WINTER INJURY OF FRUIT TREES

An analysis of factors responsible for the 1949-50 Winter Injury to Cherry, Peach, and Apricot trees in the Okanagan Valley of British Columbia with Recommendations for the care of injured trees.

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ABSTRACT

Winter Injury of Fruit Trees.

This report contains an analysis of the factors responsible for the 1949-50 winter injury to cherry, peach and apricot trees in the Okanagan Valley of British Columbia, Canada.

Included in the report are sections dealing with the history of winter injury, various theories of the causes of winter injury, and a description of the many forms of injury. The non-climatic and climatic factors affecting the intensity of injury are discussed in detail.

Recommendations for minimizing the susceptibility of trees to winter injury under Okanagan Valley conditions are included, together with recommendations for the care of trees after injury has occurred. Reports on the relative hardiness of specific stone-fruits are presented in some detail.

The report is liberally supplied with tables indicating the extent of crop damage and tree damage in each district of the Okanagan Valley. These tables are based on observations made in over two thousand orchards. The statistical analyses are based on detailed observations carried out in over four hundred orchards.

The published literature dealing with winter injury has been freely consulted, and reference is made to many of the important papers dealing with the winter injury complex. A complete bibliography is included.

TABLE OF CONTENTS

Page

F O R E W A R D

Periodically, during its history, the Okanagan Valley of British Columbia has been subjected to a winter weather pattern which has caused untold low-temperature damage, not only to the abundant crops of fruit which can be produced in this fertile valley, but also to the fruit trees which constitute its major economy. The vast devastation of crops and trees during the severe winter of 1949-50 was manifest throughout the entire valley. Yet, during the spring of 1950, there could be seen marked contrasts in the survival of various orchards. One orchard of a specific kind and variety of fruit would show almost nothing but dead trees, while an adjoining orchard, comprising exactly the same kind and variety of fruit, would show almost one hundred percent survival of trees bearing at least a partial crop. This phenomenon and others of its kind were responsible in part for prompting the present study, which was planned in an endeavour to determine the predisposing factors responsible for such marked differences in the extent of winter injury from one orchard to another.

A C K N O W L E D G M E N T

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(I) INTRODUCTION

Winter injury over a period of years has caused a heavier financial loss to Okanagan Valley orchardists than has any other single factor. When the injury is confined to the fruit buds and so affects only the current season's crop, the loss is serious enough, but when this injury reaches out to kill thousands of trees and to injure severely thousands more, the economic security of the entire valley is devastated. Not until replacements for the dead and injured trees have passed through the various stages of orchard culture to become bearing trees, can the orchard industry flourish in anything like its normal manner, and never can the new trees produce heavily enough to compensate the orchardist for the losses that winter injury has thrust upon him.

Experimental data dealing with the nature of winter injury, and the resistance of woody plants to it, indicate that certain cultural practices tend to lessen the severity of this injury to fruit trees and thereby to reduce the accompanying economic loss. Yet, so complex is the nature of plant hardiness and winter injury, that many of the thousands of experiments dealing with these phenomena have produced inconclusive results.

The pattern of winter injury to stone-fruit trees in the Okanagan Valley during the winter of 1949-50 indicated that certain combinations of factors resulted in a high percentage of tree survival, while other combinations resulted in a low survival rate. If it could be shown which combination of factors could be consistently relied upon to minimize winter injury under Okanagan conditions, it might then be feasible to establish a stereotype procedure in handling orchard trees so that economic loss from winter injury would be greatly reduced.

Although some of the great volume of published data dealing with winter injury is found to be conflicting, it does, nevertheless, form a good working background for the present comprehensive survey of stone-fruit orchards, which was carried out during the spring and summer following the 1949-1950 freeze.

(II) HISTORY OF WINTER INJURY

Throughout North America, meteorological records indicate that the weather has been, from time to time, very prone to extreme changes. Such extreme changes, especially in temperature, invariably wreak havoc among orchards in the particular areas affected. Fraser (39) states that even though some areas have been described as "frost-free", yet under certain conditions "any and all parts of the temperate zone in North America are subject to frost. No part of the mainland of United States or Canada has absolutely escaped freezing temperatures".

According to Hedrick (47), in the twenty-five year period beginning 1881 and ending 1905, the peach crop was destroyed or seriously damaged over a large part of New York in thirteen separate seasons. Cowart and Savage (27) report that winter injury is the outstanding cause of tree losses in all peach-growing sections of Georgia and it is unusual to find orchards ten or more years old still with a good stand of trees. Gourley and Howlett (42) report that during a period of one hundred sixty years, there have occurred in the northern United States at least nineteen recorded winters, or approximately one year in nine, in which abnormally low temperatures have been attained. The severity of some of these freezes is well illustrated by Maney (56), who states that the winter of 1940-41 killed from 80 to 90% of all apples and 95% of all peaches in Iowa, Northwestern Missouri, Nebraska and Kansas.

The Okanagan Valley of British Columbia has been subjected to a slightly greater frequency of severe winters than have orchard districts in the United States. Records indicate that in this area approximately once every six or seven years a winter of unusually severe temperatures occurs. Mann and Palmer (59) report severe winter injury to orchards in 1909, 1916, 1924, 1929 and 1935. Again in 1942 and 1949, unusually low temperatures caused severe injury to trees. The winter of 1949 was especially disastrous, the B.C. Fruit Growers Association (68) reporting tree losses ranging from 25% to 100% in certain orchards throughout the entire valley, and a total crop loss value in 1950 of $5,652,183. The B.C. Department of Agriculture (8), following an official survey of damage during that winter, reported that 336,110 fruit trees were killed outright and that many trees were left so permanently weakened that they became susceptible to diseases and breakage which further reduced their economic value in subsequent years.

(III) THE OCCURRENCE OF FROST INJURY

Frost injury in Okanagan orchards usually results from one of two main types of cold air movement. The most common type of frost injury is caused by radiation frost, which usually occurs at night when the air is calm and the sky is free from clouds. Under these conditions, heat which the earth has absorbed from the sun during the day, passes by radiation into the air mass adjacent to the ground. Thus, all soil and plant surfaces exposed to the air, cool. The warm air mass is quickly replaced by denser cold air from above it, and when the temperature of this air falls below the freezing point of water, we say that there has been a frost. Because the heat was lost by radiation, it is called a radiation frost. Such frosts are a feature of all arid regions due to the intense radiation made possible by the generally clear skies and lack of moisture in the atmosphere. The cold air layer near the ground is usually quite thin. Above it lies a layer of warmer air, perhaps 10° warmer, to an altitude of up to a thousand feet. It is not usually until the early morning hours that the temperature of the air reaches the freezing point and its duration may not be long enough to cause injury to plants. According to Day (30), the air is often so dry when radiation occurs that frost does not form at 32° F. or even at several degrees below 32° F.

It is readily apparent that orchardists may be able under certain conditions to cope with radiation frosts and thereby to offset much of the damage which the frosts might cause. In some orchard areas it is quite common practice to raise the temperature of the air itself or to move the thin low lying layer of cold air by using heaters in the orchards. Convection currents set up by such heaters tend to mix the upper warm air mass with the cold air adjacent to the ground, thus raising the temperature of the air surrounding the trees.

Even more fundamental is the knowledge that different vegetation cover varies in the amount of heat radiated. Experiments conducted by Comford (26) indicate that meadow grass gave rise to the coldest air, while bare soil gave rise to the warmest, the difference in temperature being 6° F. between the two extremes. Comford explains that grass forms a very large surface from which heat radiates and as the stems are poor conductors of heat, they tend to prevent the heat in the soil from passing up to replace the heat lost by radiation, so the grass blades are greatly cooled and the air in contact with them is cooled too. Bare soil, on the other hand, has the smallest possible surface from which to radiate heat and any heat radiated is quickly replaced by heat from the deeper soil levels, so that the air above bare soil is not cooled as much as that above grass.

Since radiation frosts can be offset to some extent by various orchard practices, and since they are a menace for only a short period around blossom time in certain years, and only in certain orchards, they usually cause only minor scattered losses in the Okanagan Valley.

Of much more serious nature is the injury caused by a general lowering of temperatures far below the freezing point. These low temperatures usually accompany the southward movement of a high pressure polar air mass. Such cold air movements may occur at any season, but are usually confined to the winter months. They are characterized by a general lowering of temperatures over a wide area and are often accompanied by drying winds. If the cold air mass is relatively stationary, radiation may occur within that mass, thereby causing localized differences in temperature. The nature and extent of the damage to fruit trees caused by these massive cold air movements depends largely upon the growth stage of the tree, the temperature pattern preceding and during the freeze, the duration of the freeze and absolute minimum temperature attained and many other factors, all of which contribute to the complexity of the winter injury problem.

The winter of 1949-50 in the Okanagan Valley was marked by prolonged periods of low temperatures and severe drying winds. Consequently, damage which was recorded following this particular winter resulted from this latter type of freezing and not from radiation frost.

(A) HOW FROST KILLS PLANTS

The most widely accepted theory of how frost kills plants has evolved from a number of highly speculative theories, each of which probably contains some truth.

Levitt (54) has consolidated masses of evidence into a fairly sound theory of frost injury. His theory asserts that as the temperature of a plant falls below its freezing point, its aqueous contents undercool to some degree. Since frost cannot injure a plant in the undercooled state, some species of plants are seldom injured by frost. They have the ability to undercool to about-20° C. and below this temperature their cell contents vitrify. To this end, Chandler (19) points out that such tissues as pollen and seeds when dried until there is no water to form ice, may not be killed at temperatures as low as-328° F.

There may, however, be ice formation in the tissues of even the most resistant plants. Usually ice begins to form in plant tissues if that plant cools below its freezing point. The ice crystals originate on the cell walls since the walls are covered with pure water. The cell sap, which contains many dissolved substances, does not freeze, but loses water by exosmosis. This water forms ice crystals extracellularly, leaving the cell sap progressively more highly concentrated and progressively more resistant to freezing. Even when the temperature does drop below the freezing point of the cell sap, the plasma membrane and cell wall act as effective barriers against inoculation by the ice crystals in the intercellular spaces. As the water moves out of the cells, the cells shrink. The formation of ice in the intercellular spaces is accompanied by expansion.

Dehydration of the plant cells may increase the consistency of the protoplasm to a point where it will coagulate and become irreversible. During the thawing process, however gradual it may be, the change in cell form due to endosmosis is likely to cause a fatal rupture.

All this applies only to injury caused by extracellular ice formation, which may have been the type which occurred in Okanagan fruit trees in 1949-50. But if ice formation occurs inside the cells, due to a sudden temperature drop, the crystals may lacerate the protoplasm and destroy cell structure. Hardy plants are known to resist extensive ice formation within cells by virtue of their great protoplasmic hydrophily which reduces the volume of ice crystals forming within the cell. The more capable a plant is of preventing intra-cellular freezing, the hardier it is.

Whether or not the ice will be confined to the intercellular spaces depends on whether or not the freezing point of the cell contents can drop as rapidly as its temperature. For if the cell cools below its freezing point, its undercooling point will be reached and ice will form. Thus the speed of the cooling and the speed of exosmosis of water from the cell determine the freezing resistance of that cell. Rapid freezing of a plant cell is more injurious than slow freezing since it induces intracellular ice formation.

In tender plants, cell permeability to water is very low and intracellular ice formation may occur even when the temperature drop is gradual. Hardy plants, on the other hand, have high permeability rates and can withstand rapid temperature drops without intracellular ice formation. Even after a plant is fully thawed, frost injury may progress for some time since the cells may be injured though still alive.

Repeated freezing and thawing of a plant must increase the opportunity for intracellular ice formation unless each freezing is sufficiently gradual to prevent it. Repeated expansion and contraction of the cell may injure the protoplast much more than a single contraction and expansion.

A gradual decrease in temperature produces increased permeability, sugars and osmotic pressure within the limits of the kind of plant tissue exposed. Thus protoplasmic consistency and permeability may be considered the key factors in frost resistance. A hardy plant owes its high cellular permeability and its low protoplasmic consistency (even when dehydrated) to an increased protoplasmic hydration. Its plasma membranes have larger aqueous pores than those of tender plants and permit more rapid passage of water and other substances. The protoplasm as a whole is able to retain a relatively large quantity of water even at low freezing temperatures and therefore does not coagulate so soon.

Severe cases of cell shrinkage will often cause cracks in the wood of a tree. Chandler (20) points out that this results from the greater contraction of the tissue of the tree tangentially than radially. Cells of the medullary rays, which are situated between wedges of rigid tissue, shrink to a greater extent than any of the cells situated radially. Thus the tendency is for the wood of a trunk or branch to crack longitudinally.

During long cold periods, buds and small twigs are often killed outright. This type of injury can probably be attributed to the evaporation of moisture from these buds and twigs. This cannot be replaced by the roots because the conducting tissue of the tree is frozen. Killing of this kind seems to be associated with regions having strong prevailing winds and continuous low winter temperatures.

Dorsey (32), in an examination of freezing phenomena within peach flower buds, discovered that during any period when temperatures are dropping, cellular water moves away from the vital flower parts (stamens and pistil) to lower bud scales, thus increasing the protoplasmic consistency and frost resistance of these vital parts. Sudden low temperatures, however, caused ice formation within the cells of the vital flower parts and their subsequent death. Following the break in the rest period, the cells of vital parts failed to release water as readily as before and were thus more susceptible to intracellular ice formation and subsequent frost damage. Dorsey found that cells in peach leaf buds are able to release water more rapidly than those of fruit buds and thus have more resistance to cold.

Levitt (54) found that frost injury to cell structure was closely related to the particular weather pattern of any given region. In one region the low temperature may be severe but constant. It may come gradually and leave gradually. In another region, the minimum temperature may not be so low; yet the fluctuations may be sudden and frequent. In the former, a hardy plant is one that is capable of surviving tremendous extracellular ice formation. In the latter, this is not necessary, but the essential thing is an ability to prevent intracellular ice formation and injury from the rapid thawing. Even the rate at which the plant hardens off may vary sufficiently from one variety to another to play a decisive role. This may depend on the reactions of the plant to the photoperiodic conditions which prevail, i.e. on its developmental stage at the time when the frosts occur.

Chandler (19) suggests that low-temperature killing of plant tissue may occur when the harmful effects are not due to ice formation within the tissues. The cells may be killed by products of respiration at temperatures just above freezing. He points out that some plants die slowly when grown where the summer and winter temperatures, although above the freezing point, are below that which they require for optimum performance.

(B) FROST RESISTANCE IN PLANTS

The portions of a tree most likely to be injured by low temperatures are determined by the circumstances of the freeze and the condition of the trees. (42) Generally, the root and crown are the most susceptible parts, but since vegetation and snow cover usually protect them from the same extremes of temperature to which the remainder of the tree is exposed, they often escape damage from freezes which kill less susceptible parts. According to Palmer (65), the roots and crown are usually damaged most by early fall freezes. In general, fruit buds, spurs and twigs are more readily injured by low temperatures than are the trunk, crotches and main limbs. Auchter and Knapp (5) observe that in well-hardened wood, the pith is usually the least frost resistant tissue, followed in order by sapwood, bark and finally cambium tissue.

Knowlton and Dorsey (52) and Chandler (19) have demonstrated that blossom buds become resistant to cold towards the end of the growing season. An autumn or early winter freeze may kill leaf buds or other tissue in the tree when it does not kill blossom buds. However, during the middle of winter it is generally accepted that blossom buds tend to be a little less resistant to cold than do leaf buds or cambium. During this dormant period, blossom buds of the more tender species such as apricot and peach have been shown to withstand temperatures as low as-22° F.; those of hardy species such as apple, have withstood temperatures as low as-40° F.

Chaplin (21), experimenting with peach buds, found that blossom buds withstood a temperature of 8° F. with little injury even though the leaves had not yet fallen from the trees. This cold resistance increased by several degrees just after leaf fall and greatest hardiness was achieved about thirty days later. This point of greatest hardiness seems to co-incide closely with the end of the rest period. Following this point of greatest hardiness, the buds lost resistance with the advent of each warm spell and regained some resistance with the advent of each colder spell, although they never did regain their maximum cold resistance once the rest period was broken. It would therefore appear that peach buds, if not all blossom buds, lose hardiness with each warm period during the late dormant season. Knowlton and Dorsey (52) found that there was considerable variation in the degree of development of the blossom buds on different parts of the tree by mid-winter, as measured by their degree of pollen differentiation. In general, buds on the bases of terminal twigs were latest to develop, buds in the mid-portion of twigs next and terminal buds farthest advanced. The fruit buds borne on the short spurs of the inner parts of the tree were, on the average, slightly ahead of the basal buds on the outer terminals. In all cases, the buds which were farthest advanced, were the least hardy.

Experiments with cherry buds led Roberts (70) to conclude that the rate at which blossom buds develop after differentiation determines their frost resistance. Too rapid development of the blossom buds tends to promote the presence of large vacuoles in the cytoplasm of the bud cells. Thus the cytoplasm lacks the high density which is associated with frost resistance. Chandler (19) agrees with this point of view, stating that flower buds of some varieties are more resistant to cold if the differentiation of flower parts does not advance too far before the cold weather arrives. Trees that cease growth very early in summer may cause their flower buds to advance too far by the end of autumn for maximum cold resistance.

Most investigators agree that the rate of temperature fall greatly influences the amount of tree injury. (Table I (18)) This view is directly in accord with the theory of a plant's ability to undercool its cell contents to a point below its actual freezing point. Blossom buds retain

TABLE I

Effect of slow and rapid temperature fall on freezing to death of plant tissues

Kind of buds	Manner of freezing	Date	No. of buds	% killed
Montmorency cherry	Slowly to - 20° C.	Mar. 2	163	3.0%
Montmorency cherry	Rapidly to- 20° C.	Feb.29	120	96.0%
Early Richmond cherry	Slowly to - 20° C.	Mar. 9	297	5.0%
Early Richmond cherry	Rapidly to- 20° C.	Mar.14	263	98.0%

a fairly high degree of frost resistance long after the breaking of the rest period provided that the weather is not warm enough to cause them to swell. As they take up water from the vascular system, the cytoplasm becomes less dense and their resistance drops rapidly until the flowers are fully open. At the full bloom stage, a blossom which could withstand temperatures below -30° F. in mid-winter may now be killed by a temperature of 24° F. or higher. Following full bloom, there is a further decline in frost resistance in most species, so that small fruits may be destroyed by two or three degrees of frost.

Chandler (19) relates the importance of foliage in determining the frost resistance of a tree. If the foliage is damaged or removed by insects or by pruning in late summer, all the above ground portions of the tree become less cold-resistant than if the foliage had remained. It appears that some substance is translocated normally from the leaves to the wood and that this substance is vital to the cold resistance of a tree. This theory appears to be borne out by a study of the relative acquisition of cold resistance of different portions of the tree. The last wood to acquire maximum cold resistance is usually the basal part of the trunk which is farthest from the leaves. The trunk, crotch and framework are next in order of lateness, while the small branches and twigs acquire frost resistance quite early in the winter.

Much of the explanation of frost resistance in various tissues is highly speculative. The present knowledge of the nature of cytoplasm is incomplete and hence the present knowledge of the changes in cytoplasm is incomplete. It appears to become more permeable to water during the hardening process, but this is likely to be only one of many changes that occur in the physiology of the plant.

(C) METHODS OF ASSESSING FROST RESISTANCE OF ANY VARIETY

Some writers have said that it takes at least ten years to determine the frost resistance of a variety because only in this length of time is there apt to occur a sufficient number of winters severe enough to cause cold injury. This is an understatement of the fact. As Levitt (54) points out, "It is no exaggeration to say that present methods never succeed in establishing the relative hardiness of a variety under all conditions".

Within the past few years, however, new techniques for establishing the relative frost resistance of any variety have been developed.

Levitt and Scarth (53) found that cell permeability was of practical value in predicting the hardiness of woody plants. Immersing plant material in a strong electrolyte such as KNO_3 , they found that the difference in permeability of the cells of various plants afforded an easily applied measure of their potential frost resistance, thus offsetting the necessity of waiting for a test season. On the basis of this permeability test, they classified the varieties as non-hardy, semi-hardy, and hardy.

