spring and cultivating only during the forepart of the growing season, stopping by July first.*

During the period from 1860 to 1870, besides the more severe damage done in 1865-66, injury to apple trees caused by low winter temperatures occurred during two other winters; 1863-64 and 1868-69. In the former year, some damage was reported from Fremont County. In 1869, sudden cold weather in October injured one, two and three-year old Sops-of-Wine apple trees.

**Test Winter of 1872-73**

Unprecedented in the history of the Northwest was the winter of 1872-73. Extremely low temperatures were experienced for long periods of time over most of the northern part of the United States. The minimum temperature of -23° at Chicago had been exceeded in both 1856 and 1864. During December and January, however, a continuous cold wave held the entire northern part of the country in its grasp. At East Lansing, *Anl. Rpt. Iowa St. Hort. Soc. 1:65-7. 1867.*
Michigan, the thermometer registered below zero on 31 days. J. L. Budd* summarizing the weather conditions in Iowa stated, "For the three years preceding the terribly destructive winter of 1872-73, the whole amount of waterfall, including snow reduced to water, was only 81 inches, an average of only about 27 inches per year. The autumn of 1872 was memorable for a dearth of water in wells, cisterns and streams, over the whole West, followed by an intensity of cold, reminding us of Arctic climates. As early as December 23rd and 24th, the thermometer ranged as low as 33 below zero as far south in the state as Fairfield, in Jefferson County, followed by a January fully as cold as that of 1856."

The following table shows the relation between mean and minimum temperatures during this period. The mean temperature for January 1873 was 11.4° below the average for the previous 20 years.

Table I
Mean and Minimum Temperatures in Iowa in 1872 and 1873

<table>
<thead>
<tr>
<th>Month</th>
<th>Ave. Mean</th>
<th>Mean Temperature</th>
<th>Minimum Temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>December</td>
<td>24°</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>January</td>
<td>22°</td>
<td>16.9°</td>
<td>10.6°</td>
</tr>
<tr>
<td>February</td>
<td>25°</td>
<td>23.8°</td>
<td>17.6°</td>
</tr>
<tr>
<td>March</td>
<td>35°</td>
<td>27.0°</td>
<td>22.4°</td>
</tr>
</tbody>
</table>

Trees and shrubs went into the winter with their wood well matured. Very little damage was noted on fruit trees during the winter, although in a few cases, bark cracking on the trunk was observed. Most trees started into growth the following spring, blossomed and set fruit. Soon after blossoming, however, the fruit dropped off, the leaves turned yellow and the tree died. Early in the spring, nurserymen found the roots of many nursery trees killed. C. L. Watrus of Des Moines reports "at least a fourth and probably a third of all the apple trees dug from nurseries and transplanted last spring (1873) failed to live thru the season." Widespread destruction to fruit trees, vines, ornamentals, and evergreens was reported throughout the Middlewest. The bark, cambium and outer wood was not damaged but heartwood was discolored. In all cases of death, the roots were killed.

The Ben Davis, which up to that time had been considered hardy, was severely damaged in northern Iowa. J. S. Mott of Postville (Allamakee County) did not know of a single Ben Davis left alive in his section where the temperature dropped (unofficially) to -40°. Mr. Mott reported the only varieties of apples to escape injury were Tetofsky, Red Astrachan, Oldenburg (Duchess), Saxon Stripe, St. Lawrence, Haas, Fameuse, Plum Cider, Pewaukee and Walbridge. One third of Mr. Mott's trees were killed, one third injured and one third escaped injury. In a bearing orchard belonging to Judge
Murdock in Clayton County, only six trees out of five hundred were killed, all Ralls. In a 17 year old orchard, belonging to James Redpath (Black Hawk County) containing 1840 trees, which was plowed in June, and in which no mulch grew on account of the drought, all but two of twenty-eight varieties were killed or fatally injured. The two varieties that withstood the winter were Rosseau, and Golden Russet. Another Black Hawk County orchard belonging to R. F. Speer containing 1300 trees of mostly hardy varieties from 4 to 7 years old, were not injured. This orchard was cultivated until June, when buckwheat was sown. This was later removed and the orchard plowed with the furrows thrown towards the

tree.

The amount of damage differed in the various sections of the state. The greatest injury occurred in northeastern Iowa, with comparatively little in the northwestern section. The damage was not nearly as severe in southeastern Iowa as farther north. Some damage, however, occurred in all sections of Iowa.

Most of the varieties considered hardy at that time were not injured. Growers, who had profited by their experience from previous test winters and had planted hardy sorts, reported very little injury. However, Ben Davis, Saps-of-Wine, Tolman, and White Pearmain were either severely injured or
occasionally killed. All of these varieties had been considered hardy up to the winter of 1872-73.

Serious damage occurred on both young and very old trees. Many nursery trees were killed, especially where late cultivation without cover cropping had been practiced. Old trees that had borne heavy crops the previous season and trees growing in pastured sod were mostly killed. Where the trees had been given winter protection by mulching with earth or cover crop very little or no injury occurred.

Mr. Pugsley of Woodbine (Harrison County) found where he sowed buckwheat in his young orchard, no winter injury developed, but where it was not sown and the ground was bare, the trees were all killed. Reports indicated that trees protected on the south were uninjured, while those exposed to the southwest wind were badly injured. Many trees planted in the spring of 1873 were killed.

Professor Budd states that the injury from the 1872-73 freeze was fully 50 percent greater in southern Illinois than in southern Iowa and 30 percent greater in central Illinois than in central Iowa.

**The Test Winters of 1873-74 and 1874-75**

Although the winter of 1873-74 was mild, one and two year old nursery trees were injured by a 10°F. temperature
on October 27, 1873. In some cases the trees were killed to
the ground but most of the damage occurred on the terminal
growths. More damage was reported on trees growing on high,
dry ground than on those growing on lower locations.

In 1874 the season was quite dry followed by severe
freezing weather. In many places in southern Iowa, the ground
froze to a depth of four feet. Many old, weak fruit trees,
grapes and nursery stock were reported killed. Very little
damage was reported on young vigorous fruit trees. The most
damage occurred in southeastern Iowa, with some reported from
Council Bluffs. Here most of the damage was confined to small
fruit and grapes.

Around Des Moines, a 2.5 percent loss of one-year old
apple trees in the nursery row occurred with some damage to
two and three year old nursery trees. No damage was reported
from around Davenport or from northern Iowa.

**Test Winter of 1876-77**

Following the season of 1876, when the state had its
largest apple crop up to that time, winter temperatures began
early, being quite severe from November 23 till the end of
January. In Van Buren County, the temperature dropped to -23°F
November 28th. This cold winter followed a cold wet fall,
during which growth continued till later than usual.

Most of the damage was reported from the eastern half of the state. In northeastern Iowa, much damage was expected to show the spring of 1877 as the wood just under the bark was badly discolored. However, this discoloration disappeared soon after growth started and "we are taught the lesson that too much stress should not be placed on this discoloration of wood as examined in the latter part of the season." Yet in many places, many of the more tender varieties were killed or badly injured. Bark cracking on the north side of trees was reported. More injury was noticed on trees growing on low ground.

In Jones County, Ralls was the most severely injured, some trees being entirely killed. Jonathan suffered badly, while Ben Davis, Fameuse, Plum Cider, Fall Orange, Haas, Tetofsky, and Oldenburg (Duchess) were uninjured. At Davenport, Ben Davis, Willow, Ralls, Dominie and Maiden Blush were killed or badly injured. N. K. Fluke of Davenport reported "out of an orchard of 1200 trees, six to ten years old, containing 20 varieties, all considered hardy, the only kinds uninjured were Red Astrachan, Oldenburg (Duchess), Little Romanite, Golden Russet, and Virginia Crab." He also suggests Virginia Crab as a possible stock*. No damage was reported

from Ames, but at Des Moines, there was considerable bark bursting especially on Willow and Dominie.

At Charles City, considerable damage to fruit trees was caused by sun scald, due it was thought, to a very warm February.

The following winter, 1878-79, was mild and favorable to fruit trees in most of northern Iowa. However, mild weather in March was reported as inducing an early movement of the sap, which, followed by freezing temperatures, caused the bark to "cleave from the wood" causing fatal injuries to the tree.* Farther south in the state, considerable damage was reported.

Western Iowa suffered from drought in 1879. At Sibley, Osceola County, the total rainfall for 1879 was 17.88 inches with less than one inch from August 1, 1878 to May 12, 1879. The soil was very dry around Council Bluffs during the fall of 1878. A mild winter with some snow saved most apple trees from damage, but grapes and cherries suffered heavily. A large cherry orchard in Mills County was entirely killed. Cherries budded on both Mahaleb and Morello stock suffered alike.

Perhaps the greatest damage was done in southeastern Iowa along the Des Moines River. In Van Buren County⁰, 12 inches of snow fell December 13, 1878 with the ground barely

frozen. Later the temperature ran very low during December and January, ranging from a little above zero to $-34^\circ$ F. Entire orchards were killed along the low lands of the Des Moines River. On one farm two orchards, one 38 years old and the other 10 years old were both entirely killed. In other orchards, many trees died suddenly after coming into full leaf and others later on in the season. Upland orchards lost no trees but every orchard had branches killed. Most damage was found on Falls, followed by Smith Cider, Willow and Dominie.