Swingle (77) describes the exosmosis method of determining injury from low temperatures. This method is based on the assumption that the release of electrolytes by the cell, measured by electrical conductivity constitutes a direct reading of the amount of injury inflicted by a given treatment. This, in turn, is used as a measure of the frost resistance of the plant in question. Meader, Davidson and Blake (60) used the exosmosis method for rating hardiness of peach fruit buds. They used controlled artificial freezing of dormant fruit buds to provide a rapid and reliable method for estimating the relative cold hardiness of fruit buds of different varieties of peach. When varietal samples were so frozen that only 1% to 15% of the buds of Elberta, a criterion variety, remained alive, other varieties tested had percentages of live buds that compared favourably with their previous response in the orchards. Variations occurred, however, in the hardiness of buds of the same variety on qualitatively different twigs. These variations emphasize the importance of care in the selection of samples used in such comparisons. The results of these tests indicate the advisability of testing the cold hardiness of a variety two or more times during the dormant season, since weather conditions prior to collection of samples do not affect all varieties in the same way.

These workers (60) have found that the structure and composition of the wood are directly related to hardiness, as is the moisture content of buds. Hardiness is also related to the freezing point lowering of the cell sap, moisture content of all cells, ash determinations and the adsorption by cells of certain dyes. Cold hardiness has also been measured by the enzymatic activity and by the plasmolytic method for determining osmotic pressures.

These are all steps towards a common end and there is now a great need for co-ordination of these methods into one framework of tests which will establish relative hardiness of varieties in a short period of time. Once established, such a series of tests would not only furnish information which now takes many years to obtain, but would also permit a prediction of the behaviour of a variety wherever long-time climatic records are available. Such predictions would be of great value to plant breeders who want to know the value of new varieties when they arise and who constantly endeavour to plan their breeding programs along certain directed lines.

(D) WINTER HARDINESS - A COMPLEX

Many hundreds of articles have been written on the winter hardiness of deciduous woody plants. From these articles has developed the concept that hardiness is a complex of several specific factors. Brierley (13) defines the hardiness of a woody plant as its "overall ability to escape injury during the varying conditions of winter weather over a period of several years". There seems to be no particular temperature at which killing of wood and buds is certain. Campbell (17) and others have shown that the critical temperature at which death occurs is not a definite point for any species, variety, or individual plant, but that it is governed by a complex of conditions.

Among the prime requisites of hardiness in any plant are full maturity at the onset of cold weather, healthful condition, and the ability to withstand desiccating winds. A plant must be mature before it can resist cold, but the fact that it has matured does not guarantee hardiness, since some other factors may prevent it from developing its highest degree of cold resistance. Then, too, a well-grown healthy tree, with adequate food reserves, medium-sized crops, and freedom from parasites, will invariably survive cold weather better than trees which are devitalized, have cropped heavily or been weakened by the presence of parasites. In addition to this, plants which are protected from winter desiccation by windbreaks and shelter belts are more likely to survive cold temperatures than those which are exposed to the drying winds of winter. But, if a plant is to be considered "hardy", it must be able to survive drying conditions as well as low temperature. And if the cause of such winter drying is not accurately determined, the hardiness factor becomes more complex.

Hardiness ratings of woody plants are very difficult to assess owing to great variations in rest periods, dormant periods, the time and rate at which they develop cold resistance, their ultimate cold resistance, and their ability to lose or retain cold resistance. The rest period of many plants is readily broken by a spell of warm weather following a cold spell. Late in the dormant season, for example, the rest period of apricots is more easily broken by warm weather than is that of the apple. Consequently, apricot trees are more readily injured by late cold snaps than are apple trees. Similarly, the various species of woody plants differ in their emergence from dormancy. Although most species are unable to grow at temperatures below 41° F., a few woody plants actually commence growth at temperatures between 35° F. and 40° F. Since growing plants are more susceptible to cold injury than are dormant plants, it is readily seen that the dormancy characteristics of woody species have a direct bearing on their hardiness.

The time at which a plant develops cold resistance, bears directly on its hardiness rating as well. If a certain species or variety fails to develop cold resistance early enough to protect itself against the temperatures prevailing in the district in which it is growing, it obviously lacks hardiness for that district. In the same way, a plant may fail to develop its cold resistance quickly enough to cope with the rapidly falling temperatures which may be characteristic of a certain area. Again it lacks hardiness for that area.

Plants have been shown (13) to lose hardiness with the onset of each mild spell during the dormant period. They have also been shown to regain some of that hardiness when the temperature drops again following the mild spell. But plants vary greatly in the speed with which they lose and regain hardiness. One that loses hardiness slowly and regains it quickly is said to be hardy from this point of view. The ultimate cold resistance of plants determines their absolute hardiness and is a genetic characteristic. Plants vary greatly in their ultimate cold resistance. Among the tree fruits, Chandler (19) reports that in general, apricot, almond and peach are not as hardy as apple and pear. Campbell (17) reports that thirty varieties of peaches survived a temperature of -32° F., while some apple trees did not. This exception, however, would appear to relate to some other factor of the hardiness complex than the ultimate hardiness.

With so many variable factors entering into the hardiness complex, there is little wonder that so much has been written about winter injury and so little accomplished to counteract it. Perhaps scientists should attempt to evaluate only one variable at a time, instead of attacking the hardiness problem as a whole. Certainly the hardiness complex is likely to remain a complex until it is taken apart, factor by factor, and then put together again to give a true picture of the problem.

(IV) TYPES OF WINTER INJURY

Winter injury to fruit trees may be manifested in many different ways. Not all the effects of low temperatures are quickly recognized, since the injuries in the trees may linger for many years and may be accompanied by other complications which obscure the basic trouble. Several types of winter injury, however, are quickly recognizable and a knowledge of their symptoms is important in determining the treatment which an injured tree should receive.

(A) BUD INJURY

Although leaf and fruit buds may both be killed by low temperatures, the leaf buds are generally much hardier than the fruit buds. Higgins et al (48) explain that leaf bud cells contain dense cytoplasm with small vacuoles, and do not freeze readily, while fruit bud cells generally have less dense cytoplasm with large vacuoles and are therefore more prone to winter injury. Instances have been recorded in which leaf buds have been killed or injured while a portion of the flower buds have survived and produced fruit in the absence of leaves. This phenomena has been explained on the basis of lack of maturity of the leaf tissues, while the flower buds reached maturity before the freezing occurred.

Fruit buds are usually killed if they are subjected to frost in early winter before they are fully hardened off. Again, they may be killed by low temperatures following a warm period in winter which has broken their rest period. And finally, they may be killed if the temperature drops to a point below their absolute cold tolerance. Very often, the injury to fruit buds is not easily discernible, only the tender pistil having been killed. In such cases, the flower will break open quite normally and then fall off when the fruit fails to set. If the temperature drops below the absolute cold tolerance, the flower buds do not swell, but dry up, shrivel and drop off. This characteristic is sometimes noted in stone fruits but seldom in apples and pears, the fruit buds of the latter two being well protected in clusters.

In the Okanagan, fruit buds of apricot, peach, and cherry have shown more injury from low temperatures than have buds of other fruit trees, their absolute tolerance ranging between -15° F. and -30° F., depending on variety and other factors. Prunes and plums follow closely in their tolerance, while pear and apple fruit buds will often tolerate as much cold as will their twigs, and hence their absolute tolerance may be governed by the tolerance of their twigs. Since 90% or more of the fruit buds of a tree may be winter killed without seriously reducing the crop of saleable fruit (10), a moderate killing of fruit buds does not appear to be a serious problem. Certainly it does not constitute as serious a menace to fruit growing as do certain other types of winter injury.

(B) TWIG INJURY

Low temperature injury to small fruit-bearing twigs is rather common in the Okanagan Valley. This type of injury probably results from a desiccation of such twigs by strong drying winds which are usually associated with Okanagan winters. During long cold periods, the twigs tend to give up moisture which cannot be replaced by the frozen vascular system of the tree. When the cytoplasm within the twigs is coagulated beyond a certain point by evaporation of water, it is rendered incapable of taking up water again, and hence the twig dies.

A less common type of winter injury to twigs in the Okanagan is that which involves the killing of terminal twigs through failure of the twigs to harden off before the onset of low winter temperatures, Such injury is most prevalent in apricot and peach, and usually occurs where growth has continued too late in the fall. The injury takes the form of a dieback from the tip to the more mature wood at the proximal end of the shoot.

Higgins, Walton & Skinner (48), working with several varieties of peach, found that twig injury was greater in trees of low vigour than in those of moderate to high vigour. Low vigour trees were shown to be low in total nitrogen, but high in ash and total carbohydrates. High vigour trees showed higher N content in the twigs, which was associated with a high degree of cold resistance. These workers suggest that this association may result either from increased quantity of protoplasm with resulting smaller vacuoles in the cells of the cambial region, or from the nature of the proteins present in high nitrogen trees. These observations appear to be in accord with the usual pattern of twig injury as it occurs in the Okanagan Valley. In fact, a deficiency of any nutrient appears to weaken trees, and so render them more susceptible to cold injury.

(C) <u>TRUNK AND SCAFFOLD INJURY</u>

Winter injury to the trunk and main scaffold branches may take several forms. It may show up as patches of various extent, localized crotch injury, splitting of the woody tissue, or simply as frost rings. All of these conditions were manifest in the trees of the Okanagan Valley following the winter of 1949-50.

Injury to large or small areas of the trunk or scaffold limbs is most common when trees grow late into the fall and a sudden cold wave appears, or when warm periods during the winter encourage growth activity. Sudden cold does not permit time for the cells in the trunk to undergo the changes which bring about hardiness. Similarly, if the ground is not chilled before the first snow cover arrives, there will be a tendency for the root system to carry on limited activity, which may, in turn, bring about injury to the trunk. Killing of trunk tissue is also common in varieties which inherently lack hardiness and in trees which are in poor vigour due to overcropping practices. Following killing conditions, the affected areas will first appear as sunken, darkened areas. Later on, the bark will often crack and come away from the wood of the trunk. Sometimes tree trunks are badly injured on the side next to the prevailing wind. This type of damage probably results from the increased evaporation rate on the windward side, together with mechanical damage due to the bending of the tree when the bark is under tension from freezing.

Whenever this type of bark injury extends into the crotches or lower scaffold of a tree, it is termed "crotch injury". Most investigators now agree that the crotch of a tree is among the last of the tree tissues to harden itself for cold weather, and hence is susceptible to early winter freezes. According to Fraser (39) crotch tissue often matures late because the foliage on the inside and at the "head" of a tree is insufficient to carry enough of the resistance-building materials to the cells of the crotch tissue. Evidence also favours pruning the trees to form wide angles for scaffold limbs and to let plenty of light reach the foliage in the vicinity of the crotches.

Following extremely low temperatures, the woody tissue of the trunk and framework of a tree often splits. This splitting, which usually causes the bark to split open as well, is caused by a greater contraction of the tree tissues tangentially than radially. The tangential contraction is brought about by the exosmosis of water from the large cells of the wedge-shaped medullary rays, with resulting shrinkage. The cells of other woody tissues are small and do not lose water by exosmosis to the same extent. If the tree trunk could diminish in circumference to keep pace with the shrinkage in the thin-walled cells of the medullary rays, splitting should not occur, but most of the woody tissue cells are thick-walled and do not give up moisture readily.

Not all types of cold injury are easily discernible from outward appearances. Tingely (80) describes the appearance of frost rings in woody cross-sections of hardy trees. These rings which appear as dark streaks concentric with the growth rings occur at the beginning of the season's growth, being bordered on the inside by the late wood of the previous year. They are therefore thought to be caused by low winter temperatures rather than late spring frosts. Fraser (39) explains the physiological significance of frost rings on the basis that such injury to the conducting tissues of the tree impairs the rate of travel of water and food materials within the vascular system, so impairing the growth activity of the tree.

(D) "BLACK-HEART"

"Black-heart" is a well-coined word to describe the appearance of the injured woody tissues of a tree. The dark, shiny appearance of these tissues in cross-section has been attributed by Steinmetz and Hilborn (74) to death of the protoplasm in the parenchyma cells followed by an occlusion of the vessels by a substance resembling wound gum. This occlusion prevents further translocation of materials by these woody tissues but apparently does not affect the normal functioning of the cambium layer, for there are many black-hearted trees producing commercial crops of fruit in certain areas of the Okanagan Valley. Large bearing trees, however, may eventually become punky and hollow owing to entrance and widespread activity of fungi, causing them later to topple over.

(E) SUN-SCALD

Winter sun-scald is a type of winter injury which invariably

Winter Sun-scald

Severe sun-scald on twenty-year-old Bing cherry tree. This eight-acre orchard was almost entirely wiped out, as can be seen in the background.

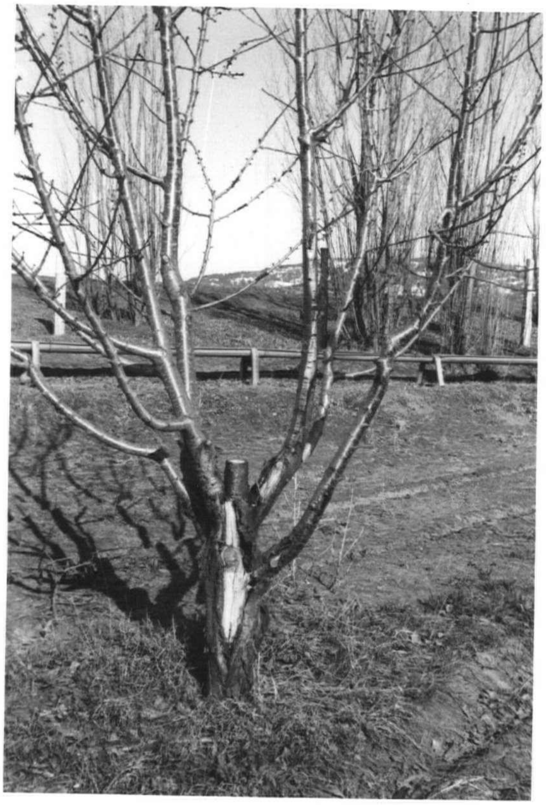
Sun-scald injury on upper scaffold limb of Red Delicious apple tree. This type of injury appeared to be aggravated by removal of small fruiting limbs on upper surface of scaffold limbs.

occurs on the south-west side of the tree trunks. For this reason, it is often called "Southwest injury". This type of injury results from the trunk of the tree absorbing radiant heat from the sun's rays during cold afternoons in mid-winter. Almost as soon as the sun goes down, the warm thawed tissue on the south-west side is again subjected to freezing temperatures. The tissue may be alternately thawed and frozen by several successive sunny days and cold nights. Such alternate freezing and thawing of tissue exerts strains on the protoplasm which result in its ultimate death. Experimental work by Mix (62) shows that sun-scald injury is characterized either by a peeling of bark from the affected parts, or a sinking and adhesion of injured tissue to simulate a sunken canker.

According to Chandler (19) this type of injury is most likely to occur during a still afternoon of a very cold day when the air tends to be free from moisture or particles that would obstruct the rays from the sun. If there is no wind to dissipate the absorbed heat, the tissues on the south-west side may absorb enough heat to thaw them, even on a day when the shaded part of the trunk is as cold as 5° F.

Eggert (35), in an experiment designed to record winter temperatures in the cambium of peach and apple trees with the aid of thermocouples found that often the temperature of the cambium reached 80° F. or higher on the south-west side of the tree when the surrounding air temperature was below 32° F. A north wind made little difference to the temperature readings. He found, too, that differences in temperature between the north and south sides of trees were as high as 50° to 55° F. It is obvious that the tissues subjected to such sudden and marked changes in temperature must undergo severe stresses which bring about mechanical destruction of cells. Upon thawing, the damaged tissues release water readily and give rise to the areas of dead tissue characterized by "south-west injury".

Winter Sun-scald.



Cherry tree showing severe sun-scald on the trunk and lower scaffold limbs. Photo taken one year following the freeze.

Sun-scald injury on south-west side of th this cherry tree has caused bark to slough away, and expose trunk wood. Healing is well under way in second year following freeze.

(F) ROOT INJURY

Damage to the roots of deciduous woody plants is a fairly common type of winter injury, especially in winters when the ground is lacking in snow-cover.

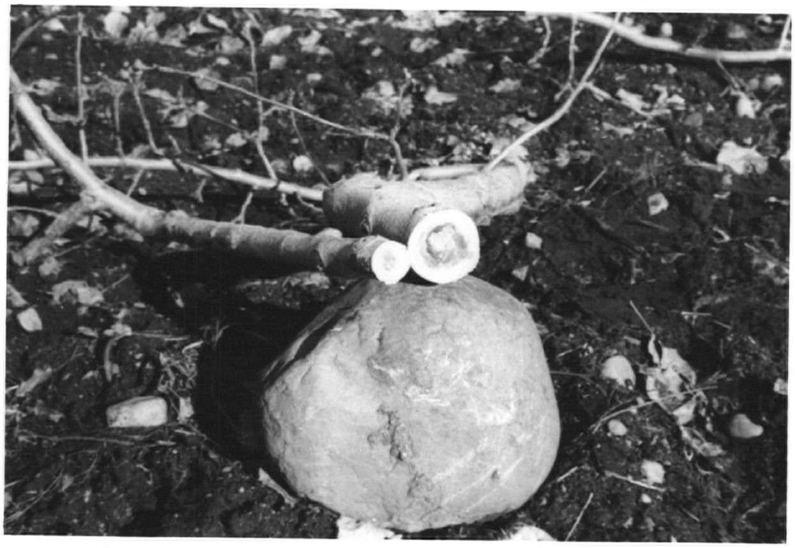
As demonstrated by Chandler (19) the root system is the most tender portion of a tree, and the roots become progressively more tender from the crown towards the extremities of the root. In a normal winter, of course, the roots do not require as much cold resistance as the above-ground portions of the tree, since the soil cools more slowly than the air and seldom reaches the extreme low temperatures of the air above the ground level. A sustained period of cold weather, causing ever-increasing soil penetration of frost, will usually cause root injury to some extent. According to Chandler (19), a long cold winter without any particularly severe temperatures may cause extensive root injury and no injury to the top of a tree, while a moderate winter with only a few hours of severe cold may cause a reversal of these conditions.

Snow, or any other type of soil cover tends to delay the cooling of the soil by reducing the soil contact with cold air. Root injury, therefore, seldom occurs where the soil is insulated by a heavy cover of snow, sawdust, green manure or other mulch.

It is well known that different rootstocks exhibit different degrees of cold hardiness. Although most peach and apricot rootstocks are raised from cannery seed, Blake (9) suggests that where hardiness is of particular concern, seedlings of Early Crawford Iron Mountain, New Jersey and Bell are particularly desirable. In the Okanagan Valley, seedlings of Lovell, Muir and Veteran are most commonly used.

Childers (22) reports that some promising hybrid peach rootstocks are being developed from the Indian variety Shalil, the Chinese

Types of Injury



"Blackheart" injury has permanently weakened many trees.

These nursery peach trees were killed back to the snow line, but sprouted from below, indicating that roots were not severely injured.

variety, Yunnan, and the Russian variety Bokhara. Elberta seedlings generally show poor cold resistance. Winklepleck and McClintock (83) tested various other peach and apricot rootstocks for hardiness and found that the Florida peach, of Pento origin exhibits serious injury after only a one-hour exposure at-15° F. He found Myrobalan Plum was more hardy than all peach rootstocks except Prunus Davidiana, Marianna plum stock was very hardy and Prunus Americana was hardiest of all stocks tested, showing no injury after forty-eight hours exposure at-15° F. Thus it appears that some of the hardier plum stocks may be of value as peach and apricot rootstocks where cold hardiness in the roots is a limiting factor to peach and apricot production.

Stewart (75) testing the cold hardiness of various rootstocks, concluded that scion roots are generally hardier than seedling stock roots. Analysis of the roots revealed that the hardiest roots contained slightly more sugar and less moisture than tender roots. Repeated checks on hardiness indicated that roots tend to increase in hardiness during the winter, reaching their maximum hardiness in March. With respect to stock-scion relationships, Stewart found that the hardiness of the scion varieties was not measurably affected by the hardiness of the stocks during one year's growth in the nursery. Stock hardiness, on the other hand, was greatly influenced by the scion variety. However, the hardiness transmitted to the stock by the scion bore no relationship to the hardiness of the scion.

When the roots of a tree have been injured by low temperatures, the trouble may not show up immediately. The trees may start to grow normally, but will soon exhibit lack of size in the leaves, or perhaps wilted leaves and blossoms. Very often the trees will appear to struggle along until the first hot spell, at which time they may quickly die. Other trees, on which only a portion of the root system may be damaged or killed, may struggle for years before finally being removed as unprofitable units in the orchard. To growers who are confronted with the problem of extensive replanting following severe winter damage, the use of hardy root stocks offers hope and encouragement.

(V) DELAYED EFFECTS OF WINTER INJURY

In many cases winter injury of fruit trees does not command attention at the time of its occurrence. It may induce minor injuries, the consequences of which are not revealed before the original cause is obscured. When all the fruit buds on a tree are killed, the loss is plain and the damage is credited to cold temperatures, but when a small portion of the trunk is killed, it often receives little attention until decay of the wood sets in. When decay occurs, the wood-rotting fungi, rather than the winter injury, are usually credited with the damage. This very subtlety of winter injury makes difficult any appraisal of its extent.

Much of the injury in the Okanagan Valley during the winter of 1949-50 was of the delayed type. In some cases the trees blossomed, set fruit, and produced foliage, but died suddenly with the advent of hot weather. In other cases, the trees survived the heat but foliage was small, fruit was undersized and terminal growth lacking. These trees usually died before the end of the 1950 growing season. Still other trees appeared quite normal until a few days before the expected harvest, at which time the leaves dropped and the fruit shrivelled. Such trees usually showed exudation of gum on the trunk and crotches. The limbs were brittle and broke easily.

But not all the after effects of the 1949-50 winter became apparent in 1950. Many of the trees were known to have "black-heart" and were apparently recovering by virtue of the uninjured cambium layer giving

Delayed Effects of Winter Injury

Failure of injured conducting tissues in trunk of this peach tree caused death in first hot weather following severe winter.

Twenty-year-old cherry tree which exhibited severe scaffold injury on south side. Tree died two years later.

rise to new tissue surrounding the blackened inner wood. According to Bradford (11), this type of injury is not, in itself, likely to cause the death of the tree, but will undoubtedly weaken its structure. Still other trees were showing dead areas on the trunk and scaffold limbs which opened the way for invasion by secondary parasites.

There is no doubt that trees will continue to show the effects of this freeze for many years to come, as they did following the winter of 1941-42, described by Brown (16), in Illinois. It is quite likely that many trees will grow for several years and when they finally begin to go to pieces, the evidence to connect the condition with a slight winter injury several years back will be scant indeed.

(VI) NON-CLIMATIC FACTORS AFFECTING INTENSITY OF INJURY

Since winter damage to fruit trees is often associated with factors other than the actual degree of cold prevailing, a review of the most important of these factors is imperative.

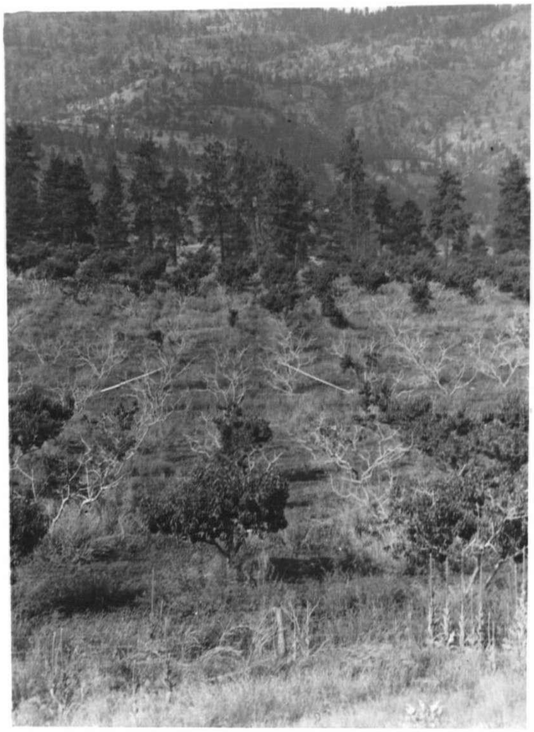
(A) SITE AND SOIL

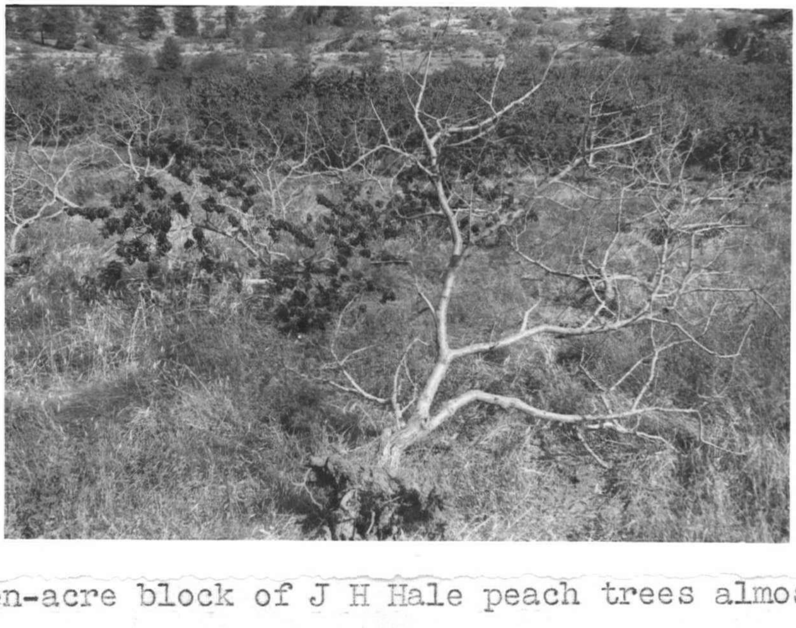
The site of an orchard and the soil associated with it are undoubtedly the most important factors determining its longevity. Certainly an orchard located on a site where the drainage is good, and where the temperatures are modified by environment, stands a better chance of surviving adverse winter conditions than one which lacks these attributes. Similarly, trees planted on deep, friable, well-drained soil have a better survival rating than those planted in excessively wet, dry or shallow soils.

Low temperature usually takes its heaviest toll of trees in depressions in valley bottoms and up against natural barriers to air drainage. As a rule, damage is also heavy in orchards which are exposed to desiccating winter winds. The elevation of an orchard above the valley

Site.

Lack of air drainage from the depression in this orchard apparently was a major contributing factor in causing death of peach trees in the central portion of the orchard.





Ten-acre block of J H Hale peach trees almost totally killed. Apricot orchard in background exhibited only slight winter injury.

floor also determines to some extent its survival rating, as evidenced by the progressively increasing amount of winter injury with increases in altitude.

Tukey and Brase (82), in a study of winter injury in New York, found that the greatest injury occurred on sandy and gravelly soils; especially when these soils were located on knolls or in low spots. Similar observations were made by Anthony, Sudds and Clarke (4) in Pennsylvania orchards. Fraser (39) describes injury resulting from trees standing in soil which is too wet while Palmer (65) warns against letting the trees go into the winter in dry soil. In Michigan, Knight (51) found that considerable freezing injury of roots occurred in surface horizons which were underlain by compact soils, and related the extent of root killing to the nature of the subsoil.

(B) FERTILIZING PRACTICES

The time of fertilizer application and the amounts applied are recognized as being important factors in determining the susceptibility of trees to winter injury. Normal spring applications of fertilizer have rarely been credited with causing injury. Fall applications, on the other hand, have been a subject of lively debate among several investigators. Most workers agree that late summer or early fall applications of nitrogen may cause delayed ripening of wood, which leaves the tree vulnerable to frost damage. But there is disagreement among workers as to the effect of late fall applications of fertilizer. Havis and Lewis (45), Palmer (65), McMunn and Dorsey (61), and Higgins et al (48) found that late fall applications of nitrogen did not increase winter injury in any parts of the trees. But Crane (28), Sudds and Marsh (76) and Tingeley et al (81) submit evidence to show that late fall fertilizer applications are harmful and do cause increased susceptibility to winter injury. In no case, however, has the writer been specific in what he means by a "late fall" application and since this term is so loosely used the evidence cannot be regarded as conclusive. Gourley and Howlett (42) report that nitrogen has been the only element directly associated with the degree of winter injury. Unlike Higgins et al (48) they found that none of the other elements appeared to be a factor in governing the extent of injury and that nitrogen became a governing factor only if it was applied too late in the growing season or in too large quantities. Unless the evidence against late fall fertilization of orchards becomes more conclusive, the practice will probably continue.

The amount of fertilizer, especially the nitrogenous fertilizer, applied to fruit trees appears to influence the extent of winter injury only in the extremes. Where the applications are too low to impart satisfactory vigour, trees are extremely vulnerable to frost damage. Similarly, where the applications are so great that the trees are forced into a late production of succulent and pithy growth, those trees are likely to be damaged. Higgins, Walton and Skinner (48) report that trees showing high ash and carbohydrate content (i.e. trees in poor vigour) were very susceptible to cold injury. They found, too, that moderate applications of nitrogen increased the quantity of protoplasm in the cambial cells, decreased the size of the cell vacuoles, and changed the nature of the cell proteins. All of these changes are known to increase cold resistance. Within the limits of moderate applications of nitrogenous fertilizers, Edgerton and Harris (34) found that cold hardiness was not appreciably affected at various nitrogen levels. Apparently other tree responses to these fertilizer treatments, such as yield, colour, maturity date and quality of fruit would be more important practical considerations than would cold hardiness.

Delayed Effects of Winter Injury

Badly injured trunk on this cherry tree caused defoliation and shrivelling of fruit at first onset of hot weather.

Poor leaf area and light set of fruit were typical of winter-injured prune tree. Note gummosis on fruit.

(C) CULTIVATION, COVER CROPS AND MULCHES

The amount of cultivation required for the greatest economy in fruit production has been the subject of prolonged debate. The timing of such cultivation has also been debated, but not to arrive at any unanimous conclusions. There still remain two main schools of thought in the matter of when to cultivate. One school persists in a fall cultivation while the other settles for a spring cultivation followed by a winter ground cover. From the point of view of winter injury, there should be no doubt about the relative merits of the two systems. Investigators all over North America have been unanimous in their observations that fruit trees suffer greater winter damage under a clean fall cultivation than under a system whereby some sort of ground cover is left intact for the winter season. Thus Kelly and McMunn (49), in a survey of winter injury in Illinois, found that wherever orchards were cultivated late or a summer cover crop was disked down in preparation for a winter cover, the trees suffered the most severe damage. Knowlton and Dorsey (52) concur with these findings and explain the lack of cold resistance on the basis that trees growing under clean cultivation were delayed in their hardening-off processes, while trees in sod ripened off early and were in an advanced stage of maturity all through the dormant season.

Barnett (6) and Gourley (41) both advocate the use of mulches or cover crops in preference to clean cultivation on the basis of their work with ground penetration of frost. Gourley states that the extremes of frost penetration in a New Hampshire orchard soil were, under clean cultivation eighteen inches and under cover crop seven inches. Barnett set up a series of plots to determine the extent of frost penetration under various mulches. As shown in Table 2, he found that greatest penetration occurred on bare ground, whether it had been cultivated or not, and discovered that where snow cover persisted there was little difference in penetration between cultivated and compact soil surfaces. A straw mulch three inches deep proved most effective in offsetting frost penetration.

TABLE 2

Ground Cover Effect

Plot #	Soil Surface	Max. depth of frost
1.	Compact - no snow	25.0
2.	Compact - snow	14.0
3.	Cultivated - no snow	23.5
4.	Cultivated - snow	12.0
5.	Rye cover crop - snow	11.0
6.	3" Straw mulch - snow	1.0
7.	3" Straw mulch - snow (2nd replication)	7.0

Havis and Lewis (45), conducting a detailed survey of winter injury in Ohio orchards following the severe winter of 1936-37, found that trees in sod were severely injured in the trunks while those which had been mulched with hay and straw survived in good condition. Trees under clean cultivation were severely injured throughout. Upon further examination they found that the roots of the injured trees had not been directly killed by frost. In this case, it would appear that there was a more constant moisture supply under mulch prior to and during the cold winter than was the case under sod or clean cultivation. The mulch apparently offset the penetration of frost and thereby permitted an adequate uptake of water by the unfrozen roots during the winter. This may partly account for the difference in injury found between trees in cultivation and trees in sod or mulch. If, however, a heavy snow cover exists, differences in cultural methods are not likely to be significant.

In general, the use of cover crops and mulches appears to be one of the most effective preventatives of winter injury. They act not only to protect the roots against frost penetration, but also cause the trees to ripen their wood early in the fall and assist in the regulation of moisture supply to the root system during the dormant period.

(D) PREVIOUS CROPS

Trees which bear heavy crops of fruit are more likely to be injured by low temperatures than are trees bearing light crops. To this end, Gourley and Howlett (42) observed that hardy apple varieties which had cropped heavily during the summer were more severely damaged during the following winter than were tender apple varieties which bore light crops. Similarly, Macoun (55) found that of fourteen identical Wealthy trees, the eight which had cropped heavily suffered severe winter injury during the following winter, while the six light-crop trees were apparently undamaged. Havis and Lewis (45) compared the effects of a light and heavy fruit-thinning of peach trees on the subsequent winter injury to buds and found that the heavily thinned trees maintained a higher bud survival rate than unthinned trees.

Crane (28) has noted that the effect of producing a crop of fruit is to reduce the hardiness of the tree tissues. He attributes this reduction in hardiness to a removal of food materials which are not replaced before leaf fall. Levitt (54) goes further and suggests that a heavy crop reduces the colloidal content of the plant cells, giving rise to large vacuoles within those cells. Such a cellular condition has already been shown to bring about cold temperature injury.

(E) PRUNING PRACTICES

Most investigators agree that fall or early winter pruning of fruit trees must be considered a hazard insofar as the susceptibility to winter injury is concerned. Havis and Lewis (45), working in Ohio, found that fruit trees pruned, even moderately, before the severe temperatures of January were usually injured more than those pruned later or not at all. Wherever early winter pruning had been severe, injury was also severe. In one orchard of grafted trees, the grower had cut back the sucker growth on some trees to let the grafts come. Other trees were not pruned. The pruned trees all died the following summer while those that were unpruned were not injured. Although young trees were usually injured less than bearing trees, they too showed the disastrous effects of early pruning. Many young trees showed injured areas around and just below the wound left by the removal of the limb. In many cases this injured area extended down the trunk to the point where the entire trunk and crotches were injured. Such trees did not survive. Then again, Crane (28), working in West Virginia, found that both summer and early dormant pruning decreased the hardiness of fruit buds. This held true regardless of the fertilizer treatment applied.

Fraser (39) suggests that pruning trees to form strong, widely diverging frameworks is good insurance, since narrow crotches tend to be slow to ripen off, and, once injured, are very difficult to heal. Hedrick (47) found that low-headed trees suffered less winter injury in both trunks and branches than high-headed trees. He suggests that the former is true because the wood loses less moisture from desiccating winds than do high-headed trees. In addition, he feels the trunks of low-headed trees are well protected from sun-scald. However, it is generally agreed that no special system of pruning trees will help to offset the deleterious effects of pruning too early, and growers who choose late fall or early winter pruning appear to be asking for trouble.

(F) CONDITION OF TREES

One of the most important factors affecting the winter hardiness of fruit trees is maturity of the various tissues. The maturity of a plant determines its cold resistance during the dormant season. Tissues of the trunk and scaffold are notably slow to mature in the fall and hence are often injured by low temperatures when other portions of the tree are uninjured. Anthony, Sudds and Clarke (4), in a survey of winter injury in Pennsylvania, report that severe injury occurred where trees were subjected to an unseasonal October freeze which delayed maturation processes. This freeze, in itself, did not cause the injury but it delayed maturity to such an extent that a sudden drop in temperature during January caused great damage. These same trees had withstood much lower temperatures in previous winters when maturation had not been delayed. Further observations indicated that trees of both extremes of vigour were damaged, while trees in moderate vigour were more resistant.

Gourley and Howlett (42) report a Canadian experiment involving the testing of thousands of native and foreign species of plants for hardiness. Plants which were most damaged under the conditions of this experiment were those native to a region with a longer growing season than that found in Canada. They were incapable of maturing their wood in the relatively short growing period.

Brierly (12) reports an unusual case of winter injury which appears to be directly related to the maturity of trees. In this case, the Haralson apple, which is very hardy in the Eastern United States, was subjected to a mid-November blizzard. Shoulder-deep snow and near-zero temperatures accompanied it. As the snow settled it began to smash branches and some were lifted from the snow, shaken and left exposed to the air. Others were not removed from the snow. Those that were removed were subjected to a drop in temperature within two or three hours from about 25° F. in the snow to a near-zero air temperature. Observations the following summer indicated that the branches which had been lifted from the snow were completely killed. Both the snow-covered branches and those above the original snow-line developed good foliage and set a fairly heavy crop. Brierly concluded that the snow cover had interfered with the normal maturation process to the extent that when the unhardened branches were suddenly exposed to low temperatures, they were severely damaged.

Further evidence of the relationship of maturity to cold injury is afforded by the fact that damage to the leaves of a tree, which doubtless interferes with the hardening process, often leads to serious killing of the wood. Similarly, the inner surfaces of branches, which usually possess the least foliage, are nearly always more tender than the exposed surfaces. And finally, young trees in good vigour, which have a dense and broadly distributed leaf surface which brings about early maturation of woody tissues, are often injured less than older trees whose hardening is delayed by lack of foliage.

(G) DEFOLIATION

Premature defoliation of deciduous fruit trees has been shown to increase their susceptibility to winter injury. To this end, Crane (28) reports that partial summer defoliation of peach trees resulted in proportionately greater winter injury both to fruit buds and limbs. In addition, Kennard (50) studied the effect on cold injury of defoliation by erroneous fertilizer treatments, drought, insect injury, disease injury and spray injury. He found that complete defoliation increased susceptibility of Montmorency sour cherry trees to low temperature injury and delayed blossoming the following spring. Trees completely defoliated by August 10 were more severely injured than those completely defoliated by

September 1. Gourley and Howlett (42) report that a partial defoliation predetermines the amount of cold injury in direct proportion to the amount of defoliation. They report that the injury to flower buds was greatest on those branches having the smallest leaf-fruit ratios during the previous summer.

Thus premature defoliation from any cause is an important factor affecting the winter injury complex. The effect of defoliation no doubt is to decrease carbohydrate formation in the storage cells of the tree since the manufacture of food ceases when the leaves are removed from the tree. Cells low in colloidal materials but high in free water content are known to be readily injured.

(H) OTHER FACTORS

The time and extent of thinning a fruit crop are known to have a definite relationship to the cold resistance of the various tree parts. The earlier the fruits are thinned the greater is the length of time left for the buildup of food materials in the woody cells. The food manufactured in the leaves will be supplied to the growing fruits if they are left on the tree, and this will be done in the case of a heavy set of fruit, at the expense of building up a reserve of food in the storage tissue of the plant. If, however, some of the fruits are removed in the spring or early summer, the leaves will supply some of the food to the remaining fruit and some for storage in the woody tissues. Removal of excess fruits at the earliest possible time would seem, therefore, to be a desirable practice from the point of view of cold hardiness.

Experiments dealing with the effect of thinning tree fruits upon the hardiness of various parts of the tree have been conducted by Knowlton and Dorsey (52), Edgerton (33) and Foot (38). Foot, working with Rome Beauty and Jonathan in the Okanagan Valley, found that trees which had been thinned at the full bloom stage by chemical means withstood temperatures of 30° F. without apparent injury, while adjacent trees of the same variety which had been hand thinned at a later date were severely damaged by the same low temperature. Similarly, results obtained by Edgerton, as shown in Table 3, indicate that effective blossom thinning of peach trees, which otherwise would set excessively increases the hardiness which the fruit buds on those trees may attain during the following winter.

TABLE 3

Effect of Blossom Thinning on the Survival of Elberta Fruit Buds Frozen under Orchard Conditions (-16° F.)