**A Late Fall and a Cold Winter**

Professor Budd* states that there never was such an extensive loss of fruit trees in the state as that caused by winter injury during the winter of 1882-83. A higher percentage of trees were damaged in 1872-73, but the larger number of trees growing in the state in 1882 made the difference. The most damage occurred in the eastern two thirds of the state; extreme northwestern and southwestern growers reporting very little or no damage. Late spring frosts in 1882 had killed much foliage. As a result, coupled with a late growing fall, the wood was not well ripened, when on December 7th,

a blizzard blanketed the state and the thermometer dropped to $-20^\circ\text{F.}$ at Waverly. The temperature over night dropped from $30^\circ\text{F.}$ to $-20^\circ\text{F.}$ On January 4, 1883, the minimum temperature was variously reported from $-33^\circ\text{F.}$ to $-40^\circ\text{F.}$ The ground under the snow was not frozen. The greatest loss of trees occurred where the snow was the deepest and the soil the wettest.

Tree roots were uninjured; all injury occurred on the trunks and in the main crotches of the trees. On the trunk, the bark was killed and in many cases, split from the ground line to the branches. In Bremer County, N. A. Reeves reported that the bark on the northwest side of Ben Davis apple trees was killed while the bark on the southeast side was uninjured.

Both young and old trees suffered. At Fort Dodge, 30 percent of the apple trees 15 years old and over were killed or injured, while young trees were not hurt so badly. In Delaware County, many trees of all ages, of varieties other than Oldenburg (Duchess) and Haas were killed. Oldenburg (Duchess) in Buchanan County were reported killed in low ground. At Waverly, Mr. Reeves reported 150 Ben Davis in one orchard all killed. He also reported that most of the Ben Davis, Jonathan, Sweet Pear and Red June were killed; Saxon, Red Romanite and Ralls were partially killed while Duchess, Red Astrachan, St. Lawrence, Plum Cider, Pewaukee, Haas, Utter,
Walbridge, Golden Russet, Tolman and Perry Russet were not damaged.

On the Missouri River bottom at Whiting (Monona County), Ben Davis and Winessap were killed while Famineuse, Willow and Perry Russet escaped any damage. Near Keokuk, a Grimes orchard, 45 years old, was entirely killed.

Trees thought injured by the winter of 1882-83 died during the next few years. Many trees died around Des Moines during the summer of 1884.

Many Early Richmond and English Morello cherries were killed in northwestern Iowa by the severe winter of 1883-84. No damage, however, was reported from other sections of the state.

The winter of 1884-85 was a repetition of that of 1882-83. A very warm October, followed by a sudden freeze with deep snow covering ground that was barely frozen caused the killing of many trees and the severe injury of many others. Trees of all sizes and ages were injured or killed with the exception of Oldenburg (Duchess), Tetofsky, Whitney and certain hardy crabs. Bark bursting on the trunk was the only form of injury reported. No doubt most of the damage was caused by the killing of the cambium on the trunk or main branches.
Most of the damage occurred in southeastern Iowa; yet considerable injury was reported from southwestern and the north central part of the state. In Harrison County, Mr. Pugsley reported that all Ben Davis, Jonathan, Winesap, Minkler and Dominie were badly injured or killed. At Odebolt (Ida County), 900 trees in a 1000 tree, eleven-year old orchard were killed. Hardy varieties such as Wealthy, Plum Cider, Red Astrachan, and Walbridge were even injured.

In Van Buren County, many nursery trees were killed to the snow line. Rambo, Wagener, Dominie and Maiden Blush suffered the most. The next spring these trees were cut back below the snow line without further injury developing.

Reports from northern Illinois show that probably as a result of the temperatures during the two bad winters of 1882-83 and 1884-85, one half the cherries, two thirds of the apples, three fourths of the pears and over nine-tenths of the peaches were dead or dying. Conditions in central Illinois were little better.

Cultural practices governed the amount of damage. One observer in Union County reported:

1. All orchards growing on a north slope were in fair condition.

2. Closely planted orchards, where the ground was shaded were in good condition.
3. Cultivated orchards were the most severely damaged; those grown up to weeds or grass were not badly injured.

4. All orchards vigorously pruned during the past 4 years were severely damaged.

The severe winter conditions of 1882-83 and 1884-85 were followed by two very dry summers in 1886 and 1887; the latter the driest known. In many places, winter injured trees that had not been killed by the cold succumbed to the drought.

A Dry Summer Followed by a Cold Open Winter

For 14 years following the disastrous winter of 1884-85, the weather conditions were such that fruit plants were not damaged. Then came the fall and winter of 1898-99, bringing conditions different than any experienced by the oldest horticulturists. A dry summer and fall followed by a very severe winter without snow, killed the roots of many fruit plants. In some places in central Iowa, the ground froze to a depth of 9 feet, with an average of 4½ feet*. Nursery and young fruit trees and old weak trees suffered the most damage. Dwarf pears on quince stock, quince, Japanese varieties of plums and

*Trans. Iowa State Hort. Soc. 34:27. 1899.
Bradshaw and Lombard plums were all killed at Davenport. Many shellbark hickory, red cedar, Balsam fir and white oak were also either killed or badly injured.

Following several dry seasons and a dry summer in 1896, late October rains caused a late growth of roots, although the tops were well matured. Leaves started to fall even before there was any frost. Around Oskaloosa during the last two weeks of January and the first two weeks of February, the thermometer went to \(-36^\circ\) to \(-30^\circ\) F. with only one or two exceptions for 21 consecutive days. The ground froze from four to six feet, as there was no snow. Greatest damage occurred on sandy soil and under conditions of clean culture and bare ground.

The greatest damage occurred throughout central Iowa with the least in the northern part of the state. Trees in southern Iowa were severely damaged. Considerable injury was also reported from Kansas and Missouri. In a 1000 tree two-year old apple orchard near Oskaloosa, 100 trees were killed. At Davenport, L. W. Clemons lost 1500 out of 2000 peach trees while only 100 out of the remaining 500 were not injured. In Guthrie County, most of the Ben Davis were killed. Northwest Iowa suffered more than the northeastern part of the state. In Cherokee County, all nursery trees were killed while many older trees were also dead. Similar conditions existed at
Milford in Dickinson County. No damage was reported from Howard County.

A survey of the state made during the summer of 1899 showed trees in good health as follows: apples 70 percent, American plums, 76 percent, European plums 20 percent; Japanese plums 18 percent, cherries, 75 percent, pears 50 percent, peaches five percent, and grapes 24 percent.

Slight damage was reported around Waverly in 1899-1900 on nursery stock and on old trees injured the previous winter, by a dry fall, followed by a cold December followed by warm weather the last of January. The extent of the damage, its nature, and the varieties most severely damaged were not reported.

No further damage to fruit trees was reported until the winter of 1911-12 when a severely cold winter caused some damage in northern Iowa to trees that had previously been damaged by drought.

Following the winter of 1916-17, many grape vines in the Council Bluffs district failed to start into growth and on many others the growth was very inferior; their roots had been killed or badly injured. Fifteen percent of the grapes in this district were killed. This injury had been caused by severe cold winter weather, with insufficient snow coverage, following a dry summer and fall. Some root injury on Jonathan was also noted on the clean cultivated plots in the State Experimental orchard at Council Bluffs.
The Test Winter of 1917-18

In 1917-18, damage by winter killing was very extensive in the East and in Canada, the area extending as far west as Nebraska and Kansas. Damage was less severe in the western portion of the affected area than further east. All the injury occurring on apple trees in the eastern states was above ground, while west of the Mississippi, root injury and black heart were more common. This difference in type of injury in these two sections of the country was due to differences in rainfall conditions throughout the previous growing season.

Eastward from the convergence of the Ohio and Mississippi Rivers, above normal precipitation during the late summer and early fall months, caused perennial plants to make a late growth. In Iowa and other western portions of the affected area, both the seasons of 1916 and 1917 had been quite dry, with no resultant late growth.

Freezing weather descended upon this area the middle of October. At Des Moines the temperature dropped to 16° F. October 13, 1917, ruining many apples that were still unpicked. A severe cold wave, which carried the thermometer to -17° F. at Des Moines, swept over the north central and eastern states the latter part of December.
At Council Bluffs the minimum air temperatures from December 31, 1917 to February 4, 1918 ranged mostly below zero, with a minimum of $-23^\circ$ F. on January 14th. In the State Experimental orchard, the soil temperatures at a depth of 12 inches for four consecutive weeks ranged between $23^\circ$ and $25^\circ$ F. Very little snow fell prior to and during this cold weather in western Iowa.

Root killing occurred on Jonathan and Grimes, especially where the ground had been clean cultivated the previous summer. Many of these trees died during the summer of 1918. Wood of many of the more tender varieties was badly blackhearted. Many older Ben Davis trees, especially, were so injured by a combination of winter injury and dry summers that they fell prey to blister canker (nummularia descreta Tul.)

It is not known if blackheart was common in all sections of the state. However, it has been particularly noted at Council Bluffs, at Ames, and in Polk County. At Sioux City and Fort Dodge, grapes were killed to the ground. C. H. True of Edgewood (Clayton County) reported some damage to more tender types of plants, but mentions no injury on apples.

The injury caused by the low temperatures of October 1925 is reported elsewhere and therefore will not be further mentioned at this time.

Some damage was observed by the extremely cold winter of 1929-30. In January of 1930, the temperature dropped to
nearly – 40° F. in Mahaska County. Many peach trees were killed or badly damaged throughout southeastern Iowa. At Bonaparte (Van Buren County) lower limbs on bearing Ben Davis trees located on low land were killed but the rest of the tree was undamaged. In the same vicinity, young Delicious trees were also badly top killed. In Clinton County, three-year old Delicious and Jonathan trees growing on low ground were killed while many others on higher sites were badly blackhearted.
METHODS OF PROCEDURE

The various subjects of this study have been approached from different angles, each requiring different methods of procedure. These methods will be described under their respective headings.

Weather Conditions that Caused the Injury.

Since temperature and precipitation relationships are the principal causal factors involved in winter injury to fruit trees, a detailed study was made of the particular weather conditions existing in 1935.

Fruit trees were injured by the sub-zero temperatures of October 28, 29 and 30, 1935 following a season characterized by sub normal precipitation during the spring months followed by above normal precipitation during late summer and fall. This heavy precipitation in early fall combined with high temperatures extended the growing season of many perennial plants. Killing frosts did not occur in Iowa until October 7 to 10. Normal temperatures held until October 25 to 27 during which time seven inches of snow fell at Ames. On the three succeeding days, the minimum temperatures were 6°, 0°, and -7° F. with a maximum ranging from 23° to 31° F. At the time of this sudden drop in temperature, apple trees were still in practically full leaf.
The U. S. Weather Bureau reports October 1925 as having a greater temperature deficiency than any October in the previous fifty years or more. This departure from normal extended over the whole country with the exception of the extreme southeastern and northwestern parts of the United States. The greatest departure from normal occurred in the north central states where the total mean departure from normal ranged from $-8^\circ$ to $-12^\circ$ F.

Fig. 1 shows the departure from normal temperatures during the month of October 1925. Iowa is included in the area where there was a departure of $-10^\circ$ F. from normal. In South Dakota and nearby territory the lowest temperatures were from $5^\circ$ to $15^\circ$ F. lower than ever before observed in October. October 1917 was the only October in the past 50 years when similar conditions prevailed. A greater departure from the mean October temperature occurred that year but the area affected was not nearly as extensive.

The lowest temperature observed was at a point in Montana, $-28^\circ$ F. $-15^\circ$ to $-30^\circ$ F. were reported from points in South Dakota, Nebraska and Iowa, with zero temperatures reported as far south as Northern Missouri. Sub-freezing temperatures were reported from some point in every state of the union with the exception of Florida where the minimum for the month was $37^\circ$ F. Most minimum temperatures occurred from October 28 to

Fig. 1. Departure (°F) of the Mean Temperature from the Normal, October, 1925.

From Monthly Weather Review
U.S. Weather Bureau.
Vol. 53 - 1925. Chart III.
31, when a cold wave swept from the Rocky Mountains to the Atlantic Ocean.

During this period in Iowa, the minimum temperatures ranged from $-15^\circ$ to $13^\circ$ F. The lowest temperature was reported from Inwood in Lyon County while the highest minimum temperature for the days of October 28, 29 and 30 was reported from Keokuk (Fig. 3). Minimum temperatures were the highest in the area adjacent to the Mississippi River from Clinton County south. With the exception of Lee County, minimum temperatures in the southern tier of counties ranged from $-10^\circ$ to $-5^\circ$ F. In all cases, the higher temperatures were reported from stations located in the larger cities of the state.

The mean temperature for Iowa for October 1925 was $41.3^\circ$ F. which was $11.7^\circ$ below normal and the coldest in 53 years. There was a striking contrast between October 1925 and October 1924 which was the warmest in 47 years. The mean temperature for the entire year of 1925 in Iowa was $48.8^\circ$ F. or $0.8^\circ$ above normal (Table 2). May, October, November and December had average temperatures below normal with the remaining months showing above normal temperatures. The mean temperatures for the first 10 days in September were the second highest ever recorded in the state.
Fig. 2. Minimum temperatures during October 28, 29, 30, 1925.
Table 2

Monthly Weather Data for Iowa 1925

<table>
<thead>
<tr>
<th>Month</th>
<th>Temp. Deg. F.</th>
<th>Precipitation Inch</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean: Normal</td>
<td>est: test: Average</td>
</tr>
<tr>
<td>Jan.</td>
<td>19.4: + 0.9</td>
<td>55: -34: 0.40</td>
</tr>
<tr>
<td>Feb.</td>
<td>38.4: + 5.8</td>
<td>66: -16: 0.83</td>
</tr>
<tr>
<td>March</td>
<td>40.1: + 5.4</td>
<td>52: - 6: 0.93</td>
</tr>
<tr>
<td>April</td>
<td>56.6: + 7.6</td>
<td>95: +21: 2.20</td>
</tr>
<tr>
<td>May</td>
<td>57.8: + 2.4</td>
<td>102: +20: 1.16</td>
</tr>
<tr>
<td>June</td>
<td>70.4: + 1.1</td>
<td>98: +35: 6.64</td>
</tr>
<tr>
<td>July</td>
<td>74.1: + 0.3</td>
<td>105: +40: 2.66</td>
</tr>
<tr>
<td>August</td>
<td>72.4: + 0.7</td>
<td>99: +39: 3.47</td>
</tr>
<tr>
<td>Sept.</td>
<td>69.0: + 4.7</td>
<td>105: +32: 5.04</td>
</tr>
<tr>
<td>Oct.</td>
<td>40.2: -11.7</td>
<td>78: -15: 2.91</td>
</tr>
<tr>
<td>Nov.</td>
<td>36.1: - 0.5</td>
<td>68: - 6: 0.71</td>
</tr>
<tr>
<td>Dec.</td>
<td>21.0: - 3.1</td>
<td>64: -25: 1.30</td>
</tr>
<tr>
<td>Means &amp; Extremes</td>
<td>48.8: + 0.8</td>
<td>105: -35: 28.34</td>
</tr>
<tr>
<td>Normals &amp; Records</td>
<td></td>
<td>113: -47: 32.22</td>
</tr>
</tbody>
</table>

Heavy precipitation in the early fall months had some effect upon the degree of injury suffered by fruit trees, yet its effect is not so well defined as in the case of temperature. Average precipitation for 1925 in Iowa was 28.34 inches or 3.98 inches below normal; only the months of June and September showing notable excesses. The western section of the state experienced serious drought during part of the year, which extended more seriously into the Dakotas. In eastern Iowa there was an excess of precipitation over normal.

Davenport reporting 7.3 inches excess for the months of April to October inclusive.

Table 3 summarizes the minimum October 1925 temperatures, the departure from normal rainfall and the severity of damage to fruit trees in various sections of the north central states.

Table 3

Summary Weather Data for October 1925
for
Certain Midwestern Points

<table>
<thead>
<tr>
<th>Departure from Normal October Temperature</th>
<th>Station</th>
<th>Min. Temperature</th>
<th>Deviation from Normal</th>
<th>Fruit Tree Injury</th>
<th>Rain Reported</th>
<th>Fall</th>
</tr>
</thead>
<tbody>
<tr>
<td>-8 to 10°F F.</td>
<td>Lansing, Michigan</td>
<td>19</td>
<td>-3.1 in.</td>
<td>Common</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8 to 10°F F.</td>
<td>Milwaukee, Wis.</td>
<td>18</td>
<td>-7.3</td>
<td>Bad</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8 to 10°F F.</td>
<td>Springfield, Ill.</td>
<td>13</td>
<td>-1.8</td>
<td>Some</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8 to 10°F F.</td>
<td>Columbus, Ohio</td>
<td>20</td>
<td>+6.9</td>
<td>Some</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8 to 10°F F.</td>
<td>Kansas City, Mo.</td>
<td>17</td>
<td>+3.2</td>
<td>Some</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8 to 10°F F.</td>
<td>Topeka, Kansas</td>
<td>16</td>
<td>+3.5</td>
<td>Slight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8 to 10°F F.</td>
<td>Wichita, Kansas</td>
<td>19</td>
<td>+4.3</td>
<td>Very slight</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-8 to 10°F F.</td>
<td>Helena, Montana</td>
<td>5</td>
<td>+6.7</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 to 12°F F.</td>
<td>Minneapolis, Minn.</td>
<td>10</td>
<td>-7.3</td>
<td>Some</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 to 12°F F.</td>
<td>Charles City, Iowa</td>
<td>1</td>
<td>+1.5</td>
<td>Some</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 to 12°F F.</td>
<td>Davenport, Iowa</td>
<td>11</td>
<td>+7.3</td>
<td>Bad</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 to 12°F F.</td>
<td>Des Moines, Iowa</td>
<td>7</td>
<td>+2.8</td>
<td>Bad</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 to 12°F F.</td>
<td>Lincoln, Nebr.</td>
<td>3</td>
<td>+2.6</td>
<td>Some</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 to 12°F F.</td>
<td>Omaha, Nebr.</td>
<td>8</td>
<td>+3.4</td>
<td>Bad</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 to 12°F F.</td>
<td>Sioux City, Iowa</td>
<td>5</td>
<td>+6.4</td>
<td>Some</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 to 12°F F.</td>
<td>Yankton, S.Dak.</td>
<td>-5</td>
<td>+3.5</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>-10 to 12°F F.</td>
<td>Bismarck, N.Dak.</td>
<td>- -</td>
<td>-1.9</td>
<td>None</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over -12°F F.</td>
<td>Rapid City, S.Dak.</td>
<td>-13</td>
<td>+1.5</td>
<td>Some</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Departure from Normal from April to October, inclusive.
Description of the Injury.