Blossom Thinning Treatments May 9,1947	No. of Trees	Fruit Set % July 8,1947	Average Yield in Bu./tree	Percent Fruit Buds Alive on Apr.1,1948	Average Fruit Bud Set	No. of Live Buds Per Foot Apr.1,1948
Elgetol, 1½ pt./100 gal.	12	13.5	3.0	88.5	18.7	16.5
DN #1, ½#/ 100 gal.	9	16.9	3.2	87.5	18.4	16.1
Check	5	35.5	3.4	67.9	10.5	7.1

The exposure of trees to cold drying winds has, in many cases, contributed to the death or injury of trees. Such injury is usually characterized by dead patches on the trunk and framework on that side of the tree adjacent to the prevailing winds. The damage has been shown to result from several effects of the wind. In the first place, the wind causes dehydration of cells on the windward side of the tree. Such dehydration, if carried to extremes may cause death of the cells. Secondly, the stretching of frozen cells on the windward side caused by the bending of the tree has been known to rupture the cells, resulting in rapid dehydration and death. And finally, the cooling of wood has been shown to be greatly accelerated by wind in comparison with wood protected from the same wind. This accelerated cooling could cause injury in itself, especially if the rate of cooling is rapid enough to overtake the natural ability of the woody cells to gain cold resistance.

(VII) RELATIVE HARDINESS OF SPECIFIC STONE-FRUITS

Not all kinds and varieties of fruit exhibit the same degree of resistance to low temperature. Nor can any specific temperature be said to be "killing" since the susceptibility of any kind or variety is closely related to its stage of development at the time when the freeze occurs. Since, however, there are variations in hardiness between kinds and varieties, an analysis of these variations appears pertinent to this study.

(A) CHERRY

Most investigators agree that sweet charries on Mahaleb rootstocks are more cold hardy than those on Mazzard rootstocks, both in the nursery and in the orchard. This difference in hardiness is attributed to the fact that cherry wood on Mahaleb ripens earlier in the fall than does the same wood on Mazzard. Coe (25) found a block of 60,000 nursery trees on Mazzard which had been killed by low temperatures, and found that adjacent blocks on Mahaleb showed little injury. He attributed the difference in survival directly to differences in maturity. In spite of its superiority over Mazzard in cold hardiness, however, Mahaleb is not now widely used as a sweet cherry rootstock. It has been found to be fairly short-lived and somewhat dwarfing in habit when compared with Mazzard. Carrich (41) in laboratory tests with these rootstocks found that Mazzard roots were killed by a temperature of 12 to 14° F., whereas Mahaleb roots were not killed until 5° F. was reached.

Palmer (66) reports that seedlings of Gold cherry have shown promise as sweet cherry rootstocks and are at least as hardy as Mahaleb. Gold is a vigorous growing seedling which is compatible with many of the sweet cherry varieties grown in the Pacific Northwest. Coe (25) mentions the use of American Morello rootstocks in areas where a high degree of hardiness is essential for growing cherries. He notes, however, that this rootstock tends to sucker badly. Hedrick (46) reports the use of Prunus pennsylvanica (Bird cherry) as a hardy stock for sweet cherry. However, it dwarfs most standard cherry varieties and suckers badly as well.

Sweet cherry varieties which are grown in the Okanagan Valley have been tested for hardiness under widely varying cultural conditions by Mann and Keane (58) at the Experimental Station, Summerland. Following is a summary of their observations:

Lambert - Among the hardiest of commercial sweet cherries. Trees less than ten years old suffered little damage. Those over twenty years old suffered injury in trunk and scaffold but appeared hardier than Bing, Deacon or Royal Ann in this respect. It was hardier in bud than Bing, Black Republican or Deacon and about the same as Royal Ann, Star and Van.

Bing - Less hardy than Lambert, but a little more so than Black Republican, Deacon or Royal Ann. Bing is less hardy in bud than Lambert, Royal Ann, Star and Van, about equal to Deacon and hardier than Black Republican.

Deacon - Less hardy than Lambert and Bing and about equal to Royal Ann. In bud-hardiness, Deacon appears less hardy than Lambert, Royal Ann, Star or Van, about equal to Bing and hardier than Black Republican.

Royal Ann - Less hardy than Bing and Lambert and about equal to Deacon. Hardier in bud than Bing, Black Republican and Deacon and about equal to Lambert, Star and Van.

Van - A new variety which was introduced in 1944. The original tree, planted in 1939, survived two severe Okanagan winters with little injury.

Star - A new variety which was introduced in 1949. The original tree, planted in 1939, survived two severe winters with slight injury rating in this respect slightly below Lambert and Van, but slightly above Bing. In bud-hardiness, Star is about equal to Royal Ann, Lambert and Van, hardier than Bing and Deacon and much more so than Black Republican.

Windsor - Hardier than all other cherries grown in the Hudson River Valley (Anderson (3)). There are no records available for Okanagan conditions.

(B) PEACH

The danger of low winter temperatures is probably the greatest single limiting factor in the commercial production of peaches in the Okanagan Valley. There is no particular temperature at which winter injury can be said to occur, since the degree of winter injury in a peach tree appears to be directly related to the stage of development of that tree and to other factors of the winter injury complex. Campbell (17) reports the survival of thirty varieties of peach at a temperature of -52° F. Brown (16), on the other hand, reports killing and severe injury to several varieties of peaches at -18° F. The fruit buds of peach are generally more tender to cold than other tissues, although Knowlton and Dorsey (52) report that the reverse has been true in certain cases. The degree of tenderness of peach fruit buds is usually closely associated with the progress of the rest period. Trees which enter dormancy early in the fall have usually completed their rest period by mid-winter and will commence growth activity during the first warm spell which occurs. If such a warm spell is followed by cold weather, the buds are often unable to regain sufficient cold-hardiness to offset the cold, and are therefore killed at temperatures considerably higher than those which would have killed them a few weeks earlier.

Cullinan and Weinberger (29) report that Elberta is a very tender variety in late winter, since it develops very rapidly after the break in its rest period and at the first warm weather. During one winter, they found that only a small percentage of fruit buds in one Elberta orchard survived a temperature of -10° F., when all buds of the same variety in another orchard 15 miles south were killed at a temperature of -7° F.

Knowlton and Dorsey (52) and Crane (28) report that the fruit buds of peach develop at vastly different rates. They indicate that the buds located on the base of a terminal shoot tend to develop late in the summer and that their rest period is not broken till late winter. This feature makes the basal fruit buds hardier than those borne on the outer portions of terminal shoots. Chaplin (21) reports that peach buds exhibit high resistance to cold during the early autumn, even before leaf fall, although the woody tissues of the tree are very tender at this time. The bud hardiness increases up to a point in mid-winter which appears to co-incide with the breaking of the rest period, and the hardiness then commences to decrease and the peach buds lose hardiness with every warm spell which occurs during the dormant period.

Observations made in Okanagan peach orchards during the winter of 1949-50 indicate that there is little difference in hardiness among the various peach rootstocks now in use. In general, seedling root-stocks of Muir, Lovell, and Veteran exhibit approximately the same degree of cold resistance. Winklepleck and McClintock (83) found that peach rootstocks are much less resistant to cold than other Prunus rootstocks. They noted that seedlings of Elberta peach were especially susceptible to cold injury and would therefore make a poor rootstock for peaches. Prunus

Davidiana, on the other hand, showed almost as much cold resistance as Myrobalan plum rootstocks and showed promise as a rootstock for peaches.

The difference in hardiness between peach varieties is not as consistent as desired. The difference varies greatly throughout the year and from year to year, depending upon environmental factors. But the relative position of varieties as to hardiness appears to remain fairly constant. The margin of difference between the most and the least hardy varieties is narrow, and consequently does not show up in years when the temperature drops so low as to nullify the differential. Whenever the low temperatures come within the range of this differential, the more hardy varieties will come through with a crop while most other varieties will lose their crops. It is erroneous to think that early-ripening varieties of peach commence growth activity during warm spells in winter, before late peach varieties do. According to Chandler (18), some of the very early varieties of the Chinese Cling group are the most slowly started into growth in early winter and bloom as late as any of the varieties.

Mann and Keane (58) have compared cold hardiness of all the peach varieties commonly grown in the Okanagan Valley. The following is a "breakdown" of their findings:

J.H. Hale - very tender both in wood and fruit bud. Not likely to withstand-15° F. without killing of buds, nor-20° F. without injury to wood.

Elberta - moderately tender in both wood and fruit bud. Somewhat hardier than J.H. Hale but less hardy than Valiant, Vedette or Veteran.

Veteran - one of the five hardiest varieties under test. Slightly hardier in wood than Valiant or Vedette; much hardier than Elberta, Golden Jubilee, J.H. Hale or Rochester. Less bud hardy than Vedette, slightly less than Rochester, about equal to Elberta and J.H. Hale and slightly hardier than Valiant.

Vedette - in tree-hardiness, slightly less hardy than Veteran, about equal to Valiant, hardier than Elberta, Golden Jubilee, J.H. Hale or Rochester. Greater bud-hardiness than all other commercial varieties, including Valiant and Veteran.

Valiant - in tree-hardiness, less hardy than Veteran, and about equal to Vedette; hardier than Elberta, Golden Jubilee, J.H. Hale or Rochester. Less bud-hardy than Vedette, slightly less than Veteran and other commercial varieties.

Rochester - less hardy than Veteran, Valiant and Vedette both in wood and bud, Hardier than Elberta, J.H. Hale, and Golden Jubilee in both.

Superior - very tender in wood, probably ranking with J.H. Hale. Slightly greater bud-hardiness than most other varieties and about equal to Vedette in this respect.

Red Haven - new variety which exhibits satisfactory hardiness in wood and bud in seven-year-old trees. Showed no fruit bud injury when J.H. Hale showed considerable injury.

Halehaven - twelve-year-old trees killed during severe winter along with other varieties of same age. Young trees appear comparable in tree-hardiness to Valiant, Vedette and Veteran and, in bud-hardiness to Vedette.

Fisher - equal in hardiness to Veteran and slightly hardier than Valiant and Vedette. Hardier in bud than J.H. Hale and Elberta.

Spotlight - young trees only, hardier in bud than J.H. Hale and Elberta. Tree hardiness appears equal that of young trees of other varieties.

Solo - greater bud hardiness than J.H. Hale and Elberta. Comparable with Valiant in tree and bud hardiness.

(C) APRICOT

Under Okanagan conditions apricot trees have shown themselves to be at least as hardy as peach trees. The limiting factor in apricot production is the early blooming tendency of the trees. Most apricot varieties bloom before the danger of late spring frost is over, and consequently the crop is frequently lost or seriously reduced. Since most apricots are budded on peach seedling roots, they exhibit about the same root hardiness as do peaches. Recently, emphasis has been placed on the breeding of later-blooming and hardier varieties from certain Russian and Manchurian strains of apricot. These strains are known to be hardy in tree and bud, and are late blooming, but the fruits are small and of poor quality.

The following summary (Mann & Keane (58)) based on observations made following the most severe winter on record, indicates the relative tree and bud hardiness of the apricot varieties most commonly grown in the Okanagan Valley:

Riland - among the hardiest of the commonly grown varieties. Rates equally with Kaleden and Wenatchee Moorpark in this respect. Intermediate in bud hardiness between Tilton and Wenatchee Moorpark.

Kaleden - hardy in tree, about equal to Wenatchee Moorpark and Riland. Lacks bud hardiness and in this respect rates lower than any other variety.

Tilton - in tree hardiness rates lower than Kaleden, Perfection, Riland, or Wenatchee Moorpark but hardier than Blenheim or Old Moorpark. Among the most bud-hardy of all commercial varieties, rating equally with Reliable in this respect.

Blenheim - lacks tree hardiness, rating lower than Kaleden, Perfection, Riland, Tilton and Wenatchee Moorpark. Less bud-hardy than Tilton, about the same as Riland, somewhat hardier than Perfection and Wenatchee Moorpark and considerably hardier than Kaleden.

Royal - similar to Blenheim in respect to tree and bud-hardiness.

Wenatchee Moorpark - consistently tree hardy, rating equal to Kaleden and Riland, and superior to Blenheim, Perfection and Tilton. Lacks bud-hardiness, rating lower than Riland and Tilton, but hardier than Kaleden.

Old Moorpark - lacks tree hardiness, rating with Blenheim in this respect. Fairly bud hardy.

Perfection - slightly less tree-hardy than Kaleden, Riland and Wenatchee Moorpark, but more so than Blenheim and Tilton. Far less bud-hardy than Tilton, less bud-hardy than Blenheim and Riland, about equal to Wenatchee Moorpark and more so than Kaleden,

Reliable - in tree-hardiness, about equal to Perfection, less hardy than Riland or Wenatchee Moorpark, but hardier than Tilton or Blenheim. Very hardy in bud, being equal to Tilton in this respect.

Rose - in tree-hardiness about equal to Perfection, less than Riland or Wenatchee Moorpark, but hardier than Tilton or Blenheim. Slightly less bud-hardy than Tilton.

(D) PRUNE AND PLUM

Prunes and plums have exhibited greater hardiness under Okanagan conditions than any others of the stone-fruits. Prunes and plums are usually grown on Myrobalan Plum rootstocks, which are also quite hardy. In some orchards, especially where the soil is light, prunes and plums have been grown on peach seedling rootstocks, in which case the hardiness of the prune or plum top is limited by the degree of hardiness found in the rootstock.

Plums are of relatively small importance in the Okanagan Valley when compared with the other stone-fruits, In general, however, most varieties are quite hardy both in tree and bud. The hardiness of plums in the Okanagan follows quite closely the findings of Brierly and McCartney (14). In general, varieties of the insititia type were hardier than those of the domestica type. The one outstanding exception to this statement is the Stanley plum, which appears to be consistently hardy and has withstood-30° F.

Prunes, during the most severe winter on record, appeared to be hardy both in tree and bud in most districts of the South Okanagan where the soil was considered suitable for prunes (Mann (58)). Prunes lacked tree hardiness - however, in most sections of the North Okanagan between Kelowna and Kamloops. This held true for all three strains of Italian prunes which are commonly grown in the Okanagan, namely Italian (De Maris), Italian (Greata) and Italian. The Italian (Richards) strain has not yet been assessed for hardiness.

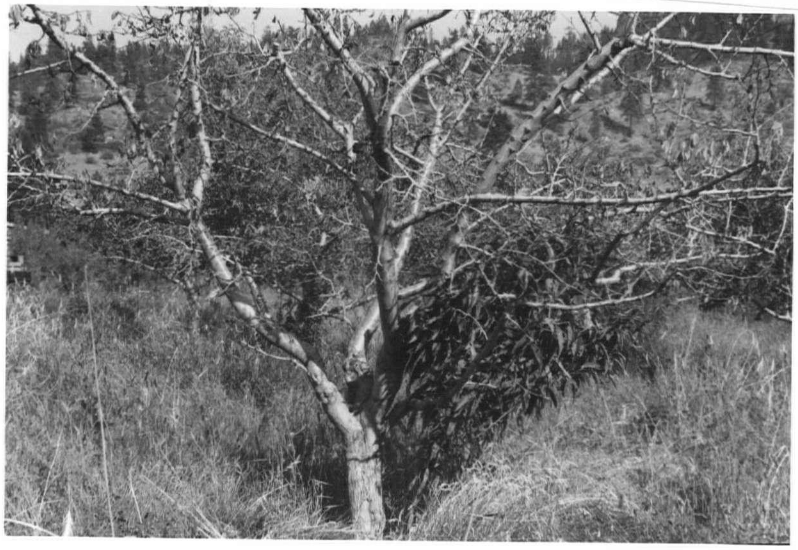
(VIII) THE 1949-50 WINTER IN THE OKANAGAN VALLEY

(A) NATURE OF DAMAGE

"Okanagan Firewood Worth $1000 a Cord" - This headline appeared in a British Columbia newspaper (71) following one of the coldest winters in the history of the Okanagan fruit industry. The headline is based on the fact that an acre of mature peach trees, worth about $2000 before the freeze, yields about two cords of firewood, In all, the Okanagan Valley cut about 2,100 cords of peach firewood in 1950, to say nothing of the amount of cordwood from injured apple, pear, apricot and other kinds of fruit trees.

Devastation in all kinds of tree-fruits grown in the Okanagan Valley was widespread following the 1949-50 winter. No particular pattern of damage followed the severe temperatures, orchards in some areas suffering far greater damage than those in other areas. Typical of the most severe damage found in orchards of the Osoyoos area, on the 49th parallel, was the following count of dead and living trees in one five-acre orchard: - 340 dead peaches, 7 alive; 70 dead cherries, 2 alive; 11 dead

Nature of Damage



The above-ground portions of this prune tree were killed outright. There was no apparent injury to the root system. Note vigorous peach shoot arising from the root system.

Same tree as above showing the vigorous shoot arising from an apparently un-injured peach root system.

apricots, 4 alive; 50 dead prunes, 1 alive; 25 dead pears, 70 alive; 13 dead plums, none alive.

A survey (7) of 2,249 orchards throughout the Okanagan Valley indicated a total of 336,610 dead trees out of a total of 1,664,037 trees in the valley. This represented an average loss of 20% of the trees in each orchard. However, average losses are not representative of the intense damage in certain areas and the relatively light damage in other areas. A breakdown of the damage according to kind of fruit tree and according to district is shown in Tables 4 and 5. Figures in this table are compiled from figures presented in Appendix A. In the ninety-one orchards surveyed in the Lytton-Kamloops-Chase district, 54% of the total trees were killed. In the Salmon Arm-Sorrento district, 31% of the trees were killed. Vernon district suffered a 25% loss while losses in other districts to the south ranged from six per cent to thirty per cent. One hundred per cent losses were suffered by many growers in different districts. Table 6 outlines the percentage of trees killed by size groups.

In addition to the trees killed outright by the 1949-50 frosts, there was also very heavy injury to fruit spurs and wood of other trees, resulting in a very small crop of some fruits for the 1950 season. Figures in Appendix A show a loss of about 111,000 peach trees out of a total of 343,500. But the peach crop following the freeze was only 160,000 boxes in 1950 as compared with 2,003,732 boxes harvested the previous season. Similarly, the 1950 apricot crop was 29,303 lugs, as compared with 603,339 lugs in 1949; the 1950 cherry crop totalled only 115,805 lugs compared with 520,431 lugs in 1949. Table 7 shows the total reduction in crop by district and kind of fruit.

A brief (68) prepared by the British Columbia Fruit Growers' Association for presentation to the Dominion and Provincial governments,

TABLE 4

Winter Injury Survey - Okanagan - Mainline - Grand Forks Area
British Columbia 1949-50

Number of Trees Killed

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"	Total	Total Trees as at Jan. 1,1950	% of Total Killed
Apple	5,729	6,645	14,712	46,521	33,421	107,028	1,117,215	31.8
Peach	9,859	24,285	39,108	30,774	7,287	111,313	343,534	33.0
Apricot	14,335	14,108	5,515	3,233	790	37,981	186,364	11.3
Cherry	2,312	2,618	1,850	4,678	6,988	18,446	99,316	5.5
Pear	9,940	6,348	3,215	2,524	693	22,720	333,807	6.8
Plum	301	1,002	1,626	1,723	497	5,149	16,149	1.5
Prune	3,105	6,907	12,102	9,620	2,239	33,973	200,200	10.1
TOTAL	45,581	61,913	78,128	99,073	51,915	336,610	2,296,585	100.0

TABLE 5

Winter Injury Survey by Districts
(British Columbia 1949-50)

District	Total Dead Trees	Total Trees as at Jan. 1,1950	Number Orchards Reported	Average % Loss Per Orchard
Lytton - Chase	24,629	45,435	91	54.0
Salmon Arm - Sorrento	24,956	80,404	160	31.0
Armstrong	2,919	7,871	22	37.1
Vernon	53,619	212,750	252	25.2
Oyama, Winfield, Okanagan Centre	16,144	117,832	175	13.7
Kelowna	50,536	354,977	395	14.2
Westbank	12,368	79,890	78	15.5
Peachland	8,423	45,885	68	18.3
Summerland	13,739	150,726	243	9.1
Penticton	5,915	89,007	139	6.7
Naramata	2,665	36,190	60	7.3
Kaleden	3,235	27,231	32	11.9
Keremeos - Cawston	19,112	81,465	108	23.5
Oliver - Osoyoos	94,826	339,434	398	27.9
Grand Forks	3,524	14,939	28	23.6
Total	336,610	1,684,037	2,249	19.9

2,249 orchards represents 68% of all orchards in the Okanagan Valley of British Columbia.