The injuries to apple trees caused by the low temperatures of October 1925 were on those parts of the plant above ground. Roots were apparently not injured. Bark splitting at the ground line was the most common type of injury observed. In many cases the cambium was killed on the trunk, in the main crotches and in a few cases on the southwest side of scaffold and secondary branches. Terminal growth was killed back on many trees which had been growing one and two years in the orchard. This type of injury was very serious on nursery stock, especially in southwestern Iowa.

The most seriously injured tissue was the late formed xylem, which in most tender varieties was injured or killed. Cambium was killed, especially in areas of varying size on the trunk, and in the main crotches of the tree. Black heart was common, which indicates considerable injury to the older xylem. Killing of pith was not studied. Neither was the killing of cork cambium or outer bark studied. No doubt in most cases where the bark was dead, its death was caused by the killing of the cambium directly below it. No study was made of injury to phloem.

On the apple most of the injury occurred on trees under ten years of age of those varieties usually considered susceptible to winter injury. Golden Delicious and Grimes were
the most seriously affected varieties followed in order by Stayman, Delicious, Jonathan and Winter Banana. Since these varieties compose 92 percent of the young trees in commercial orchards in Iowa, considerable economic loss was sustained by the fruit growers of the state. No damage was noted on Yellow Transparent, Oldenburg, Wealthy, Whitney, Ben Davis or Cano.

Slight damage was observed in a few orchards on bearing trees but in most cases trees from three to ten years old sustained the greater injury. No external damage was noted in two orchards set out in 1924, except some killing back of terminals. Subsequently, however, black heart was observed in both orchards. Apple trees growing in the nursery were more seriously damaged, many trees being killed to the snow line and many others badly blackhearted. One nursery in south-western Iowa suffered extremely heavy losses on tender varieties. The trees were growing on a very fertile bottom land soil.

Such factors as soil fertility, orchard site, and soil cultural methods practiced during the 1925 season, played but a slight part in the amount of damage sustained. No difference in the amount of injury showing on trees growing in cultivated and uncultivated orchards was observed. A difference was noted in one Des Moines County orchard where there was a difference in elevation and soil fertility. In this orchard the ground sloped to the north with trees of larger
size on the lower, more fertile soil. These larger trees showed considerably more damage than the smaller trees in the higher parts of the orchard. Several trees were completely killed in this orchard, all of them located in the lower part of the orchard, and all of them the largest trees in the orchard.

In Lee County one orchard growing on a very sandy soil on the second bottom of the Mississippi River showed 30 percent of the 687 trees examined injured to a greater or less extent. Two other orchards within 10 miles of this one but located on a heavy soil type and on the bluffs above the river showed less damage. These two orchards were not checked carefully, however, for the exact percentage of damage. With the exception of the above mentioned cases no other differences were observed in amounts of injury on trees growing under different cultural conditions.

Immediately after the low temperatures occurred, the first injury observed was the cracking of the bark at the ground line. Upon examining the cambium and outer xylem, growers found a browning of this area on most trees of the tender varieties. This browning usually extended from the snow line into the main crotches of the tree and on all sides, some reporting a greater discoloration on the north side of the tree. Many growers feared that most of their trees had been killed. However, by late winter most of this browning
had disappeared. A similar condition was reported by an Iowa fruit grower in 1877. A microscopic examination of this discolored tissue was made by the Pomology Section during the early winter of 1925-26. Microphotographs showed many scattered cambial cells killed, but enough were left alive to regenerate the tissue the following spring. The latest formed xylem tissue was much more severely injured than the cambium. After the 1926 growing season, cases were found on apparently normal wood where the xylem formed during 1926 entirely encased a ring of dead xylem about one eighth inch thick. A more extensive examination of Delicious hybrids, made in 1930, showed that this condition was quite general.

In some cases, however, all the cambial cells were killed. Usually these were confined to small areas (Fig. 10), which later entirely healed over. Two cases were noted, however, where the cambium had been killed for a distance of eight to ten feet from the ground on the southwest side of larger branches (Fig. 3)
Fig. 3. Close-up of northwest branch of Grimes tree in Story County, showing injury, resulting from the October 1925 freeze. The branch broken off was dead. Photo taken September 1927.
A large number of cases were observed where the cambium had been killed in the main crotch of the tree. Some trees were noted where the cambium around all the main scaffold branches was killed. Such trees never leafed out in 1926. More cases were noted where the dead cambium encircled only one or two main branches, killing them while the rest of the branches were apparently uninjured. Such damage was most common on Grimes, Golden Delicious, and Jonathan.

Although the killing of cambium caused considerable damage, bark bursting at the ground line was more common and caused much loss. In most cases one crack was found on a tree, and it was usually on the northwest side. However, on many trees two to four cracks ranging in length from two to ten inches were formed. In these cases, the bark dried back from each crack about two inches, often girdling the tree. (Fig. 4).
Fig. 4. Delicious tree about 10 years old in orchard of J. W. Harper, south of Ames, Story County, killed by bark cracking in several places at ground line which resulted in the death of the intervening strips of bark. Photo taken September 23, 1927.
Where only one crack occurred, the injury usually healed completely within five years, and where these injuries were protected from wood rotting organisms, little damage was done.

Another form of damage near the ground line was crown injury. In this, the cambium was killed but the dead bark continued to adhere to the wood. It was not always possible to tell the exact cause of the injury at the ground line when this study was made. Consequently, the two forms of injury were recorded together. Fig. 5 shows a large trunk injury on a 10 year old Delicious tree, which was photographed in 1927 two years after the injury occurred. Patches of dead bark are still adhering to the wood, especially on the lower right hand corner of the injury. It is not possible to tell whether this injury was caused by bark splitting, by a direct killing of the cambium by low temperature, or by a combination of the two.
Fig. 5. Trunk injury on a 10 year old Delicious tree. Photo taken September 23, 1927. Trees still alive May 1931.
Besides these two more commonly observed forms of injury, perhaps the type that will cause the most economic loss as time goes on is black heart, or the killing or injury of the xylem. A study of 1496 Delicious hybrids at Ames showed 50.8 percent of the trees showing varying degrees of black heart in the wood formed prior to 1926. Examination of pruning wounds on many trees all over the state shows much black heart in the 1925 and older wood. Many trees that were older than 10 years in 1925 show this black heart (Plate F).

Geographic Distribution of the Injury*. Fruit trees were injured by the low temperatures of October 1925 to a greater or less extent in eleven North Central states. The most severe damage was noted in the area extending from southeastern Nebraska and northwestern Kansas, northeastward thru northern Missouri, Iowa, southern Minnesota, Wisconsin and Michigan. Some damage to nursery stock and orchard trees was reported from Hot Springs, South Dakota. Slight damage to apples, and, in some cases, rather severe damage to cherries and peaches occurred in south central and southeastern Kansas, southern Missouri, Illinois, southern Indiana, and in both southern and northern Ohio. No damage

*From correspondence with Middle West Horticulturists.
was noted in Kentucky, in eastern South Dakota, North Dakota or Montana.

A study of Fig. 6 shows the area in which injury occurred. It closely coincides with the isotherm of $-30^\circ$ F. (as shown on Fig. 1) with the exception of the northwest section of this area. During October 1935 where there was a deficiency of temperature of from $-30^\circ$ to $-10^\circ$ F. from the normal October temperatures, injury occurred to fruit trees. In the northwestern part of this area, namely eastern Montana, North Dakota and the greater part of South Dakota, no damage was reported, although temperatures were as low and, in most cases, lower than in Iowa.

Two conditions probably, combined to produce this result. The first is found in the fact that only exceptionally hardy varieties are or can be grown in this area. The second is found in a sub-normal precipitation throughout this area during the summer of 1935, resulting in early maturity of fruit tree wood, making it resistant to low temperatures injury. For the months of April to October inclusive, 1935, there was a total deficiency of precipitation at Yankton, South Dakota of 8.5 inches and at Bismarck, North Dakota of 1.9 inches. The only point in this territory reporting normal or excess rainfall was Rapid City, South Dakota, which may be taken as representative of the vicinity of Hot Springs which received 1.5 inches of rainfall over the normal during the same period.
Fig. 6. Geographic Range of Injury to Fruit Trees Caused by Low Temperatures in October 1925.

+ = Severe Damage
- = Slight Damage
o = No Damage
Here there was also a departure in temperature from normal of \(-13^\circ\), the lowest reported in the whole country. This extreme departure from normal temperature, combined with the above normal rainfall, no doubt explains why injury occurred in this section while none was reported from eastern South Dakota.

In Iowa, injury to apple trees has been observed in forty-six counties while none was noted in three counties. Fig. 7 shows the location of these counties. These observations have been made during the past five years and are based upon an examination of a very limited number of orchards in each county. The amount of damage was much greater in the southern and central parts of the state where those varieties usually considered more susceptible to winter injury are commonly grown. These same varieties were also damaged in northern Iowa, but very few of them are found in this section of the state. Since the greater proportion of the apple trees in northern Iowa consist of varieties usually considered hardy, comparatively little loss was sustained by growers in that section.
Fig. 7. Where injury caused by the low temperatures of October 28, 29, 30, 1935 has been observed in Iowa.

\[ x = \text{Injury found} \]

\[ o = \text{No injury found} \]
Furfural Mixture No. 1 as a Wound Dressing for Winter Injured Apple Trees.

During the summer of 1926, trunk injuries on a number of trees in the orchard of E. J. Garlock, Grimes, Polk County were treated with a furfural mixture prepared by the Plant Pathology Section of Iowa State College. This furfural mixture, commonly called Furf I, was made from the following formula: one pound each of commercial creosol and furfural were boiled in a reflex condensor with about one third ounce of sodium bi-carbonate until a resin formed. Boiling was discontinued when a thin film, upon cooling, became brittle. The resultant resin was thinned to the consistency of varnish by a mixture of equal parts of acetone and furfural.

In treating some of the injuries, the dead bark was removed and the edges of the injury smoothed back to live bark. In other cases, the dead bark was left and the mixture painted directly on it. In all cases several coats of Furf I were applied. This mixture readily penetrated exposed dead tissue.

The treated wounds were examined September 20, 1927. Where the dead bark had been scraped off before applying the Furf I, most of the injured areas were covering with new tissue at a satisfactory rate (Fig. 8). In some cases, however,
the bark had been killed back nearly an inch from the original wound by the Furf I. Where the Furf I was applied direct to the adhering dead bark, it did not penetrate the wood beneath (Fig. 9). On the larger wounds, wood checking was not prevented by painting with Furf I.

Furf I did not prove a satisfactory wound dressing for winter injured apple trees.
Fig. 9. Injury on northwest side of five year old Golden Delicious tree in orchard of E. J. Garlock, Polk County. In 1926 this wound was scraped of all dead bark and painted with Furf I. In this case this wound dressing did no harm to adjacent live cambium, but in other cases the cambium was killed back about an inch. Photo taken September 20, 1937.
Fig. 9. Severe injury on southwest side of Golden Delicious tree. In 1936 Furf I was painted over the dead bark then adhering to the injury. Photo taken September 30, 1937, two growing seasons after injury occurred. The dead bark was scraped from this wound just before photographing. Note that the Furf I did not penetrate thru the dead bark into the wood. Also note work of the apple tree bark beetle (Scolytus rugulosus Ratz) in dead branch.
The Persistence of the Injury in Certain Iowa Orchards

To note the persistence of the injury caused by the low temperatures of October 1925, a detailed external examination of 1112 trees in four young orchards in widely separated sections of the state was made from two to four years after the injury occurred. Casual examination of many other trees in other sections has been made during the past six years. In some instances, no accurate check upon the number of trees killed could be made as they had been removed and replaced by new trees at the time of the examination.

Detailed examinations were made in the following orchards:

George Schurk, Fort Madison, Lee County, 687 trees.
W. P. Campbell, Woodbine, Harrison County, 238 trees.
Asbery Bond, Richland, Keokuk County, 33 trees.
S. W. Brookhart, Washington, Washington County, 154 trees.

The trees in these orchards ranged in age from five to seven years in 1925. Varieties examined were Jonathan, Grimes, Stayman, Golden Delicious, Delicious and Gano.

Two types of injury were observed on the injured trees, dead bark on the base of the trunk which originally was caused by bark splitting or crown injury, and dead bark in the main
crotches caused by the killing of the cambium and perhaps
the last formed xylem tissue in 1925. A summary of the
injury found on the 1112 trees examined is shown in table
4.

Table 4.
Injuries Showing on Trees Two to Four Years after
Low Temperature of October 1925

<table>
<thead>
<tr>
<th>Variety</th>
<th>No. Trees</th>
<th>Injury</th>
<th>Percentage of trees showing injury on</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Trunk</td>
<td>Crotch</td>
</tr>
<tr>
<td>Gano</td>
<td>25</td>
<td>100%</td>
<td>0</td>
</tr>
<tr>
<td>Delicious</td>
<td>292</td>
<td>77</td>
<td>18.2</td>
</tr>
<tr>
<td>Jonathan</td>
<td>453</td>
<td>73.8</td>
<td>22.7</td>
</tr>
<tr>
<td>Stayman</td>
<td>49</td>
<td>57.2</td>
<td>36.7</td>
</tr>
<tr>
<td>Grimes</td>
<td>216</td>
<td>48.1</td>
<td>41.6*</td>
</tr>
<tr>
<td>G. Delicious</td>
<td>70</td>
<td>13.0</td>
<td>82.6</td>
</tr>
<tr>
<td>Mean</td>
<td>1112</td>
<td>65.3</td>
<td>29.4</td>
</tr>
</tbody>
</table>

*13.8% were injured on both trunk and crotch.

By an examination of table 4, it will be noted that
in these orchards the average percentage of killed trees of the
more tender varieties was 2.3 while 32.4 percent showed injury
on the trunk at the ground line or on the inside of the
crotches of the main scaffold branches, and 65.3 percent
showed no injury two to four years after the freeze. It will also be noted that the varieties ranged in amount of injury as follows: Golden Delicious, Grimes, Stayman, Jonathan and Delicious. It was the concensus of opinion of Iowa fruit growers that Grimes suffered more seriously than any of the more commonly grown varieties.

Strangely contrasting effects of the freeze were observed, in two orchards of approximately the same age located at opposite sides of the state where Grimes was double worked about 14 to 16 inches from the ground line on Delicious stock. In the orchard of George Schurk in Lee County, the Grimes showed considerable injury in the crotches and on the trunk as far down as the Delicious wood, on which no injury could be observed. In a few cases the Grimes were completely killed to the Delicious wood. Sprouts grew from the Delicious stock in the spring of 1926, and the tops of all these trees are now Delicious. The opposite condition prevailed in the orchard of W. P. Campbell in Harrison County where the Delicious stock was injured while the Grimes wood above the stock showed no damage two years after the injury occurred. On only one double worked Grimes tree in this orchard, out of 8 showing injury, was there damage on the Grimes. Fig. 10 shows typical injury after two years' growth on Grimes topworked on Delicious.
Fig. 10. Typical injury on Grimes topworked on Delicious. Photo taken September 20, 1927 in orchard of E. J. Garlock, Grimes, Polk County. Injury on north side of tree. Trees four years old in 1925. Note how injury extends in the Grimes wood to the Delicious stock.
There was considerable variation in the behavior of the varieties which showed the most damage and in the percentage of injured trees in these two orchards, as will be noted in table 5. Perhaps the differences in location and soil type explain the variations. The Lee County orchard is located on a very sandy soil on the second bottom of the Mississippi River, while the Harrison County orchard is located on a high level elevation on Missouri loess soil.
Table 5.
Variation of Injury Showing on Certain Tender Varieties of Apples Caused by the Low Temperature of October 1925.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Lee County</th>
<th>Harrison County</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Percent of trees showing</td>
<td>Percent of trees showing</td>
</tr>
<tr>
<td></td>
<td>No Trunk : Crotch:</td>
<td>No Trunk : Crotch:</td>
</tr>
<tr>
<td></td>
<td>Damage: Injury: Dead</td>
<td>Damage: Injury: Dead</td>
</tr>
<tr>
<td>Grimes</td>
<td>27.8% : 54.7% : 35.2%</td>
<td>9.2 : 36.0 : 15.0 : 0 : 0</td>
</tr>
<tr>
<td>Golden</td>
<td>0 : 100.0 %</td>
<td>0 : 0 : 6.5 : 87.0 : 0 : 6.5</td>
</tr>
<tr>
<td>Delicious</td>
<td>75.6 : 21.4 : 1.0</td>
<td>2.0 : 52.0 : 40.0 : 2 : 6.0</td>
</tr>
<tr>
<td>Jonathan</td>
<td>80.4 : 17.0% : 4.8%</td>
<td>1.0 : 95.0 : 5.0 : 0 : 0</td>
</tr>
</tbody>
</table>

*26.9% of trees showed injury on both trunk and crotch.
*3.3% of trees showed injury on both trunk and crotch.

The outstanding difference in injury as shown in these two orchards was on the Grimes and Jonathan. Twenty three and two tenths percent more of the Jonathan examined in the Harrison County orchard showed injury than in the Lee County orchard. On the other hand, only 15 percent of the Grimes in the former orchard showed damage, most of this on the Delicious stock, while in the Lee County orchard 9.2 percent of the Grimes trees were dead or dying and 63.0 percent showed greater or less injury.
Many growers did nothing to protect the exposed wood from wood rotting fungi. To secure data on the need for treatment of these injuries, 154 trees of Stayman, Delicious, Golden Delicious, Grimes and Jonathan in a young orchard in Washington County were examined in 1930, four years after the injury occurred. At the time of examination, 50.6 percent of the trees showed no external indications of having been injured. No doubt some of these trees would have shown slight injury if they had been examined in 1926 or 1927. Of the remaining 49.4 percent that showed injury (most of which was on the northwest side of the trunk at the ground line), 35.7 percent were healing satisfactorily while 13.7 percent had been attacked by wood rotting organisms which were causing enough further damage to materially shorten the life of the trees.

Newly planted orchards and orchards of only two or three years standing did not suffer as much external damage as orchards four to ten years from planting. Gerald Adams, Moorhead, Monona County, has an orchard which had grown two seasons when the low temperatures of October 1925 occurred. This orchard is about 15 miles northwest of that of W. P. Campbell at Woodbine and is growing on a similar soil type and location. In 1927, 40 Stayman were examined, none of which showed external injury. Mr. Adams reported practically no damage observed on the rest of the twenty-acre orchard, most
of which consisted of Delicious, Grimes and Jonathan. In subsequent pruning in this orchard, however, black heart has been observed in many trees of all these varieties.