TABLE 6

Percentage of Trees Killed by Size Groups

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"	Total
Apples	5.35	6.21	13.75	43.47	31.22	100.00%
Peaches	8.86	21.82	35.13	27.65	6.54	100.00%
Apricots	37.74	37.15	14.52	8.51	2.08	100.00%
Cherries	12.53	14.19	10.03	25.36	37.89	100.00%
Pears	43.75	27.94	14.15	11.11	3.05	100.00%
Plums	5.85	19.46	31.58	33.46	9.65	100.00%
Prunes	9.14	20.33	35.62	28.32	6.59	100.00%
TOTALS	13.54	18.40	23.21	29.43	15.42	100.00%

Note: All tree trunks measured at a point six inches above ground level.

TABLE 7

Reduction in Crop Following 1949-50 Winter
Number of Packages

District	Kind	Average Crop 1946-49	Crop 1950	Total Reduction in Crop	Per Cent Reduction
All Districts	Peach	1,819,986	206,346	1,613,640	87
	Apricot	372,060	46,132	325,928	88
	Cherry	339,137	139,939	199,198	59
Lytton-Chase	Peach	395	40	355	90
	Apricot	307	306	1	3
	Cherry	277	251	26	9
Salmon Arm - Sorrento	Peach	50	0	50	100
	Apricot	40	0	40	100
	Cherry	6,350	156	6,194	98
Armstrong	Peach	0	0	0	0
	Apricot	23	0	23	100
	Cherry	478	0	478	100
Vernon	Peach	3,204	0	3,204	100
	Apricot	725	0	725	100
	Cherry	2,612	320	2,292	88
Oyama-Winfield Okanagan Centre	Peach	34,039	0	34,039	100
	Apricot	8,131	0	8,131	100
	Cherry	17,872	711	17,161	96
Kelowna	Peach	67,976	0	67,976	100
	Apricot	12,338	0	12,338	100
	Cherry	82,756	382	82,374	99
Westbank	Peach	58,956	0	58,956	100
	Apricot	2,487	0	2,487	100
	Cherry	12,890	2	12,888	100
Peachland	Peach	175,992	7,494	169,303	96
	Apricot	6,689	396	6,293	94
	Cherry	13,716	2,270	11,446	83
Summerland	Peach	285,836	30,753	255,083	89
	Apricot	95,844	655	95,189	99
	Cherry	46,759	20,047	26,712	57
Penticton	Peach	315,582	81,481	234,101	74
	Apricot	50,421	8,494	41,927	83
	Cherry	47,306	39,405	7,901	17
Naramata	Peach	67,646	16,805	50,841	75
	Apricot	39,191	4,838	34,353	88
	Cherry	24,794	16,643	8,151	33
Kaleden	Peach	98,147	15,807	82,340	84
	Apricot	26,835	545	26,290	98
	Cherry	9,951	7,460	2,491	25
Oliver-Osoyoos	Peach	674,250	53,700	620,550	92
	Apricot	124,955	30,949	94,006	75
	Cherry	71,606	52,270	19,336	27
Keremeos-Cawston	Peach	37,913	0	37,913	100
	Apricot	4,074	4	4,070	100
	Cherry	1,770	233	1,537	87

outlined the loss in value of the soft fruit crop for 1950 in comparison with the 1949 crop, as shown in Table 7 A.

TABLE 7 A

Sale Value of Crop

	1949	1950
Peaches	$2,432,850	$ 327,926
Cherries	1,651,765	577,371
Apricots	825,826	92,555
Pears	1,608,688	1,455,748
Plums	180,756	146,661
Prunes	784,989	496,135
	$7,484,874	$3,096,396
1950 Crop Loss -		$4,388,478

The B.C. Fruit Growers' Association requested partial compensation for growers on the basis shown in Tables 8 and 9.

TABLE 8

Compensation for Apple, Cherry and Pear Trees

a) For removing trees and preparing land

Trees under 2" diam.	Nil
Trees 2"-5" diam.	$2
Trees 5"-7" diam.	$4
Trees 7"-12" diam.	$6
Trees over 12" diam.	$8

b) For replanting to orchard

Per tree	$2

c) For equipping for use other than orchard

Per acre	$100

TABLE 9

Compensation for Peach, Apricot, Plum and Prune Trees

a) For removing trees and preparing land

Trees under 2" diam.	Nil
Trees 2"-5" diam.	$2
Trees 5"-7" diam.	$4
Trees 7"-12" diam.	$5
Trees over 12" diam.	$6

b) For replanting to orchard

Per tree	$2

c) For equipping for use other than orchard

Per acre	$100

On the basis of the above figures, the recommended compensation would be:

Apples	$618,632
Peaches	602,594
Apricots	71,181
Cherries	96,608
Pears	46,244
Plums	20,105
Prunes	123,756
Total	$1,379,120

Removing trees and preparing land -	$1,379,120
Rehabilitation at $2 per tree	673,220
Total	$2,052,340

(Comment: When, in 1951, growers were compensated on the basis of the above figures, the amount actually paid out by the federal and provincial governments totalled $250,000, a very disappointing amount which worked a real hardship on the tree fruit industry.)

A survey of Okanagan orchards during the spring and summer of 1950 indicated that winter injury was present in practically every known form. The most common form was injury to the trunk and crotches of bearing trees. This was manifested by the appearance of frost cankers on the injured areas. A line of demarcation soon appeared between the dead and living tissues. In late summer the dead bark began to crack and slough off from the tree and rot fungi were often present. In some trees, there appeared a distinct line of demarcation between living and dead tissue at exactly the level on the trunk where the snow-line had been. In such cases the entire top of the tree was killed while the lower portions were unhurt. Large watersprouts often arose below the snow-line and many growers used these to form new trees.

Nearly all stone-fruit trees showed some injury in the trunk and framework, as was evidenced by the appearance of varying shades of brown in the cambium layers. Where this colour was a deep walnut shade, the trees generally did not recover. But trees in which the cambium layer was less discoloured, exhibited varying degrees of recovery during the summer of 1950. Blackheart was evident in most trees examined, both in the spur wood and in the main limb structure. This injury has become increasingly evident with the passing of time, and it is safe to say that the lives of the trees injured in this manner have been greatly reduced. Extensive splitting and breaking of limbs of blackhearted trees has occurred since the 1949-50 winter.

Vertical splits in the trunks of certain trees, especially cherry trees, were also in evidence after the freeze. Such splitting was probably the result of contraction of the medullary rays of the wood. These splits invariably led to drying out, and sometimes death, of the trunk tissue.

Another type of injury showed up in the form of dead areas on the trunk and scaffold, especially on the north and south sides of the tree.

This injury appeared to result from the evaporation caused by drying winds from the north and south and from the tearing of trunk tissue due to bending of the tree when the bark was under tension. This injury was not confined to large wood, but was present in spur and twig growth as well and doubtless accounted for many of the dead spurs and twigs. It is probable that at least a part of the injury on the south side of trees could be attributed to winter sun-scald.

Fruit buds of stone-fruit trees were generally killed or badly injured. This injury can be attributed to the desiccating effects of both the very low temperatures and highly drying winter winds. Fruit buds in protected positions appeared to survive better than those on the periphery of the tree. This may have been due to their earlier formation and hence better maturity, and to the partial protection afforded them. Leaf buds were usually not injured unless the entire twig or spur had been killed or injured.

Root damage appeared not to be the primary cause of injury in the 1949-50 winter. Most orchards were well blanketed with snow which afforded good protection. However, the winter was characterized by strong, drying winds, which blew much of the snow away from the exposed areas of certain orchards. Wherever this happened and root injury occurred, the trees usually produced their normal blossoms and small leaves in the spring, as described by Brown (16). At the end of the blossoming period, after the fruit had set, definite injury began to show. The small leaves shrivelled and died, the limbs and small branches appeared dry and the bark shrunken, and the trees soon died. They had probably functioned normally on the food stored in the surrounding tissues until this was exhausted. When they came to depend upon food from the roots, the demand was greater than the roots could supply. More trees died with the advent of each hot spell. Some trees matured their crops before dying; others lingered on until the end of the summer and still others are dying slower deaths and may struggle along for many years.

Abnormalities in the few fruits which appeared in 1950 were abundant. Peaches were running heavily to "split-stones", a term used to describe fruits in which the pits have split in half so that each half adheres to the fleshy part of the fruit. This condition may have resulted from the fact that there were only a few fruits on each tree and their growth was forced to such an extent that the pits did not harden properly. But the likelihood is that the blossoms were injured and so did not have the ability to set normal fruits.

Prunes were characterized by the presence of numerous checks in their skins. From the checks there exuded small masses of clear gum, which hardened on the surface. Beneath the checks, there appeared discoloured cavities containing callous tissue. These blemishes made the prunes very unacceptable on the commercial market.

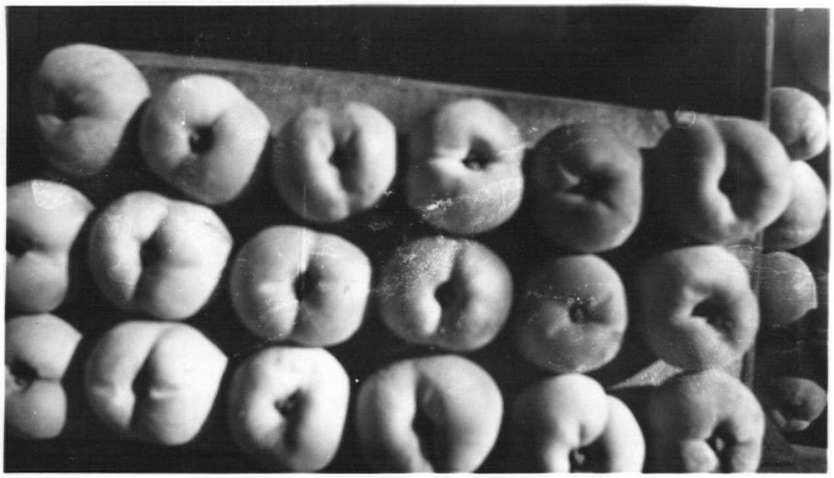
Many cherries showed abnormally deep sutures, and pears and apples often appeared "slab-sided", indicating that injury to some of the floral parts had probably occurred during the winter.

The extent of injury from orchard to orchard varied considerably, and, from surface observations, no single system of orchard culture could be said to be superior from the point of view of tree survival. It is true that, in some cases at least, the cause of severe injury was obvious, as in the case where fifty cherry trees were killed outright after having been heavily pruned and grafted the previous spring. However, in many cases, the cause of the damage from the point of view of orchard management, at least, was obscure.

(B) <u>RECORD OF TEMPERATURE AND PRECIPITATION</u>

The winter of 1949-50 in the Okanagan Valley was characterized by a prolonged period of extremely low temperatures, accompanied by continual

Fruit Malformations.



Peaches harvested during 1950 exhibited a high incidence of "split-stone" malformation. Such "split-stones" are not permitted in the commercial pack.

Prunes from injured trees exhibited severe gummosis during 1950. Such fruits are classed as "culls".

high, drying winds. (See Fig. 1 and 2) That the winter was most unlike the usual Okanagan winter is evidenced by a quotation of Palmer (64) in an annual report written in Summerland, the heart of the Okanagan Valley, some years earlier. "Extremes of temperature are never experienced either in summer or winter. During the twenty year period prior to 1936, the maximum temperature recorded was 103° F., the 100° F. mark having been reached only ten times. There was an average of eleven days each year when the temperature reached 90° F. or over. On the other hand, the coldest temperature recorded was -16° F. Most winters periods of zero temperatures are experienced, but these are of only very short duration."

In late December of 1949, the temperature dropped suddenly to figures ranging from 0° F. to -10° F. in various parts of the Okanagan. These temperatures dropped much lower during January and February as shown in Fig. 1 and 2. Throughout the twenty-four hours on some days temperatures remained well below zero, and in the Oliver and Osoyoos districts reached the extreme low of -23° F. during both January and February.

The Okanagan, like most arid regions, is subject to intense radiation freezing, as described by Day (30), Shankland (72) and Comford (26). Cold daytime winds and clear skies were characteristic of the 1949-50 winter. They usually died down towards evening, giving way to intense radiation of heat under clear skies. Thermometer readings taken at night in various orchards at different levels in the valley indicated that on some radiation nights, the lowest places were coldest and temperatures increased with altitude. But on other nights in the same places when temperatures were all at or below zero, the lowest place was the warmest and the temperature decreased with altitude. Thus, during most nights, there existed a mosaic of cold and warm air patches. Temperatures within these patches differed by as much as 7° F., even within a one-half mile radius. Since

Fig. 1

DAILY RECORD OF MAXIMUM AND MINIMUM TEMPERATURES — DEC. 1949 – MAR. 1950.

PENTICTON B.C.

Wind Record.

	Dec. '49	Jan. 50	Feb. 50	Mar. 50
Average Speed M.P.H.	7.4	7.9	10.7	7.0
Prevailing Direction	North	North/South	S.S.E.	S.S.E
Max. Speed, Direction, Date	S 30/5th	S 33/20th	SSE 25/1st	S 22/26th

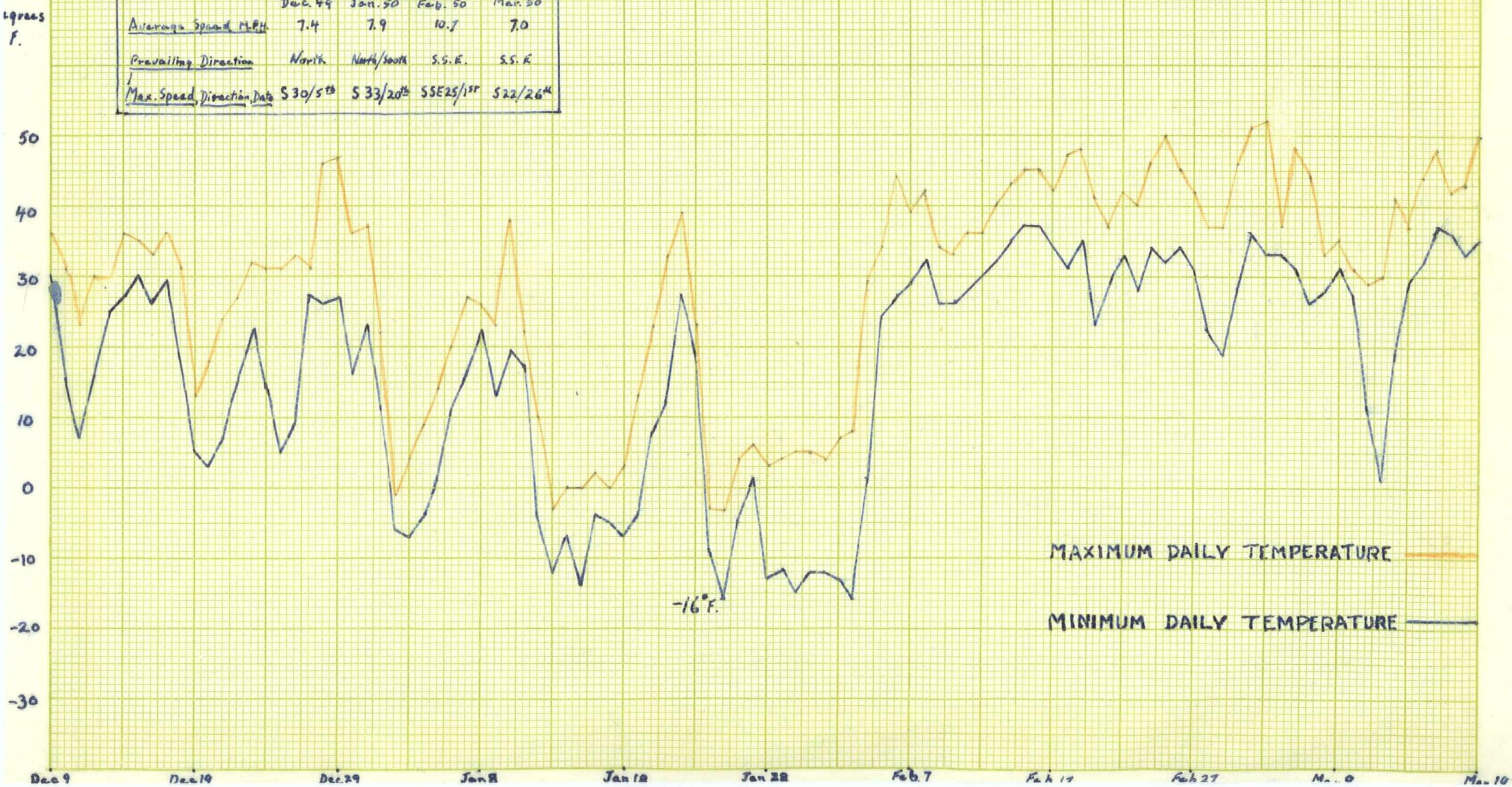
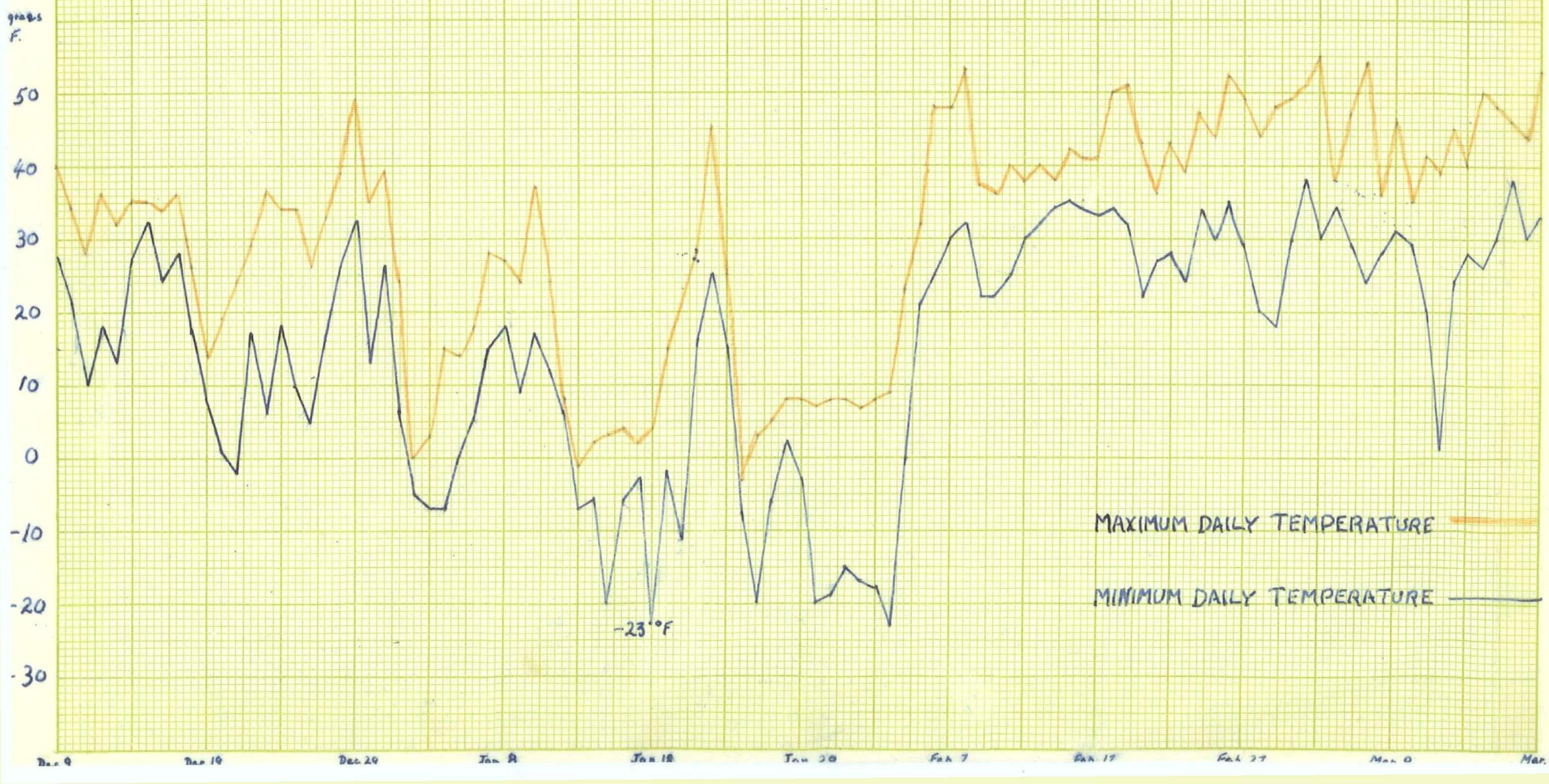


Fig. 2

DAILY RECORD OF MAXIMUM AND MINIMUM TEMPERATURES — DEC. 1949 - MAR. 1950.