In a twenty-acre orchard at Delphos in Ringgold County owned by W. P. Lauck, planted in 1923, much of the current season's growth of 1925 was killed back. This orchard consists mainly of Delicious, Grimes and Jonathan. The difference in susceptibility of these varieties to this type of injury was not observed. No injury was noted on the trunk or in the crotch of any of these trees.
The Persistence and Degree of Injury on Certain Delicious Hybrids caused by the Low Temperatures of October 28, 29, 30, 1925.

Included in the thousands of cross bred apples growing in the Horticultural orchards at Iowa State College are 1553 young seedling trees of Delicious parentage that were growing in the orchard at the time of the unseasonable low temperatures of October 28, 29, 30, 1925. These appeared to offer desirable material for a study of low temperature injury, (1) to ascertain the effect of low temperatures on Delicious hybrids, (2) to study the nature, degree and persistence of this injury after five years of growth, and (3) to note any possible correlation between this injury and the grade and size of the trees.

History of Orchard

All of the Delicious hybrids included in this study, were secured by hand pollination, made prior to 1919. The seeds were planted in 1918, 1919 and 1920, and the resultant trees planted in their present locations in 1924 and 1925. These Delicious hybrids included 22 different crosses using 19 varietal parents. In five cases, the Delicious was the female parent, in three, reciprocal crosses are included, while in the remaining 14 cases, Delicious was the male parent.
The number of trees in the various progenies growing in the orchard in 1930 ranged from two in the case of Ames 411 to 352 in the case of Antonovka. Only those crosses containing 30 or more trees were included in the following statistical study, but all the Delicious hybrids were examined for winter injury. The hybrids not included in the study were those where the following parent was crossed with Delicious; Harrington, Patten 1015, Hibernal, Repka Malenka, Willow Twig, Wolf River, King David, and Ames 411.

The different crosses studied will be found in the following tables. These Delicious hybrids included reciprocal crosses made with Northern Spy, Jonathan and Salome. In each of these cases, the reciprocals have been summarized together. Of all the remaining crosses, Delicious was the male parent. In all 1496 trees were included in the statistical study.

Included in the material studied were progenies of Delicious with three Patten seedlings, Patten 1000, Patten 1003, and Patten 1011. The parent trees of these seedlings were originated at Charles City, Iowa, by C. G. Patten and were selected for breeding because of their apparent hardiness. The Patten 1000 was called Roman Stem No. 10 by Mr. Patten and was an open pollinated seedling of Roman Stem. Seedlings of this variety show characteristics indicating Russian origin. Patten 1003 is an open pollinated Oldenburg seedling. The origin of Patten 1011 is not known.
Records on injury were secured by removing one large limb and counting the annular growth back to the 1925 wood. In cases where the branch had grown since 1925, another limb was cut and examined. In a few cases, on smaller trees, where the removal of such a branch would severely injure it, records were not taken. When these cuts were examined, many showed no discoloration, while others showed various degrees of browning ranging from a very slight browning to very bad blackheart in which various wood rotting organisms were growing.

All wood showing browning in the annular rings formed prior to 1926 was further classified on the degree of browning into three classes, "slight", "medium" and "bad". (Plate E). "Slight" injury (Plate C) included those showing a very slight degree of browning, an injury so slight that it is doubtful if it had interfered in any way with the normal functioning of the wood. "Medium" (Plate B) included those showing a darker browning, indicating, in the judgment of the experimenter, that normal functioning had been affected detrimentally but not to a degree that would later materially affect the proper functioning of the limb. The classification, "bad" (Plate A) included wood black in color; xylem that could not function.
Plate A

Range of injury classified as "bad" persisting in Delicious hybrids five years after the low temperatures of October 1925. Wood rotting organisms have gained entrance in some of these injuries.
Plate B

Range of injury classified as "medium" persisting in Delicious hybrids five years after the low temperatures of October 1925.
Plate C

Range of injury classified as "slight" persisting in Delicious hybrids five years after the low temperatures of October 1925.
Plate D

Normal wood of Delicious hybrids classified as showing no injury due to the low temperatures of October 1925.
Plate E

Classification of degrees of injury persisting in Delicious hybrids five years after the low temperatures of October 1935.

1. No injury.
2. Slight injury.
Plate F

Black heart persisting in 13 to 14 year old Grimes wood, following the low temperatures of October 1925. Sections taken at six inch intervals. Photographed September 1930.
Plate G

Discoloration showing in healed over pruning wounds. Most of the discoloration extends downwards while a lighter discoloration extends upwards from the wound.

(Longitudinal section of wound entirely healed over is upside down).
In some cases, wood rotting organisms had gained entrance and the heartwood was disintegrating. Uninjured or normal wood is shown in Plate D. Early in the study, it was observed that a few cases of badly browned wood accompanied old pruning wounds (Plate G). Where this was found to be the case, another limb was removed and examined.

Dorsey (14) in examining similar injuries on a large number of apple varieties in Minnesota, found the browning in the wood of the trunk variable. By cutting into the trunk with a sharp hatchet, he observed greater injury on the south than on the north side. In the branches of the tree, however, he did not observe this difference in browning between the northern and southern sides.

In the present study, with the assistance of Dr. J. H. Martin of the Botany Department and H. L. Lantz of the Pomology Section, the writer made a preliminary examination on 15 trees to determine whether the injury showing in one branch was indicative of the condition of the whole tree. Where several branches from one tree were removed and examined, it was found that the degree of injury was quite constant in nearly all cases. As a result of these preliminary examinations the records taken were based on the observations of one branch taken from each tree.

Data on the "grade" of the trees examined were taken from records made in 1929 by H. L. Lantz. In placing the trees in the different grades, both vigor and habit of growth were
considered. Generally speaking, those trees which were classed as "very good" were strong, vigorous growers and generally averaged 18 inches or more in terminal growth, were strongly shouldered and otherwise of good orchard habit. The compact or bushy types, even though making a growth of 18 inches or more were placed in the lower grades as were also the undesirable upright, narrow crotched trees. The trees rated as "good" were less vigorous and were less desirable in habit of growth than those graded as "very good". "Fair" trees, in most cases, were deficient both in vigor and desirable orchard habit, and generally made short annual growths varying from 6 to 13 inches. Those trees graded as "poor" were slow weak growers, which very often made less than six inches of growth annually. The trees in the two upper grades would normally be classified as desirable orchard trees. Those trees in the two lower grades, in all probability, would be undesirable and discarded because of their deficiency in vigor or habit of growth.

In the fall of 1939, Mr. Lantz also measured the height and breadth of these trees. From these data the "volume" index of the trees was computed by the formula \((H-3)B^2\). Two feet was subtracted from the height to allow for the distance from the lower branches to the ground. Apple trees vary in shape from conical, through ellipsoidal to spherical.
As time did not permit the making of an estimate of the shape of each tree, this factor, together with the constant \( \pi \), was omitted from the calculations. The resultant "volume index" is somewhat larger than the actual volume of the tree, and therefore is not the true volume. The range of the volume indices of all the Delicious hybrids was from 12 to 1859, with a mean of 400.3 ± 5.14.

**Injury and Grade Indices**

As the data on the degree of injury and the grade of tree does not lend itself to arithmetical measurements, the usual methods of computing correlation were not used. Therefore another form of average, called here the "Injury Index" and the "Grade Index" was employed.

In computing the "Injury Index" the numerical value of 0 was arbitrarily given to those trees showing no injury, 5 to those showing slight injury, 12 to those showing medium injury and 30 to those showing bad injury. The number of trees in each line of breeding showing these various degrees of injury were multiplied by their respective numerical values and the sum of the products was divided by the total number of trees. For example in Northwestern Greening X Delicious, there was a total of 102 trees of which 30 showed no injury,
26 slight injury, 21 medium and 25 bad injury. The injury index was computed as follows:

\[
\frac{(30 \times 0) + (26 \times 5) + (21 \times 13) + (25 \times 30)}{102} = 11.098.
\]

The grade index was computed in a similar manner, with the numerical value of 1 arbitrarily given to the very good trees, 3 to the good trees, 5 to the fair, and 7 to those grading poor. These grade and injury indices give a value whereby the grade of tree and winter injury of one line of breeding may be compared with another.

The numerical value of the index figure for winter injury is directly proportional to the severity of damage. The higher the index figure the greater the injury observed. In the case of the grade index, the higher its numerical value the lower the grade of tree.

**Results - Amount of Winter Injury Persisting in Delicious Hybrids**

The low temperatures of October 1925 caused varying degrees of damage to 50.8 percent of all the Delicious hybrids examined in the eleven lines of breeding which contained thirty or more trees. Forty nine and two tenths percent of these 1496 trees showed no injury. There was, however, considerable variation in the amount of damage in the different lines of
breeding (Table 6). Where a hardy variety had been crossed with Delicious, the percentage of trees showing no injury ran very high, while the crosses with more tender parents showed considerable damage. In 35 Patten 1000 hybrids, 83.3 percent were found to be uninjured. The percentage of uninjured trees in the hardy varieties such as Antonovka and Anisim also ran very high, 70.5 and 74.4 percent respectively. The progenies of Northern Spy and Jonathan, two of the least hardy of the parent varieties studied, showed the smallest number of trees uninjured. In 285 Northern Spy hybrids, there were only 20.6 percent which did not show injury, and 23.3 percent of the Jonathan hybrids were uninjured.
### Table 6

Persistence and Degree of Injury on Certain Delicious Hybrids Caused by the Low Temperatures of October 1925, together with their 1930 Grade Estimate. Observations made in July and August 1930.

<table>
<thead>
<tr>
<th>Other</th>
<th>No. Trees</th>
<th>Percentage of Trees Showing Injury</th>
<th>Percentage of Trees Grading</th>
</tr>
</thead>
<tbody>
<tr>
<td>Parent</td>
<td>Ob-</td>
<td>: None: Slight: Medium: Bad: Good: Good: Fair: Poor</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>:</td>
<td></td>
</tr>
<tr>
<td>Antonovka</td>
<td>352</td>
<td>: 70.5: 19.0: 6.8: 3.7: 56.0: 26.1: 12.2: 5.7</td>
<td></td>
</tr>
<tr>
<td>Anisim</td>
<td>242</td>
<td>: 74.4: 10.7: 5.8: 9.1: 22.3: 38.0: 26.0: 13.7</td>
<td></td>
</tr>
<tr>
<td>Jonathan</td>
<td>198</td>
<td>: 23.3: 15.7: 20.7: 40.4: 13.6: 27.7: 32.3: 26.4</td>
<td></td>
</tr>
<tr>
<td>Northwestern Greening</td>
<td>102</td>
<td>: 39.4: 25.5: 20.6: 34.5: 24.5: 24.5: 25.5: 25.5</td>
<td></td>
</tr>
<tr>
<td>Black Annette</td>
<td>92</td>
<td>: 53.3: 18.5: 13.0: 14.3: 0: 19.4: 34.3: 46.8</td>
<td></td>
</tr>
<tr>
<td>Pewaukee</td>
<td>67</td>
<td>: 46.3: 30.9: 13.4: 19.4: 30.0: 23.8: 25.3: 20.9</td>
<td></td>
</tr>
<tr>
<td>Patten 1011</td>
<td>60</td>
<td>: 56.7: 23.3: 8.3: 11.7: 10.0: 63.3: 25.0: 1.7</td>
<td></td>
</tr>
<tr>
<td>Patten 1000</td>
<td>35</td>
<td>: 83.3: 8.3: 5.3: 2.8: 40.0: 25.7: 31.4: 2.9</td>
<td></td>
</tr>
<tr>
<td>Salome</td>
<td>32</td>
<td>: 43.7: 31.3: 9.4: 15.7: 25.0: 40.6: 25.0: 9.4</td>
<td></td>
</tr>
<tr>
<td>Patten 1003</td>
<td>31</td>
<td>: 48.4: 22.5: 16.1: 13.0: 45.3: 19.3: 22.5: 13.0</td>
<td></td>
</tr>
</tbody>
</table>
Of the 50.8 percent of the hybrids that showed injury, 31.7 percent showed slight injury only, 14.2 percent medium injury and 14.9 percent bad injury. Although there were some variations, in general, crosses with those varieties usually considered hardy showed the least amount of bad damage while the more tender sorts showed the most. Forty and four tenths percent of the Jonathan were badly injured, while but 2.8 percent of the Patten 1000 and 3.7 percent of the Antonovka showed bad damage. Fig. 11 shows the amount of injury found in these 11 Delicious hybrids.

There was a close relationship between the amount of injury found in these Delicious hybrids and the hardiness rating of the parent varieties. Table 7 lists the standard parental varieties observed in this study in order of their hardiness and shows the percentage of their hybrids with Delicious that showed no injury and bad injury respectively.

Table 7

<table>
<thead>
<tr>
<th>Parent Varieties</th>
<th>Percent of Hybrids Showing no Injury</th>
<th>Percent of Hybrids Showing bad Injury</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antonovka</td>
<td>70.5</td>
<td>3.7</td>
</tr>
<tr>
<td>Anisim</td>
<td>74.4</td>
<td>9.1</td>
</tr>
<tr>
<td>Black Annette</td>
<td>53.3</td>
<td>14.2</td>
</tr>
<tr>
<td>Pewaukee</td>
<td>46.3</td>
<td>19.4</td>
</tr>
<tr>
<td>*Salome</td>
<td>43.7</td>
<td>15.7</td>
</tr>
<tr>
<td>*Northern Spy</td>
<td>20.6</td>
<td>14.4</td>
</tr>
<tr>
<td>*Northwestern Greening</td>
<td>29.4</td>
<td>24.5</td>
</tr>
<tr>
<td>Jonathan</td>
<td>23.2</td>
<td>40.4</td>
</tr>
</tbody>
</table>

*Probably ranking almost equal in relative hardiness.
Fig. 11. Percentage of trees of Certain Delicious hybrids showing browning in Xylem caused by the low temperatures of October 1925. Observations made summer 1930.
By the use of the "injury index" in table 8 it is apparent that the progenies of hardy parent varieties show greater hardiness than those produced by less hardy parent varieties. A further study of table 8 shows parent varieties ranging in hardiness between hardy and tender, have likewise produced progeny whose "injury index" follows closely the hardiness rating of their parent varieties. The progenies of Patten 1000 and Antonovka, both hardy parent varieties, have an injury index of 1.971 and 2.877 respectively while the injury index of the Jonathan progenies is 15.388, while the other progenies range between. The mean injury index of all the Delicious hybrids studied was 7.263 ± 0.206.
The percentage of the 1496 Delicious hybrids under observation falling into the different arbitrary grades were as follows: "Very good" 27.5 percent; "Good" 28.6; "Fair" 36.2; and "Poor" 17.7 percent (Table 6). Here again there was considerable variation between the 11 different lines of breeding. Fifty-six percent of the Antonovka hybrids graded "Very good" while none of the Black Annette hybrids could be so classified. Only 2.9 percent of the Patten 1000 and 5.7 percent of the Antonovka were rated "poor" while 46.8 percent of the Black Annette were so classified (Fig. 12).

The mean grade index of all the Delicious hybrids was 3.713 ± 0.295, ranging from 2.352 in Antonovka to 5.565 in Black Annette (Table 8). The Black Annette hybrids ran quite small in size, while the Antonovka and Patten 1000 trees averaged much larger and were more vigorous as well as having a more desirable shape for orchard purposes.

**Volume Index of Delicious Hybrids**

The mean volume index of the 11 lines of breeding was 400.3 ± 5.14. The Antonovka progeny showed the largest volume index mean, 571.5 ± 13.32 with the Black Annette progeny the
Fig. 12. Certain Delicious Hybrids Rated as to their Grade as Orchard Trees.
Table 8
Summary of Injury, Grade and Volume Indices of Various Delicious Progenies.

<table>
<thead>
<tr>
<th>Delicious Crossed by</th>
<th>Trees Index*</th>
<th>Injury Index*</th>
<th>Grade Index*</th>
<th>Mean Volume Index*</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jonathan</td>
<td>198</td>
<td>15.388</td>
<td>4.424</td>
<td>324.5 ± 9.58</td>
</tr>
<tr>
<td>Northwestern Greening</td>
<td>102</td>
<td>11.098</td>
<td>4.039</td>
<td>334.8 ± 16.94</td>
</tr>
<tr>
<td>Northern Spy</td>
<td>285</td>
<td>9.437</td>
<td>4.354</td>
<td>267.0 ± 7.21</td>
</tr>
<tr>
<td>Pauwaukee</td>
<td>67</td>
<td>9.477</td>
<td>3.746</td>
<td>530.0 ± 28.34</td>
</tr>
<tr>
<td>Salome</td>
<td>32</td>
<td>7.375</td>
<td>3.375</td>
<td>282.5 ± 17.94</td>
</tr>
<tr>
<td>Patten 1003</td>
<td>31</td>
<td>6.935</td>
<td>3.064</td>
<td>412.3 ± 33.09</td>
</tr>
<tr>
<td>Black Annette</td>
<td>92</td>
<td>6.728</td>
<td>5.565</td>
<td>239.6 ± 11.01</td>
</tr>
<tr>
<td>Patten 1011</td>
<td>50</td>
<td>5.666</td>
<td>3.366</td>
<td>530.1 ± 38.33</td>
</tr>
<tr>
<td>Anisim</td>
<td>242</td>
<td>3.958</td>
<td>3.619</td>
<td>371.6 ± 9.98</td>
</tr>
<tr>
<td>Antonovka</td>
<td>352</td>
<td>2.877</td>
<td>2.352</td>
<td>571.5 ± 15.32</td>
</tr>
<tr>
<td>Patten 1000</td>
<td>35</td>
<td>1.971</td>
<td>2.943</td>
<td>503.7 ± 42.04</td>
</tr>
<tr>
<td>Mean</td>
<td></td>
<td>1496.7 ± 7.263</td>
<td>3.713 ± 2.95</td>
<td>400.3 ± 5.14</td>
</tr>
</tbody>
</table>

*Injury and grade index are figured from the formula \( \frac{a+b+c+d}{n} \) where \( n \) equals the number of trees in each progeny and

(1) under injury

\[ a=\text{No. trees with no injury} \times 0 \]
\[ b=\text{No. trees with slight injury} \times 1 \]
\[ c=\text{No. trees with medium injury} \times 1 \]
\[ d=\text{No. trees with bad injury} \times 3 \]

(2) under grade

\[ a=\text{No. trees grading vigorous} \]
\[ b=\text{No. trees grading good} \times 3 \]
\[ c=\text{No. trees grading fair} \times 5 \]
\[ d=\text{No. trees grading poor} \times 7 \]

*The volume index is the tree's height, minus 2 feet x the square of its diameter; \((H-2)^2\)
smallest, 239.6 ± 11.01. In calculating Volume index only two factors were considered, height and spread of the tree. In estimating the grade of these trees besides these two factors of height and spread, vigor of growth and shape of the tree were also included. Table 9 shows the relationship between these two averages.