OLIVER B.C.



there was never any constant difference in temperature between any two areas, it is quite understandable that the winter injury was not confined to any particular altitude or region.

Winter precipitation in the Okanagan Valley during 1949-50 was well above the average as is evidenced by the Precipitation figures for the Oliver district which are presented in Table 10.

TABLE 10

Precipitation for the Winter 1949-50 and Average Precipitation for the period shown. (inches)

	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.
Oliver	1.73	1.52	1.07	.99	2.01	1.22
Average	.95	1.07	.79	.81	.65	.67

The snow, driven by high winds, drifted into most orchards, thereby providing good frost protection for the roots of orchard trees. However, it was not deep enough to provide much protection for trunks and lower scaffolds.

(IX) MATERIALS AND METHODS

Early in the spring of 1950, when it first became apparent that low winter temperatures had caused serious damage to orchard trees, a detailed questionnaire (See Fig. 3) was prepared for mailing to commercial fruit growers in the South Okanagan Valley. Seven hundred of these questionnaires were distributed in June, 1950, and growers were requested to answer the questions and return the completed forms as soon as possible.

By July, 1950, only thirty completed questionnaires had been forthcoming, and it was decided that a contact survey was the only feasible means of recording the desired information. Between July 7 and September 18, more than four hundred orchards were visited. The survey was confined to the area between Penticton and the International Border at Osoyoos. Peach, cherry, and apricot trees only were included in the survey, since previous injury records on these kinds of fruits indicate that they have received very scant attention from the point of view of winter injury under Okanagan conditions.

During the survey, questionnaire forms were used to record the information and were supplemented with more detailed information whenever the need arose. A record of the actual number of trees of each variety killed or severely damaged was made and was calculated as a percentage of the total number of trees of that variety grown in any given orchard. Orchards visited were all selected at random to ensure that representative samples were being taken.

All data were later sorted for each factor under consideration and were separated to provide replication. Each set of data was statistically analyzed by Fisher's Analysis of Variance technique and, where necessary, variances were tested for significance by the Single Degree of Freedom technique as described by Snedecor (1946).

FIGURE 3 Questionnaire Used in A Survey of Winter-Injured Stone-Fruit Trees in the Okanagan Valley

1. General Information

Name of grower ______________________________

Location of orchard ___________________________

Orchard exposure ____________________________

Soil type ___________________________________

Orchard elevation ____________________________

Air drainage ________________________________

Distance from nearest large body of water __________

Windbreaks - windward or leeward side? __________

Depth of snow cover during January and

February 1950 __________

2. Specific Information

A. Kind of Fruit __________

(Insert here "Cherry", "Peach", <u>or</u> "Apricot". If you have inserted "Cherry" in the above space, answer the following questions for cherry only.)

When was the last complete irrigation

applied during 1949? __________

System of irrigation used __________

Did the trees produce normal vigorous

growth during 1949? __________

Were trees well hardened off in fall of 1949? __________

Were trees damaged by low temperatures of

1948-49? __________

Was 1949 crop heavy, moderate or light? __________

Did trees suffer any insect, rodent or spray damage

during 1949? Specify. __________

What fertilizer was applied during 1949? __________

At what rate? __________

What cultivation do you practise? __________

What cultivation was done in 1949? __________

In 1948-49 were trees short-pruned or long-pruned? ____

Were trees pruned before or after January 1,1950? ____

B. Variety of Fruit

Please supply the following information for each variety of each kind of fruit:

Variety	Number of Trees			
	Under 10 yrs. old		Over 10 yrs. old	
____________	Damaged	Undamaged	Damaged	Undamaged

For the above variety, indicate the nature of the injury:

Bud injury

Killing of terminal growth

Crotch injury

Dead areas on trunks and branches

Bark splitting

Root injury

Trunk injury

(X) RESULTS AND DISCUSSION

The following results, which are presented in tabular form, are based upon figures which are presented in Table 1 of Appendix B of this report. The values recorded in each table in the Appendix represent average percentages of the damaged trees in as many orchards as could be found for the factor under consideration.

(A) EFFECT OF DISTRICT, SOIL TYPE, AND KIND OF FRUIT

The analysis below represents figures compiled from nearly four hundred orchards.

Analysis of Variance

Factor	SS	Degrees Freedom	Variance	F	Sig. .05	.01
Total	11027	35				
Treatment	9446	11	858	57.2"	2.25	3.18
Soil	1253	2	627	41.8"	3.43	5.69
Error	328	22	15			

Effect of District - Single Degree of Freedom Analysis

Factor	Oliver 198	Osoyoos 395	Okanagan Falls 142	Penticton 51	Variance
Oliver vs. Osoyoos	-	+			$\frac{(197)^2}{2x9}$ = 2156.0"
Oliver vs. Okan. Falls	+		-		$\frac{(56)^2}{2x9}$ = 174.2"
Oliver vs. Penticton	+			-	$\frac{(147)^2}{2x9}$ = 1200.5"
Osoyoos vs. Okan. Falls		+	-		$\frac{(253)^2}{2x9}$ = 3556.0"
Osoyoos vs. Penticton		+		-	$\frac{(344)^2}{2x9}$ = 6574.2"
Okan. Falls vs. Penticton			+	-	$\frac{(91)^2}{2x9}$ = 460.0"

Required F Value		.05	.01
	N_1 = 1)		
	N_2 = 22)	4.30	7.94

Error Variance = 15

Value Required for Significance: .05 = 15 x 4.30 = 64.5

.01 = 15 x 7.94 = 119.1

Effect of Soil Type - Single Degree of Freedom Analysis

Factor	Gravel Sand 362	Sandy Loam 216	Silt Loam Clay 208	Variance
Gravel & Sand vs. Sandy Loam	+	-		$\frac{(146)^2}{2x12} = 888.1$ **
Gravel & Sand vs. Silt loam & clay	+		-	$\frac{(154)^2}{2x12} = 988.1$ **
Sandy loam vs. Silt loam & clay		+	-	$\frac{(8)^2}{2x12} = 2.7$

Required F Value $N_1 = 1$, $N_2 = 22$ — .05: 4.30; .01: 7.94

Error Variance = 15.0

Value Required for Significance: .05 = 15 x 4.30 = 64.5

.01 = 15 x 7.94 = 119.1

Effect of Kind of Fruit - Single Degree of Freedom Analysis

Factor	Cherry 187	Apricot 216	Peach 383	Variance
Cherry vs. Apricot	-	+		$\frac{(29)^2}{2x12} = 35.0$
Cherry vs. Peach	-		+	$\frac{(196)^2}{2x12} = 1600.6$ **
Apricot vs. Peach		-	+	$\frac{(167)^2}{2x12} = 1162.0$ **

Required F Value $N_1 = 1$, $N_2 = 22$ — .05: 4.30; .01: 7.94

Error Variance = 15.0

Value Required for Significance: .05 = 15 x 4.30 = 64.5

.01 = 15 x 7.94 = 119.1

DISCUSSION

Among the districts of the South Okanagan, the Osoyoos district suffered more damage to its stone-fruit trees than did any other district. The analysis indicates that damage in the Osoyoos district was highly significant at the 1% level over all other districts. Similarly, Oliver district encountered heavier damage than all other districts except Osoyoos, while Okanagan Falls had less damage than either Oliver or Osoyoos but significantly more damage than Penticton. It will be noted that trees in the Penticton district were damaged less than those in any other district and produced partial crops of stone-fruits in 1950.

The results of this analysis appear to be in direct relationship to the extent of the various soil types in each district. Osoyoos soils are predominantly light, with only small areas of loamy soils distributed among the coarser sandy and gravelly soils. The Oliver district is characterized by sandy soils with somewhat larger areas of loamy soils interspersed than in the Osoyoos area. This lineal tendency towards larger areas of the heavier soils from south to north in the valley holds true for both Okanagan Falls and Penticton. The Okanagan Falls soils are generally heavier than those in Oliver and much heavier than those in Osoyoos. Penticton soils are predominantly heavy, having large areas of clays, clay loams and silt loams with relatively small areas of sandy soils.

The analysis on soil types indicates that trees growing on the lighter soils were severely injured in comparison with those planted on the heavier loams and clays and it is suggested that the significance between districts results directly from the difference in soil types in the respective districts.

In what manner the soil types induced variable amounts of injury is difficult to say. It is known, however, that trees growing on light soils tend to drop their leaves and harden off earlier in the fall than do trees growing on heavy soils. This early hardening off, in turn, induces an early breaking of the rest period following the first warm spell in late winter. It seems entirely feasible that trees growing on light soils commenced growth activity at the first sign of warm weather following the extreme cold. Trees on heavy soils, having entered dormancy later, probably had less tendency to break their rest period at this time. Scrutiny of the temperature charts for February and March 1950 indicates that there was a severe temperature drop on March 12 following a long period of relatively warm weather. It is suggested that this temperature drop may have been responsible for the severe injury sustained by trees growing on light soils.

Results of the analysis of cherry, peach and apricot tree hardiness indicate that the peach was least hardy of all the stone-fruits during the winter of 1949-50. This lack of hardiness may have resulted from the failure of peach trees to ripen their wood following the heavy 1949 crop of peaches. Peach trees were conspicuously late in dropping their leaves and entering rest period and it is probable that their woody tissues never did attain maximum cold resistance before the onset of cold weather. There appeared to be no significant difference in hardiness between cherry and apricot trees at the 5% level but the trend in damage indicated that apricot trees were more heavily damaged than cherry trees.

(B) RELATIVE COLD INJURY TO SEVEN VARIETIES OF APRICOT

The following analysis may be considered to be a hardiness rating for the seven most commonly grown apricot varieties.

The table on which this analysis is based appears as Table 2 of Appendix B.

Analysis of Variance

Factor	SS	Degrees of Freedom	Variance	F	Sig. .05	Sig. .01
Total	1,423	20				
Variety	1,042	6	173.7	5.68**	3.00	4.82
Replications	14	2	7.0	.23	3.88	6.93
Error	367	12	30.6		2.179	3.055

Apricot Varieties in Order of Magnitude of Injury:

Wenatchee Moorpark	33.00%
Reliable	30.67%
Perfection	22.33%
Tilton	20.33%
Riland	19.67%
Blenheim	17.33%
Kaleden	11.00%

Minimum Significant Difference Between Varieties:

.05 level $\sqrt{\frac{30.6 \times 2}{3}} \times 2.179 = 9.83\%$

.01 level $\sqrt{\frac{30.6 \times 2}{3}} \times 3.055 = 13.80\%$

DISCUSSION

The fact that Wenatchee Moorpark trees proved to be the least hardy of all Apricot varieties studied in this survey is surprising. This variety has been rated among the most hardy by Mann and Keane (58).

It should be noted, however, that the Wenatchee Moorpark is among the oldest of the apricot varieties grown in the Okanagan, and at the time of the freeze, there were many old Wenatchee Moorpark trees in the orchards surveyed. Since old trees, regardless of variety, were usually more seriously injured that were young trees, it is probable that the high percentage of injury recorded for Wenatchee Moorpark, as a variety, was weighted by the severe injury to nearly all old trees of this variety.

On the other hand, injury to the Reliable apricot was not significantly less than injury to the Wenatchee Moorpark. The Reliable apricot is a relatively new variety and no trees more than ten years old were included in the survey. Ever since this variety was introduced commercially on peach roots, growers have experienced difficulty with breakage of the young trees at the bud union. This frequent breakage suggests an incompatibility between stock and scion, and this one fact alone may have been partially responsible for the high percentage of winter injury recorded for Reliable apricot.

Perfection and Tilton appeared moderately tree hardy in this survey, being significantly hardier than Wenatchee Moorpark, but significantly less hardy than Kaleden.

Kaleden apricot appeared more tree-hardy than all other apricot varieties, but was not significantly hardier than Riland and Blenheim at the 5% level.

(C) RELATIVE COLD INJURY TO SIX VARIETIES OF CHERRY

The following analysis may be considered to be a hardiness rating for the most commonly grown cherry varieties. The table on which this analysis is based appears as Table 3 of Appendix B.

Analysis of Variance

Factor	SS	Degrees Freedom	Variance	F	Sig. .05	.01
Total	14578	17				
Variety	12785	5	2557	14.45**	3.33	5.64
Replications	24	2	12	.07	4.10	7.56
Error	1769	10	176.9		2.228	3.169

Cherry Varieties in Order of Magnitude of Injury:

Royal Ann	85.00%
Carnival	41.67%
Bing	19.00%
Windsor	15.33%
Deacon	13.67%
Lambert	7.67%

Minimum Significant Difference Between Varieties:

.05 level $\sqrt{\frac{176.9 \times 2}{3}} \times 2.228 = 24.20\%$

.01 level $\sqrt{\frac{176.9 \times 2}{3}} \times 3.169 = 34.41\%$

DISCUSSION

Royal Ann was more severely injured than any other cherry variety recorded in the survey. The injury to this variety was highly significant at the 1% level, and was most pronounced in trees over the age of 15 years.

Carnival, a variety which is not widely grown in the Okanagan, was also severely damaged, and in tree hardiness, rated significantly lower than Windsor, Deacon and Lambert.

Bing appeared intermediate in tree hardiness and rated approximately equal to Windsor and Deacon in this respect. Lambert, although appearing to be the least injured of the cherry varieties, was not significantly less damaged than Bing.

In general, the results of this survey of cherry varieties appears to be in accord with the findings of Mann and Keane (58), with the exception of the Deacon variety, which appeared hardier than Royal Ann in this survey.

(D) RELATIVE COLD INJURY TO EIGHT VARIETIES OF PEACH

The following analysis may be considered to be a hardiness rating for the most commonly grown ~~cherry~~ Peach varieties. See Table 4 of Appendix B for information on which this analysis is based.

Analysis of Variance

Factor	SS	Degrees Freedom	Variance	F	Sig. .05	.01
Total	9342	23				
Variety	8550	7	1221	290.7**	2.77	4.28
Replications	198	2	99	2.35	3.74	6.51
Error	594	14	42		2.145	2.997

Peach Varieties in Order of Magnitude of Injury:

J. H. Hale	80.33%
Golden Jubilee	66.00%
Rochester	62.33%
Elberta	44.33%
Veteran	42.67%

Vedette	39.00%
Valiant	28.33%
Red Haven	20.33%

<u>Minimum Significant Difference Between Varieties:</u>

.05 level $\sqrt{\frac{42 \times 2}{3}} \times 2.145 = 11.35\%$

.01 level $\sqrt{\frac{42 \times 2}{3}} \times 2.977 = 15.75\%$

<u>DISCUSSION</u>

The three peach varieties which appeared to be most severely injured, J.H. Hale, Golden Jubilee, and Rochester, are no longer recommended for commercial planting in the Okanagan. J.H. Hale was least hardy of all the peach varieties. Golden Jubilee and Rochester rated significantly less tree-hardy than all other peach varieties with the exception of J.H. Hale.

Intermediate in tree hardiness were Elberta, Veteran and Vedette. Among these three varieties there was no significant difference.

Valiant and Red Haven exhibited greater tree hardiness than all other varieties surveyed. The hardiness rating for Red Haven, however, may not be entirely representative for that variety, since it was introduced only a few years ago, and there are no commercial plantings over ten years of age.

In general, the results of this hardiness rating for peach varieties are in accord with the findings of Mann and Keane (58).

(E) <u>EFFECT OF LATE IRRIGATION</u>

The following analysis, based on Table 5 in Appendix B, represents comparative damage to trees in orchards which received late irrigation (after October 15) and those which received no late irrigation.

Analysis of Variance

Factor	SS	Degrees Freedom	Variance	F	Sig. .05	.01
Total	4247	17				
Treatment	3386	5	677	11.36**	3.33	5.64
Replications	265	2	132.5	2.22	4.10	7.56
Error	596	10	59.6			

Effect of Late Irrigation - Single Degree of Freedom Analysis

Factor	Late Irrigation			No Late Irrigation			Variance
	Peach 100	Cherry 45	Apricot 52	Peach 170	Cherry 88	Apricot 106	
Late Irrigation vs. No Late Irrigation	-	-	-	+	+	+	$\frac{(167)^2}{6x3} = 1549.4^{**}$
Late Irrigation vs. No Late Irrigation							
Peach	-			+			$\frac{(70)^2}{2x3} = 816.7^{**}$
Cherry		-			+		$\frac{(43)^2}{2x3} = 308.2^{*}$
Apricot			-			+	$\frac{(54)^2}{2x3} = 486.0^{*}$

Required F Value		.05	.01
$N_1 = 1$)		4.96	10.04
$N_2 = 10$)			

Error Variance = 59.6

Value Required for Significance: .05 level 59.6 x 4.96 = 295.6

.01 level 59.6 x 10.04 = 598.4

DISCUSSION

Within the past few years, there has been a tendency on the part of fruit growers to apply a late irrigation to their orchards. Previously, the trees had been irrigated up to the time when the crop was harvested, after which the water was turned off. The use of a late irrigation sometime after October 15 and following the time when trees have begun to harden off, has become increasingly popular.

The results of this survey indicate that late irrigation of stone-fruit orchards is a desirable practice from the point of view of reducing winter injury. The percentage of trees injured in late-irrigated orchards was significantly lower than that in orchards not late-irrigated. This held true for all kinds of fruit surveyed and was highly significant in the case of peach orchards.

These findings are in accord with the relationship of soil moisture to dormant trees. A moderately high level of soil moisture during the winter months apparently replenishes the water lost from the tree top due to the desiccation of drying winds. This movement of water probably occurs at any time during the winter when the vascular system is not frozen, and serves to prevent excess moisture depletion from cells of the woody tissues.

(F) EFFECT OF AGE OF TREE

The analysis of injury to trees according to their age is based upon two age groups, those trees under ten years of age and those over ten. The percentage of injury recorded within the two age groups is presented in Table 6 of Appendix B. Since the age of a tree is difficult to judge precisely, the two age groups used in this survey were based entirely on trunk diameters.

Analysis of Variance

Factor	SS	Degrees Freedom	Variance	F	Sig. .05	.01
Total	5930	17				
Treatment	4090	5	818.0	5.82 **	3.33	5.64
Replications	435	2	217.5	1.54	4.10	7.56
Error	1405	10	140.5			

Effect of Age - Single Degree of Freedom Analysis

Factor	1 - 10 yrs Peach 97	1 - 10 yrs Apricot 56	1 - 10 yrs Cherry 35	Over 10 yrs. Peach 179	Over 10 yrs. Apricot 79	Over 10 yrs. Cherry 89	Variance
1 - 10 yrs. vs. Over 10 yrs.	-	-	-	+	+	+	$\frac{(159)^2}{6x3}$ = 1404.5*
1 - 10 yrs. vs. Over 10 yrs.							
Peach	-			+			$\frac{(82)^2}{2x3}$ = 1120.7*
Apricot		-			+		$\frac{(23)^2}{2x3}$ = 88.1
Cherry			-			+	$\frac{(54)^2}{2x3}$ = 486.0

Required F Value		.05	.01
N_1 = 1)			
N_2 = 10)		4.96	10.04

Error Variance = 140.5

Value Required for Significance: 5% level 140.5 x 4.96 = 696.9

1% level 140.5 x 10.04 = 1410.6

DISCUSSION

Results of this survey indicate that trees over ten years of age were more severely injured than trees under ten. This held true for all trees as a group, but further analysis indicates that there was no significant difference between the two age groups of cherries and apricots. Injury to peach trees of the older age group, however, was significantly greater than the injury shown by younger trees.