### Table 9

**Comparison of Grade Index and Volume Index Mean**

<table>
<thead>
<tr>
<th>Hybrids with Delicious</th>
<th>Grade Index</th>
<th>Volume Index Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Antonovka</td>
<td>2.352</td>
<td>571.5 ± 13.32</td>
</tr>
<tr>
<td>Patten 1000</td>
<td>3.042</td>
<td>503.7 ± 42.04</td>
</tr>
<tr>
<td>Patten 1003</td>
<td>3.084</td>
<td>412.3 ± 33.09</td>
</tr>
<tr>
<td>Patten 1011</td>
<td>3.366</td>
<td>530.1 ± 28.33</td>
</tr>
<tr>
<td>Salome</td>
<td>3.375</td>
<td>262.5 ± 17.94</td>
</tr>
<tr>
<td>Anisim</td>
<td>3.619</td>
<td>371.6 ± 9.98</td>
</tr>
<tr>
<td>Pewaukee</td>
<td>3.746</td>
<td>530.0 ± 23.34</td>
</tr>
<tr>
<td>Northwestern Greening</td>
<td>4.039</td>
<td>394.3 ± 16.94</td>
</tr>
<tr>
<td>Northern Spy</td>
<td>4.354</td>
<td>367.0 ± 7.21</td>
</tr>
<tr>
<td>Jonathan</td>
<td>4.424</td>
<td>324.5 ± 9.58</td>
</tr>
<tr>
<td>Black Annette</td>
<td>5.565</td>
<td>239.6 ± 11.01</td>
</tr>
<tr>
<td>Mean</td>
<td>3.713 ± .295</td>
<td>400.3 ± 5.14</td>
</tr>
</tbody>
</table>

The Antonovka, Patten Nos. 1000 1003 and 1011, Anisim, Northern Spy and Black Annette progenies show a rather close relationship between the grade index and the volume index mean. This relationship is not so marked in the progenies of Salome, Jonathan, Pewaukee and Northwestern Greening. Salome and Jonathan hybrids with Delicious graded fairly well
because of good branching habits and fair vigor in spite of rather small size, in contrast to which Pewaukee and Northwestern Greening hybrids graded somewhat low because of sharp angles in their branches and an upright habit of growth, although they were vigorous and large.

**Correlation between Injury and Grade of Tree**

Since these data did not lend themselves to exact arithmetical measurement, it was not possible to apply the usual methods of calculating correlations. By using the grade and injury indices of the various lines of breeding, the correlation was found to be .5549, which is on the border line of significance.*

Plotting the injury and grade indices of these 11 Delicious progenies (Fig. 13), it was found that 10 of the 11 clustered rather closely along the XY axis. The exception was found with Jonathan, mainly because of the high percentage of winter injury showing in its hybrids.

**Correlation between Injury and Volume of Tree**

A statistical study of the possible correlation between the injury indices and the volume index means of the 11 Delicious progenies was also made. The correlation was -.5297. Fig. 14 shows that there was not as close a

Fig. 13. Relation between Grade and injury indices on certain Delicious hybrids.

Fig. 14. Relation between Volume index mean and injury index on certain Delicious hybrids.
correlation between the volume index mean and the injury index as where the grade index was used as a measure for vigor. Yet 10 of the 11 progenies were clustered fairly close to the XY axis. Again the Jonathan hybrids showed the least correlation due to the large number of winter injured trees.
DISCUSSION

The presentation of a history of Iowa test winters is included in this study to bring together the more important facts concerning the effect of Iowa's climate upon fruit growing. Several workers have briefly reviewed the more important test winters, but, so far as known, this is the first time a comprehensive history has been attempted. This history is far from complete, as contemporary reporters have not recorded all the essential facts. Particularly lacking is a description of the various types of injury that occurred on fruit trees. Fruit growers, in describing the damage, used such general terms as "ruthless destruction", "thousands of trees killed or injured", or "severely damaged". It is hoped, however, that this history of Iowa test winters will be of assistance to future workers on this subject.

The survey of the damage to apple trees caused by the low temperatures of October 28, 29 and 30, 1925, is far from complete. This study was started in 1927 and many essential facts, especially those dealing with the tissues injured, could not be studied. Consequently this study has dealt more with the persistence of the injury, climatic relationships and its geographic extent.
The degree of browning of the wood is a good index to the relative hardiness of apple varieties and their progenies, provided the trees have been exposed to a test winter. The amount of winter injury in individual cases, short of death, is difficult to record with mathematical precision. The observations recorded at present, necessarily, are the best judgment of the observer. Nevertheless, where applied to a large number of trees of different varieties or, as in this study, to various Delicious progenies, such judgments are believed to provide a means of determining relative hardiness.

The use of an injury index provides an arbitrary means of expressing this relation with one numerical figure.

The use of an index figure could be used in future studies of various relationships between different progenies; especially those relationships that do not lend themselves readily to exact measurement.
SUMMARY AND CONCLUSIONS

1. Following 20 of the past 90 winters, so-called winter injury has been reported as having occurred on fruit trees in Iowa. After nine of these 20 winters, widespread damage was reported while following the remaining 11, low temperature injury was reported in certain sections of the state. Most damage was reported following the winters of 1842-43, 1855-56, 1865-66, 1872-73, 1882-83, 1884-85, 1898-99, 1917-18 and 1925-26. Years when less general damage was reported were 1856-57, 1862-63, 1869-70, 1874-75, 1876-77, 1878-79, 1886-87, 1899-1900, 1911-13, 1916-17 and 1929-30.

Winter injury to the roots of fruit trees occurred during the winters of 1842-43, 1855-56, 1872-73, 1878-79, 1898-99, 1899-1900, 1916-17, and 1917-18. No report has been preserved of the weather conditions that caused damage in 1856-57, 1862-63, and 1869-70, nor to the type of damage sustained.

2. Low temperatures during October 28, 29 and 30, 1925, following a period conducive to late growth, caused the death of about 2.3 percent of apple trees under 10 years of age of the more tender varieties growing in Iowa, with 32.4 percent showing injury to trunk or crotch and 65.3 percent showing no external signs of injury.
3. The more important varieties of apples which were injured were Golden Delicious, Grimes, Stayman, Jonathan and Delicious. No injury was observed in Ben Davis or Gano, Wealthy, Oldenburg (Duchess), Tolman, Fameuse or Yellow Transparent.

4. Types of injury occurring on apples as a result of the low temperatures of October 1925 were blackheart, bark splitting, crown injury, and killing back of terminal shoots.

5. The geographic area in which injury occurred closely coincided with that over which there was a deficiency from the normal October temperatures of -9° or more. This area included the eastern parts of Nebraska, Kansas, all of Missouri, Illinois, Indiana, Ohio, Michigan, Wisconsin, Minnesota and Iowa. North and South Dakota and Montana escaped injury with the exception of a small section of South Dakota in the Black Hills.

6. Fifty and eight tenths percent of the Delicious hybrids, involving 11 parents and including 1496 trees growing in the Horticultural orchards at Iowa State College showed injury in the form of blackheart when examined five years after the low temperatures of October 1925. On those trees showing injury, 21.7 percent were slightly injured,
14.2 percent showed medium injury and 14.9 percent were badly injured.

7. A close correlation was found between the hardiness rating of the varieties studied and that of their progeny when crossed with Delicious. Hybrids of the eight named varieties crossed with Delicious rated in degree of injury as follows: Antonovka, Anisim, Salome, Black Annette, Pewaukee, Northwestern Greening, Northern Spy and Jonathan, with Jonathan showing the most and Antonovka the least injury.

8. Hardiness is not necessarily accompanied by vigor, but it is axiomatic that trees cannot be continuously vigorous without sufficient hardiness to insure reasonable health and longevity. In the present study, vigor as indicated by volume and grade of tree, showed some correlation with resistance to winter injury. Correlation between vigor and resistance to winter injury, however, varied in the different Delicious progenies studied, being rather close in the case of all the progenies studied excepting Black Annette and Jonathan.
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The writer is very appreciative to Director R. K. Bliss of the Agricultural Extension Service and to the State Board of Education for allowing him time to conduct these studies.
VITA

Name: Harry Esmond Nichols

Date and Place of Birth: March 15, 1893, Chicago, Illinois

Father: Lincoln Nichols. 208 N. 15th St. Marshalltown, Iowa.

Maiden Name of Mother: Lucy Palmer (Deceased)

Elementary School Education: Public Schools of Mason City, Iowa and Monmouth, Illinois


Work since Graduation:

- Managed a fruit farm at Sioux City, Iowa, 1917.
- Assistant in Pomology Section, Iowa State College, January to September 1918.
- Private in U. S. Army, September to November, 1918.
- Extension Specialist in Fruit Growing from December 1918 to present time.

Family:

- Married Mary A. Mears, August 22, 1919. Have two children, Donald, age 9 and Paul, age 7.

Professor B. S. Pickett, Head of the Department of Horticulture has had charge of my major work. I also wish to
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my minor work in Plant Pathology.