These findings may relate directly to the time of hardening off of the various kinds of fruits. Peaches were notably late in dropping their leaves following the 1949 harvest, and may have lacked tissue maturity at the onset of winter. Apricots followed the normal pattern of hardening off in the fall of 1949, while cherries were very nearly normal in their hardening-off activities. It would therefore appear that the age factor may not have come into play for apricots and cherries owing to the probability that both young and old trees had gained normal cold resistance before the arrival of cold weather. At any rate, age did not appear to be an important factor in the case of cherry and apricot.

(G) EFFECT OF PRUNING TECHNIQUE

Both long and short methods of pruning are used in the Okanagan Valley. The following analysis is designed to evaluate each method in relation to its influence upon winter injury. This analysis has been made for peaches and apricots only, since pruning of cherries is not an annual practice and since cherries are seldom short-pruned even when the pruning operation is carried out. See Table 7 in Appendix B.

Analysis of Variance

Factor	SS	Degrees Freedom	Variance	F	Sig. .05	.01
Total	2885	11				
Treatment	2038	3	679.0	7.42*	4.76	9.78
Replications	298	2	149.0	1.63	5.14	10.92
Error	549	6	91.5			

Effect of Pruning Technique - Single Degree of Freedom Analysis

Factor	Long-Pruned Peach 87	Long-Pruned Apricot 55	Short-Pruned Peach 162	Short-Pruned Apricot 91	Variance
Long-Pruned vs. Short-Pruned	-	-	+	+	$\frac{(111)^2}{4x3} = 1026.8$ *
Long-Pruned vs. Short-Pruned					
Peach	-		+		$\frac{(75)^2}{2x3} = 937.5$ *
Apricot		-		+	$\frac{(36)^2}{2x3} = 216.0$

Required F Value $N_1 = 1$) $N_2 = 6$) — .05: 5.99; .01: 13.74

Error Variance = 91.5

Value Required for Significance: 5% level 91.5 x 5.99 = 548.08

1% level 91.5 x 13.74 = 1257.2

DISCUSSION

The above analysis of the effect of pruning technique on cold temperature injury is based on the style of pruning carried out during the 1948-49 winter.

Short-pruned trees as a group suffered more injury than long-pruned trees. This finding appears to bear out the suggestion that removal of large quantities of leaf surface by heavy pruning reduces the ability of the tree to build up adequate food reserves for normal tissue hardening. Once again, however, peaches suffered heavily from short-pruning while the difference in injury to short and long-pruned apricots was not significant. The reason for this lack of significance may lie in the degree of short-pruning carried out on apricots. The term "short-pruning" is, at best, only a relative term, and while the short-pruned trees surveyed in this project were definitely pruned heavily, few of them could be considered to have been pruned as heavily as were the short-pruned peaches.

In spite of the unexpected results with apricots, however, it would appear that short-pruning is an unwise and unprofitable practice and should be discontinued, at least in the case of peaches.

(H) EFFECT OF VIGOUR

During the planning of the survey, it was found difficult to establish tangible descriptions of vigour. Since, however, the degree of vigour inherent in a tree is chiefly manifested by its terminal growth, "good" vigour was classified as meaning "terminal growth 10" - 18" long", while "poor" vigour meant "terminal growth less than 8"." The terminal growth measured in each case was the 1949 growth. (See Table 8 in Appendix B.)

Analysis of Variance

Factor	SS	Degrees Freedom	Variance	F	Sig. .05	.01
Total	2166	17				
Treatment	1792	5	358.4	9.8**	3.33	5.64
Replications	7	2	3.49	.09	4.10	7.56
Error	367	10				

Effect of Vigour - Single Degree of Freedom Analysis

Factor	Good Vigour Peach 68	Good Vigour Apricot 48	Good Vigour Cherry 45	Poor Vigour Peach 133	Poor Vigour Apricot 94	Poor Vigour Cherry 75	Variance
Good Vigour vs. Poor Vigour	-	-	-	+	+	+	$\frac{(141)^2}{6x3} = 1104.5$ **
Good Vigour vs. Poor Vigour							
Peach	-			+			$\frac{(65)^2}{2x3} = 704.1$ **
Apricot		-			+		$\frac{(46)^2}{2x3} = 352.7$ *
Cherry			-			+	$\frac{(30)^2}{2x3} = 150.0$

Required F Value		.05	.01
$N_1 = 1$)		4.96	10.04
$N_2 = 10$)			

Error Variance = 36.7

Value Required for Significance: .05 level 36.7 x 4.96 = 182.0

.01 level 36.7 x 10.04 = 368.5

DISCUSSION

Vigour or the lack of it appeared to be of utmost importance in determining the extent of winter injury of stone-fruits. Trees in poor vigour were badly damaged when compared with trees in normal vigour. This held true for all stone-fruit trees as a group, showing high significance at the 1% level. A separate analysis for each kind of fruit indicated that the relationship held true for both peaches and apricots but did not follow through for cherries. Some factor other than vigour appears to be more important to the cold resistance of sweet cherry trees.

The explanation for heavy damage in trees of poor vigour probably relates directly to the lack of carbohydrate build-up in the cells of woody tissues. Trees showing lack of growth during 1949 usually bore heavy crops of fruit and were lacking in leaf surface. It is probable that the scanty leaf surface was taxed to the limit in sizing the fruit and was not able to manufacture a sufficient reserve of food materials to offset the low winter temperatures.

(I) EFFECT OF CULTIVATION

Two basic cultural systems are practised in the Okanagan. The first involves a permanent cover of some kind, either a legume cover crop or grass sod. The second involves either continuous clean cultivation or intermittent clean cultivation. The following analysis strives to evaluate the effect of each system in relation to its influence on winter injury. See Table 9, Appendix B.

Analysis of Variance

Factor	SS	Degrees Freedom	Variance	F	Sig. .05	.01
Total	1072	17				
Treatment	225	5	45.0	.55	3.33	5.64
Replications	23	2	11.5	.14	4.10	7.56
Error	824	10	82.4			

No significance from "Treatments"

DISCUSSION

The results obtained in this analysis do nothing to support either the permanent cover or cultivation systems of orchard culture. There was no significant difference recorded between the two types of culture.

It is probable that any effects resulting from one or other system of culture would be felt chiefly by the root systems of the trees. Since snow cover was generally heavy and frost penetration of the ground slight, the root systems were not usually injured. Whether or not the heavy snow cover was responsible for nullifying any possible effect from cultural practices, the analysis seems to indicate that cultivation or the lack of it was not a contributing factor to winter injury during the winter of 1949-50.

(J) EFFECT OF SNOW MULCH

During the progress of this survey, an effort was made to determine the effect of a snow mulch in reducing winter injury. Accurate measurements of snow depth, however, had not been made by most growers and the meagre data available did not justify an analysis.

At the first onset of snow in December, the cover was fairly uniform throughout the Southern Okanagan Valley. But as the winter progressed, the snow drifted heavily in most areas, leaving the ground almost bare in some places. Snow cover varied from 0" to 40" in some orchards, the high knolls and ridges often showing bare ground.

Trees growing on knolls and ridges were usually killed outright, indicating that the roots had been frozen to death. Trees growing nearby, but with a snow mulch covering the roots, were often killed as well, but differed from the others in that they often exhibited a vigorous shoot growth from the base of the trunk. This shoot growth appeared to coincide closely with the height of the snow line, and indicated that roots had not been damaged by the low temperatures. Many growers elected to retain the old roots and removed the original tree top, training one of the vigorous young shoots to form a new tree.

(K) EFFECT OF PREVIOUS CROP

Since nearly all stone-fruit crops had been heavy in 1949, there appeared to be no basis of comparison for the effect of the previous crop upon inducing winter injury. A statistical analysis for this factor was therefore impossible.

It seems reasonable to suppose, however, that the extremely heavy crop borne by stone-fruit trees in 1949 was a major contributing factor to winter injury. This crop apparently depleted food reserves to the point where vigour was at a generally lower level than that desired for profitable stone-fruit production. This resulted in a high degree of susceptibility of the woody tissues to low temperature injury.

(XI) MEANS OF OFFSETTING WINTER INJURY

Results of this survey and a close scrutiny of the voluminous literature dealing with winter injury to stone-fruit trees, indicate that there are certain practices which growers might well follow in an attempt to minimize winter injury in their orchards. A summary of these practices follows.

Healthy trees will survive low temperatures better than trees which have been weakened by overcropping, drought, wet feet, spray burn, insects, disease and other factors. Assuming, however, that trees are in a healthy condition when they enter the dormant period, one may adopt certain techniques to minimize injury during a winter which would ordinarily damage even the healthiest of trees.

(A) SITE

During every severe winter, some orchards always fare better than others from the point of view of cold injury. These differences are not just a matter of good luck for one orchardist and ill luck for another.

Means of Reducing Winter Injury

Trunk of cherry tree protected from "south-west" injury by presence of V-shaped board placed against the tree. Trees showed no injury where such protection was provided.

This protector was cut too short and injury has occurred above the board.

They are the result of certain patterns of planning and procedure, some of which lead to severe tree injury and others to less injury or perhaps none at all. Often the orchards which survive well in low temperatures do so more by good luck than good management. Nevertheless, the reasons for good survival are there and are well worth observing.

Possibilities of the occurrence of winter injury in any proposed orchard area should be considered before any actual planting is undertaken. This is best done by a careful study of weather records as far back as such records have been kept. Factors such as frost free periods, the frequency of temperatures low enough to cause injury to orchard trees, and the duration of these low temperature periods are of utmost importance. In any given area which appears suitable, the selection of a site which is close to a large, deep body of water is desirable, since a body of water is known to exert a modifying influence upon temperature in the nearby orchards. In addition, the ground selected for planting should be "frost free", or situated on ground which is subject to good air drainage. The use of depressions in the land, or areas located in the midst of heavily-wooded country is to be avoided, since air drainage in such locations is usually poor.

(B) SOIL

Soil type, too, has a definite bearing on the ability of trees to withstand cold. A deep, well-drained soil which is capable of holding adequate moisture for tree growth is ideal. Light sandy soils generally freeze deeper than loams and are thus apt to experience deeper frost penetration. Roots in such soils are therefore often injured. Shallow, sandy soils which are underlain with gravel should be avoided since trees on such soils tend to be shallow rooted and hence are susceptible to cold injury. Trees growing on poorly drained soils are also very susceptible to winter injury and should never be planted on such soils until adequate drainage has been provided. Even some of the heavy clays and silts, which are otherwise suitable as orchard soils, are better with a drainage system installed. Such heavy soils tend to provide available moisture, such that they promote prolonged tree growth, beyond the time when normal fall hardening-off should take place. Delayed hardening-off is a common cause of cold injury.

(C) HARDY ROOTSTOCKS, FRAMEWORKS AND VARIETIES

Assuming that a suitable site and soil have been selected, one of the best forms of insurance against cold injury is the choice of suitable kinds and varieties of fruits for the particular area in question. Stone fruits, for instance, should ordinarily not be planted in any area where temperatures can regularly be expected to go below about -10° F. Apples, on the other hand, generally have a somewhat greater tolerance to low temperatures and might safely be planted in areas which, from the standpoint of winter temperatures, are questionable for stone fruits. Within any given kind of fruit there occurs a wide range of varieties. Some of these varieties inherently have more cold resistance than others. In planting consideration should be given to the cold hardiness ratings of the varieties selected. Orchardists should always adhere to the kinds and varieties of fruit recommended by authorities for use in their particular districts.

The use of hardy varieties in cold districts is a useless procedure unless some attention is given to the use of hardy rootstocks and hardy frameworks. Unfortunately, too much use is made of seedling rootstocks of unknown cold-hardiness, and too little use made of clonal rootstocks of known hardiness. Growers may often wonder why three or four trees in a row of some fifteen to twenty survive the winter while the rest are damaged beyond recovery. Without doubt, there are instances when this hit-and-miss type of injury can be attributed to seedling rootstocks, each one having a somewhat different degree of cold hardiness.

Certain semi-tender varieties of fruit may be adapted to cold areas through the use of hardy framework stocks. Red Delicious apple, for instance, a variety ordinarily too tender in trunk and scaffold to be grown in the Kelowna, B.C. district, may be adapted to this district by topworking Red Delicious on McIntosh. Some combinations in "double-worked" trees are commonly used in the Okanagan Valley of British Columbia as a safeguard against winter injury.

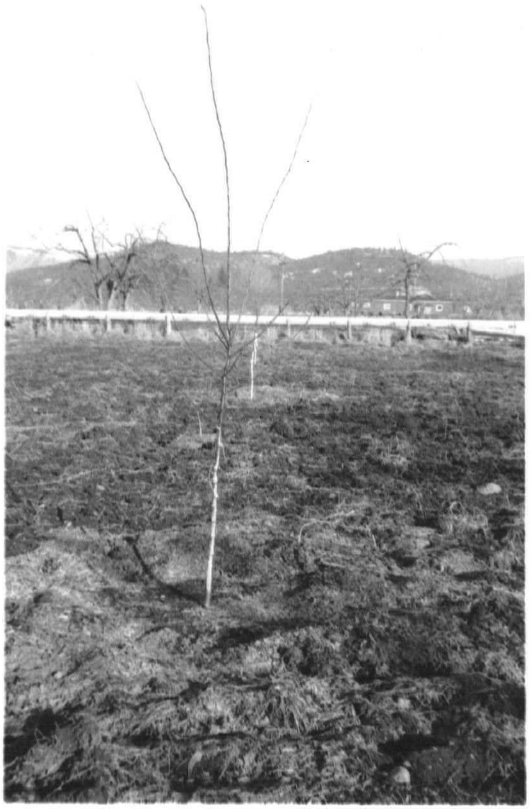
(D) HANDLING YOUNG TREES TO PREVENT SUNSCALD

Reduction of the incidence of winter sunscald or south-west injury may be assisted by certain techniques used in the handling of young trees. In areas where sunscald is a familiar type of winter injury, young trees should be planted so that they lean slightly to the south-west. This procedure helps to reduce the angle at which the sun's rays strike the trunk of the tree. In addition, pruning of young trees should be carried out in the late winter or early spring, and the pruner should strive to leave a low limb on the south-west side of the tree to help break the direct contact of the sun's rays with the trunk. Some growers make a practice of loosely wrapping the trunks of young trees with waterproof paper. Where this procedure is followed, the paper should be put on late in the fall and removed early in the spring.

(E) COVER CROPS OR MULCHES VS. CULTIVATION

It is well known that a mulch of hay, straw or sawdust, or a heavy cover crop will tend to delay the deep ground penetration of frost. Such ground covers thus permit root activity during cold weather and enable the tree to replace moisture lost by evaporation through winter desiccation. From the point of view of winter injury, then, the practice of fall cultivation

Means of Reducing Winter Injury



Young Red Delicious apple trees showing use of aluminum paint on trunks to reduce susceptibility to winter sun-scald.

appears to be unwise. A deep snow mulch will retard frost penetration in the same way as vegetation mulches and offers good winter protection both to roots and to trunks. Snow is known to drift away from certain exposed areas in the orchard, and where this occurs, growers would do well to erect snow fences in an effort to hold the snow in the exposed orchard area. Good as snow may be, sufficient quantities of it to be helpful against cold cannot be relied upon from year to year in most districts, and it is for this reason that fall cover cropping and mulching are recommended as being sound orchard practices. The use of fall-sown cover crops probably has an advantage over the use of mulches, in that a late-sown crop tends to absorb any surplus nitrogen at the expense of the tree and thus tend to stop tree growth at an early fall date. Such early hardening-off is known to be desirable.

(F) FERTILIZER PRACTICES

Trees which are showing moderate vigour are more tolerant of low temperatures than are those in high or low vigour. Thus a bearing apple tree should be fertilized only to the extent that will promote approximately 12 to 15 inches of terminal growth each year. In general, mature stone-fruit trees should be fertilized to promote 18 to 24 inches of terminal growth each year. This terminal growth should occur early in the growing season and should not continue much beyond mid-summer. Termination of this growth will promote early hardening-off of tissue in preparation for the colder months to come.

This early growth is best obtained in the Okanagan Valley by fertilizer applications during the very late fall on heavy soils and very early spring on the light soils. Summer or early fall applications of fertilizer must be avoided. Failure to apply adequate quantities of fertilizer will undoubtedly lead to low vigour, which in turn will often lead to winter injury. In general, it appears that the lack of any essential food element will upset the physiological balance of the trees and might well lead to winter injury.

(G) PRUNING PRACTICES

Pruning practices should always be patterned to minimize the effects of low temperatures on the trees. If a normal winter has been experienced, orchards should be pruned in the late winter or early spring. If a severely cold winter has been experienced, little or no pruning should be done. These latter two statements apply particularly in the case of soft fruits and to a lesser extent in the case of apples. Late pruning also affords the tree better opportunity to start healing its wounds promptly. It also reduces the possibility of die-back from the pruning cuts and the possibility of fungous invasion at the wound.

Even when there has occurred no particularly cold weather prior to the pruning season, only a moderate pruning of limbs should be practised. Heavy pruning reduces the leaf surface of the trees during the following growing season and so limits the ability of those trees to build up adequate food reserves in the storage cells. This lack of sufficient food naturally weakens the tree and renders it susceptible to injury during the following winter. For this reason, too, grafting of trees should be delayed until early spring.

Where risk of cold damage to late fall or early winter pruned trees exists, orchardists would be wiser to hire additional help to prune the orchard at a later date than to run the risk of winter injury by pruning their acreages over a longer period of time. In general, the most tender fruits should be pruned last, and within any given kind, the most tender varieties should be pruned last.

(H) THINNING THE CROP

Overcropping of trees tends to deplete food reserves to the point where woody tissues are unable to withstand low temperatures. Thus trees should be adequately blossom-thinned or fruit-thinned in relation to their leaf surface. The thinning operation should be carried out at the earliest possible date, since the longer the excess fruits are left on the tree, the greater will be the tendency to reduce the food storage processes within the woody tissues. To this end, the blossom thinning of tree fruits appears to be a promising method of reducing the set of fruit at the earliest possible date, so that the trees will develop maximum food reserves during the growing season. Edgerton (33), using dinitro-ortho-cresol materials for blossom thinning increased fruit bud hardiness of peaches as noted in Table 3. No doubt such treatment also increases the hardiness of the woody tissues.

(I) IRRIGATION PRACTICES

Both excess and lack of water appear to enhance the probability of winter injury. An excess of water may cause growth to continue too late into the fall months, or, if carried to the extreme where trees have wet feet, may cause a decided lack of vigour. Both results of this excess moisture will render the trees susceptible to winter injury. Similarly, a lack of water induces low vigour in trees with resulting poor hardiness characteristics. On the basis of these observations, growers should irrigate their trees to promote adequate growth during the early part of the season and to size the crop prior to harvest. Following the harvest, irrigation should be reduced or perhaps stopped entirely to encourage cessation of growth and to hasten the ripening of woody tissues. When the trees have commenced to harden off, they may then require, depending on the season, a late irrigation to ensure that the soil moisture is adequate to meet tree requirements during the winter months.

(J) OTHER PRACTICES

The practice of whitewashing tree trunks to offset winter sunscald may have some virtue with certain varieties of fruit which can tolerate heating of the cambium layer on the south-west side of the trunk up to but not past a certain temperature. Aluminum paint used for the same purpose may offset the danger of sunscald to an even greater extent, since aluminum is known to exhibit remarkable heat-reflecting properties. The use of aluminum paint as a trunk treatment, however, is in the experimental stage only and more knowledge of its abilities is necessary before it can be recommended.

The practice of hoeing around trees very late in the fall cannot be recommended since it tends to expose the crowns of the trees to the ravages of low temperature. Where the presence of crown rot or mouse infestation demands the removal of debris from the tender crowns late in the fall the debris should be replaced by coarse ashes or pea gravel. A much better practice, however, is to remove the debris early enough in the fall to permit hardening-off of the crown tissues.

The use of windbreaks in orchard areas is a commendable practice only when the windbreaks do not prevent good air drainage through the orchard. Too often, they are so dense and so poorly placed that they create frost pockets which are most detrimental to the orchards. Windbreaks should be used to protect exposed areas of orchard only and should be so placed that they act as wind deflectors.

Over long periods of time, most fruit growers find it impossible to prevent entirely all winter injury. Sooner or later, some or all of their trees are affected. It is therefore wise for a grower to diversify his plantings as much as good economy will permit. He should maintain an acreage of each kind of fruit and might well grow several varieties of each kind. Finally, growers should try to carry out such a program of constant orchard renewal, that they will have plantings of trees of varying ages and of varying susceptibility to winter injury. Some such plan would tend to minimize disastrous tree or crop losses in any one season, such as occurred in 1949-50.

(XII) CARE OF TREES AFTER INJURY

Trees which are suspected of having been injured during the winter should receive very special attention. It is often impossible to forecast by an examination of the tree early in the spring the extent or severity of the injury. Very often, trees which appear dark brown in the cambium layer recover to the extent that they once again become profitable entities in the orchard. Hasty decisions to pull out apparently injured trees should therefore be discouraged.

Injured trees should receive their regular dormant sprays to reduce the possibility of an infestation of insects and diseases which could weaken the trees. No pruning should be done to an injured tree, since it is difficult to judge the extent of the injury and there is danger of removing sound wood and leaving injured wood. Furthermore, any removal of potential leaf surface would minimize the chances of tree recovery.

Mulching of the trees with some moisture-holding material would be a wise practice, since the moisture relations in the soil beneath an injured tree are most important to its welfare. Moderate fertilizer applications with ammonium nitrate, if none has been applied the previous fall, would tend to assist the tree in developing a maximum amount of new leaf surface. Irrigation practices should be geared to prevent any over

Treatment of Injured Trees

This six-year-old peach tree was seriously weakened by trunk and scaffold injury, causing it to break down under only a moderate crop.

Five-year-old apricot tree which was badly injured in cold winter. Owner elected to cut off the entire top of the tree. Photo taken in 1954 indicates almost complete recovery, with only one small pruning wound showing on the trun[k]. Entire orchard was treate[d] the same way with complete success.

supply of water, especially where there is injury to the tree roots. Wherever clean cultivation is to be practised only very shallow cultivation is recommended to remove weed growth.

During the growing season following the severe winter, the orchardist should study the injured trees and decide which are to be kept, which are worth repairing, and which should be removed or replaced. This cannot be done by rule-of-thumb. Each tree will be a problem in itself and will call for the exercise of careful judgment. Trees having the trunk and a considerable portion of the scaffold damaged, should probably be removed. If there has been no root injury, however, it may be possible to renew badly damaged trees by cutting them off near the ground at a decided slant, saving a new sprout at the upper edge of the cut. In this case, the large, uninjured root system may soon grow a new top and a profitable tree be formed much sooner than as if the old tree were replaced with a new nursery tree. This practice of renewal should not be attempted with trees over ten years of age, however, since the wound would be so large that it is doubtful if it would heal before decay would set in. The renewal sprout should be staked to prevent it breaking away from the old stump.

Trees which the grower elects to keep should be examined for loose bark. Such loose bark should be tacked in place with roofing nails at an early stage of growth to prevent the drying out of tissues beneath the bark and thereby to encourage rapid healing. The practice of tacking cherry bark with nails is to be discouraged, since the tree will often bleed through the punctures. Binding the trunks with cloth strips is the desirable practice on injured cherry trees. After the healing process has continued into late summer, the loose sections of bark should be removed to reveal the extent of healing. Wherever the new tissue has not covered the old heart-wood, this wood should be treated with a good, prepared tree emulsion, or white lead paint containing mercuric bi-chloride. Such treatment will reduce the possibility of entrance of fungi and insects. Painting, however, should always be delayed until the newly-formed tissue is calloused sufficiently to offset possible burning or injury to the cambium layer.

If an apple or a pear tree appears to have a fair chance of recovery, the dead limbs should be removed flush with the trunk or large limb from which they extend. The winter injury cankers around the base of dead limbs should be removed neatly by scraping the dead bark away with a sharp knife or chisel. The extremities of the wounds should be left pointed to hasten healing and the exposed wood painted with a suitable protectant. Such treatment does not apply to peach and apricot, where the procedure should be to remove dead limbs and paint large pruning wounds.

In cases where the injury is known to be localized in the trunk or a small portion of main scaffold branches, the damaged areas may be inarched or bridge-grafted in the same manner as would be done for mouse damage. Care should be used in selecting the scions for this purpose so that injured shoots are not used as grafting material.

Whether or not injured trees recover depends largely on the weather conditions that follow the injury. If the spring and summer following the injury are cool and growing conditions are good, the trees may make a remarkable recovery. Hot, dry weather following the freeze, however, is most unfavourable to recovery. Under such weather conditions, trees which appeared to suffer only slight winter injury may succumb entirely by the end of summer. Whatever the extent of recovery, growers must expect their trees to become rather brittle in the years following a freeze, and must therefore be prepared to brace the scaffold limbs and prop heavily when the trees are in crop. This brittleness results from the failure of resins and gums to infiltrate the young sapwood which has been frozen to death. The young sapwood therefore never develops the same strength that heartwood ordinarily would.

(XIII) SUMMARY

A winter injury survey of several hundred stone-fruit orchards in the South Okanagan Valley of British Columbia following the severe winter of 1949-50 indicated that numerous factors contributed to the widespread damage.

Sudden temperature declines following periods of relatively mild weather were undoubtedly responsible for a major portion of the damage. Notwithstanding these temperature declines, however, statistical analyses indicate that certain factors, both controllable and uncontrollable, affected the degree of severity of injury. Soil type bore directly on the amount of injury, the lighter soils being responsible for greater injury than were the heavier soils. The intensity of injury in the various districts surveyed appeared to be directly associated with the soil type most predominant in each district.

Of the various kinds of fruit included in the survey, peach trees were injured more than apricot trees and apricot trees more than cherry trees. Within each kind of fruit, varieties exhibited variable degrees of hardiness, some varieties showing almost 100% injury, others less than 10% injury.

Irrigation practices appeared also to have a direct bearing on the extent of winter injury. Trees which were irrigated later than October 15, after first having been allowed to commence hardening-off, came through the winter with less injury than trees which were not late-irrigated.

The age of trees was of significant importance to all trees when trees over ten years of age were compared with trees under ten years of age. This fact was particularly evident in the case of peach trees - the older age group showing most injury.

Then again, the pruning technique used on trees, regardless of age, appeared to be a factor involved in the extent of injury sustained. Short-pruned trees, especially in the case of peaches, suffered more winter injury than long-pruned trees.

Vigour of the trees was also an important contributing factor to the amount of injury sustained. Trees in low vigour, regardless of variety or kind, exhibited more cold injury than trees in good vigour. This factor was especially important in the case of peaches and apricots.

Orchard cultivation or lack of cultivation did not appear to be an important factor bearing on the extent of winter injury. There was no statistical difference between trees growing in cultivated orchards and those growing in orchards having permanent cover crops. This similarity in response probably resulted from the heavy snow cover in all orchards, nullifying any possible root damage attributable to one treatment or the other. Root damage did not appear to be an important form of winter injury in 1949-50.

An analysis of the effect of snow mulch in reducing injury was impossible since snow cover was general and comparisons were lacking. Reliable data on actual depth of snow cover was also lacking. Similarly the effect of previous crops could not be analysed since nearly all trees bore a heavy crop of fruit in 1949.

Interactions between the various factors could not be analysed, even though interactions are recognized to be of extreme importance in any study of winter injury. In a survey of this kind, however, setting up data to facilitate analysis of interactions did not seem feasible, since the variables from orchard to orchard were not controlled. The results of this survey and the difficulties encountered in tabulating data from such a vast number of orchards, points out the desirability and necessity of setting up controlled experiments dealing with the various factors associated with the winter injury complex. The results indicate, too, the desirability of analysing one small phase of the complex at a time, so that the results of all these small phases may ultimately be related to each other to present a clear picture of the factors responsible for winter injury.

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APPENDIX A

TABLE 1

Record of Winter-Injured Trees

Totals - All Interior B.C. Orchards Reported

(2,249 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"	Total All Sizes	% Killed
	Number of Trees						
Apples	5,729	6,645	14,712	46,521	33,421	107,028	31.8
Peaches	9,859	24,285	39,108	30,774	7,287	111,313	33.0
Apricots	14,335	14,108	5,515	3,233	790	37,981	11.3
Cherries	2,312	2,618	1,850	4,678	6,988	18,446	5.5
Pears	9,940	6,348	3,215	2,524	693	22,720	6.8
Plums	301	1,002	1,626	1,723	497	5,149	1.5
Prunes	3,105	6,907	12,102	9,620	2,239	33,973	10.1
Totals	45,581	61,913	78,128	99,073	51,915	336,610	19.9

Total Trees in Orchard 1,684,037

Average Loss per Orchard 19.9%

APPENDIX A

TABLE 2

Record of Winter-Injured Trees

Lytton - Chase

(91 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	459	1,246	3,088	8,408	6,982
Peach	29	324	161	30	-
Apricot	7	122	86	14	11
Cherry	7	301	22	78	13
Pear	156	351	64	129	1
Plum	7	84	123	33	2
Prune	31	581	1,198	476	5

Total dead trees	24,629
Total trees in orchard	45,435
Average loss per orchard	54%

APPENDIX A

TABLE 3

Record of Winter-Injured Trees

Salmon Arm - Sorrento

(160 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	531	635	2,691	8,301	7,175
Peach	11	90	57	122	1
Apricot	25	32	124	2	-
Cherry	175	85	254	332	364
Pear	79	236	509	858	218
Plum	9	71	129	119	76
Prune	227	183	564	425	246

Total dead trees	24,956
Total trees in orchard	80,405
Average loss per orchard	31%

APPENDIX A

TABLE 4

Record of Winter-Injured Trees

Armstrong

(22 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	49	69	84	539	382
Peach	7	20	19	5	3
Apricot	3	10	6	1	1
Cherry	80	38	28	72	45
Pear	38	36	143	100	17
Plum	-	21	51	105	69
Prune	9	111	383	332	43

Total dead trees	2,919
Total trees in orchard	7,871
Average loss per orchard	37%

APPENDIX A

TABLE 5

Record of Winter-Injured Trees

Vernon

(252 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	847	2,253	5,053	13,147	6,498
Peach	362	1,451	1,000	235	18
Apricot	252	1,870	124	94	7
Cherry	75	214	88	193	72
Pear	514	1,581	823	606	64
Plum	80	346	470	254	95
Prune	576	2,789	6,311	4,295	962

Total dead trees	53,619
Total trees in orchard	212,750
Average loss per orchard	25.2%

APPENDIX A

TABLE 6

Record of Winter-Injured Trees

Oyama, Winfield - Okanagan Centre

(175 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	281	261	541	2,848	2,783
Peach	199	957	1,308	1,185	281
Apricot	377	565	213	141	45
Cherry	146	162	107	416	765
Pear	310	247	144	77	135
Plum	5	11	45	88	36
Prune	195	76	227	641	326

Total dead trees	16,144
Total trees in orchard	117,832
Average loss per orchard	13.7%

APPENDIX A

TABLE 7

Record of Winter-Injured Trees

Kelowna

(395 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	602	1,000	1,972	10,987	7,542
Peach	551	1,645	2,785	1,618	243
Apricot	803	1,590	916	373	82
Cherry	548	658	429	1,861	3,146
Pear	1,202	2,096	834	397	145
Plum	52	106	317	602	51
Prune	314	885	1,362	2,372	450

Total dead trees 50,536

Total trees in orchard 354,977

Average loss per orchard 14.2%

APPENDIX A

TABLE 8

Record of Winter-Injured Trees

Westbank

(78 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	1	296	405	647	385
Peach	229	1,655	2,569	2,064	137
Apricot	126	683	200	101	20
Cherry	63	99	79	229	316
Pear	1,020	87	63	19	1
Plum	7	86	219	187	39
Prune	42	86	117	25	66

Total dead trees	12,368
Total trees in orchard	79,890
Average loss per orchard	15.5%

APPENDIX A

TABLE 9

Record of Winter-Injured Trees

Peachland

(68 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	22	-	6	65	46
Peach	217	892	3,262	2,016	966
Apricot	72	59	42	56	19
Cherry	60	15	12	94	289
Pear	63	1	11	10	13
Plum	-	17	8	15	18
Prune	1	4	43	7	2

Total dead trees	8,423
Total trees in orchard	45,885
Average loss per orchard	18.3%

APPENDIX A

TABLE 10

Record of Winter-Injured Trees

Summerland

(243 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	107	86	45	234	246
Peach	133	848	2,411	4,281	758
Apricot	550	915	480	454	89
Cherry	37	119	38	182	822
Pear	223	30	65	12	21
Plum	1	15	66	131	50
Prune	114	59	51	61	5

Total dead trees	13,739
Total trees in orchard	150,726
Average loss per orchard	9.1%

APPENDIX A

TABLE 11

Record of Winter-Injured Trees

Penticton

(139 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	3	3	4	19	49
Peach	307	590	697	1,925	731
Apricot	203	339	93	271	38
Cherry	13	15	2	72	324
Pear	41	18	17	10	1
Plum	-	2	5	37	13
Prune	10	23	4	15	21

Total dead trees	5,915
Total trees in orchard	89,007
Average loss per orchard	6.7%

APPENDIX A

TABLE 12

Record of Winter-Injured Trees

Naramata

(60 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	32	2	11	38	44
Peach	87	302	397	359	354
Apricot	356	60	56	75	70
Cherry	2	12	11	35	257
Pear	30	2	-	6	-
Plum	-	8	-	26	4
Prune	6	5	12	6	-

Total dead trees	2,665
Total trees in orchard	36,190
Average loss per orchard	7.3%

APPENDIX A

TABLE 13

Record of Winter-Injured Trees

Kaleden

(32 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	6	9	1	28	166
Peach	78	35	494	530	97
Apricot	1,105	227	50	81	37
Cherry	34	10	2	10	25
Pear	88	3	2	-	-
Plum	7	-	-	1	1
Prune	29	22	47	8	2

Total dead trees	3,235
Total trees in orchard	27,231
Average loss per orchard	11.9%

APPENDIX A

TABLE 14

Record of Winter-Injured Trees

Keremeos - Cawston

(108 orchards)

Kind of Tree	Under 2"	2"-5"-	5"-7"	7"-12"	Over 12"
Apple	1,470	102	147	387	467
Peach	2,792	2,210	1,819	909	628
Apricot	2,591	1,603	247	85	38
Cherry	443	34	20	76	71
Pear	2,094	131	50	32	38
Plum	6	37	1	12	10
Prune	164	217	155	9	17

Total dead trees	19,112
Total trees in orchard	81,465
Average loss per orchard	23.5%

APPENDIX A

TABLE 15

Record of Winter-Injured Trees

Oliver - Osoyoos

(398 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	1,250	410	111	222	116
Peach	4,845	13,254	22,123	15,495	3,070
Apricot	7,863	6,030	2,874	1,483	332
Cherry	629	855	743	1,012	437
Pear	4,060	1,500	473	253	33
Plum	102	108	170	109	28
Prune	1,377	1,760	999	619	81

Total dead trees	94,826
Total trees in orchard	339,434
Average loss per orchard	27.9%

APPENDIX A

TABLE 16

Record of Winter-Injured Trees

Grand Forks

(28 orchards)

Kind of Tree	Under 2"	2"-5"	5"-7"	7"-12"	Over 12"
Apple	69	273	553	651	540
Peach	12	12	6	-	-
Apricot	2	3	4	2	1
Cherry	-	1	15	16	42
Pear	22	29	17	15	6
Plum	25	90	22	4	5
Prune	10	106	629	329	13

Total dead trees	3524
Total trees in orchard	14939
Average loss per orchard	23.6%

APPENDIX B

TABLE 1

Effect of Soil Type

District	Kind	Per Cent Damaged Trees: Sand & Gravel	Sandy Loam	Silt Loam & Clay	Total
Oliver	Cherry	26	11	10	47
	Apricot	28	16	9	53
	Peach	43	27	28	98
	Total	97	54	47	198
Osoyoos	Cherry	42	32	30	104
	Apricot	49	35	28	112
	Peach	66	48	65	179
	Total	157	115	123	395
Okanagan Falls	Cherry	15	8	2	25
	Apricot	18	8	6	32
	Peach	41	22	22	85
	Total	74	38	30	142
Penticton	Cherry	8	2	1	11
	Apricot	12	3	4	19
	Peach	14	4	3	21
	Total	34	9	8	51
Grand Totals		362	216	208	786

APPENDIX B

TABLE 2

Relative Cold Injury of Seven Varieties of Apricot

Variety	Per Cent Damaged Trees			Total
Wenatchee Moorpark	31	39	29	99
Perfection	22	26	19	67
Riland	16	27	16	59
Tilton	20	17	24	61
Blenheim	18	14	20	52
Reliable	26	36	30	92
Kaleden	14	2	17	33
Total	147	161	155	463

APPENDIX B

TABLE 3

Relative Cold Injury of Six Varieties of Cherry

Variety	Per Cent Damaged Trees			Total
Bing	24	19	14	57
Lambert	9	12	2	23
Royal Ann	95	60	100	255
Deacon	12	20	9	41
Carnival	22	57	46	125
Windsor	12	14	20	46
Total	174	182	191	547

APPENDIX B

TABLE 4

Relative Cold Injury of Eight Varieties of Peach

Variety	Per Cent Damaged Trees			Total
Veteran	36	50	42	128
Vedetta	38	42	37	117
Valiant	24	33	28	85
J. H. Hale	78	78	85	241
Elberta	46	39	48	133
Golden Jubilee	60	72	66	198
Rochester	50	79	58	187
Red Haven	25	20	16	61
Total	357	413	380	1,150

APPENDIX B

TABLE 5

Effect of Late Irrigation

Irrigation Practice	Kind	Per Cent Damaged Trees			Total
	Peach	32	38	30	100
Late Irrigation (After Oct.15)	Cherry	17	19	9	45
	Apricot	9	23	20	52
	Total	58	80	59	197
	Peach	59	68	43	170
No Late Irrigation	Cherry	24	32	32	88
	Apricot	22	38	46	106
	Total	105	138	121	364
Grand Total		163	218	180	561

APPENDIX B

TABLE 6

Effect of Age of Tree

Age	Kind	Per Cent Damaged Trees			Total
Under 10 Years	Peach	33	35	29	97
	Apricot	20	18	18	56
	Cherry	9	12	14	35
	Total	62	65	61	188
Over 10 Years	Peach	48	39	92	179
	Apricot	32	18	29	79
	Cherry	24	28	37	89
	Total	104	85	158	347
Grand Total		166	150	219	535

APPENDIX B

TABLE 7

Effect of Pruning Technique

Type of Pruning	Kind	Per Cent Damaged Trees			Total
	Peach	26	32	29	87
Long	Apricot	16	21	18	55
	Total	42	53	47	142
	Peach	46	40	76	162
Short	Apricot	24	31	36	91
	Total	70	71	112	253
Grand Total		112	124	159	395

APPENDIX B

TABLE 8

Effect of Vigour

Vigour	Kind	Per Cent Damaged Trees			Total
Good 10"-18"	Peach	28	24	16	68
	Apricot	19	14	15	48
	Cherry	8	15	22	45
	Total	55	53	53	161
Poor <8"	Peach	41	42	50	133
	Apricot	31	37	26	94
	Cherry	27	18	30	75
	Total	99	97	106	302
Grand Total		154	150	159	463

APPENDIX B

TABLE 9

Effect of Cultivation

Culture	Kind	Per Cent Damaged Trees			Total
Permanent Cover	Peach	32	37	28	97
	Apricot	22	19	22	63
	Cherry	36	40	41	117
	Total	90	96	91	277
Cultivated (Either Clean or Turned Under in the Fall)	Peach	29	40	30	99
	Apricot	24	26	21	71
	Cherry	39	36	44	119
	Total	92	102	95	289
Grand Total		182	198	186	566