A STUDY OF CERTAIN PHENOLOGICAL FACTORS AS THEY INFLUENCE GROWTH IN THE APPLE, *Malus pumila*, (MILL.)

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Abstract

The investigation is a study of the science of phenology in relation to the maturation of the fruit of the apple, Malus pumila, (Mill.) through the medium of the Heat Unit Theory, which is an expression of the climatological factor of temperature and more particularly average temperature.

The study may be divided into three parts, the first of which introduces the problem of variability in total degree days (the basic unit employed in the Heat Unit Theory) between varieties of apple and between years. A maturity classification is established based on total degree days for several varieties grown at the Central Experimental Farm, Ottawa, Ontario.

The second part examines the three basic difficulties encountered in the establishment of a phenological period, namely, when to begin the period, what base or unit temperature below which the apple is assumed not to grow and when to end the period. It was found that starting the phenological period ten days before full bloom gave better precision than when the period was started at full bloom. No one base temperature or combination of

temperatures appeared to be entirely satisfactory although the base temperature of 42°F. occupied a medial position. The adoption of the ordinary date of harvest as obtained from field records proved to be as reliable as the index of maturity established by research.

Temperature statistics other than the average, such as minimum and night temperatures, used in the calculation of heat units did not improve the precision of a prediction. An accumulation of temperature range appeared superior to accumulation of temperature statistics based on the Heat Unit Theory.

No relationship was found to exist between accumulation of sunshine and solar radiation units and the length of the phenological period.

In the third part of the investigation the value of total degree days as well as that of various base temperatures is determined for a relatively long period of time at two Experimental Stations, one at Summerland, British Columbia, and the other at Ottawa, Ontario. Actual measurements of the rate of enlargement of an apple are correlated with average temperature for the same period. No increases in precision were noted with the extension of the time interval under study, nor were the correlations obtained indicative of a good relationship between growth of an apple and average temperature.

The number of days in the phenological period proved to be as good for prediction purposes as any of the methods used in the investigation, particularly for the climatological environment experienced at Summerland.

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A STUDY OF CERTAIN PHENOLOGICAL FACTORS AS THEY INFLUENCE GROWTH IN THE APPLE, *Malus pumila*, (MILL.)

It has been said that energy rules the universe. On Earth it is the delicate balance of temperature and light supplied by the sun which activates the photosynthetic and chemical processes so necessary for the initiation and continuation of plant growth. Since plants form the basic source of energy for most living matter on earth it may be concluded that the really significant source of energy on the earth is the sun or more generally what is known as climatological environment. The kind of climate dictates what shall be grown, where it shall be grown, when and how well it will grow. Tomatoes may be grown in most regions of Canada but only in the Okanagan where there is found that happy combination of warm, sunny days and cool nights, do the plants achieve their real excellence of color and flavor. All the nutrients in the world will not permit the growth of peaches on the prairies, for it is said that the severe winter temperatures experienced there provide the limiting factor to peach production on the prairies. But it is equally true that peaches will not grow in districts where the winter season is not cold enough to break the rest period of the tree. There is, therefore, an optimum temperature at which peach trees will winter best. But an optimum temperature is not confined to the winter season, it apparently also can vary with the period of growth of the tree itself. Another and quite different optimum temperature may be established for the summer's growth period. Therefore it follows that the optimum temperature at which growth processes are carried out in the plant must necessarily vary from season to season. It is this study of the relationships between climate and certain vegetative and reproductive phases in the life cycle of plants that has been named phenology.

Although a vast amount of work has been done on the response of plant growth processes to change in nutrient level, the phenological approach has been relatively ignored, particularly during the last sixty years. Such apparent neglect of an exceedingly important subject is difficult to understand, unless consideration is given to complex problems encountered when an attempt is made to reproduce the vagaries of climate within the limited confines of a laboratory. Without the assistance of modern equipment and building facilities research was of necessity limited in scope and directed primarily toward the moisture and mineral requirements of plants with some study being made on the effects of light.

However, interest in phenology and its practical applications has been revived recently as a result of the construction of modern growth chambers wherein many combinations of light and temperature can be readily synthesized, and also as a consequence of investigations borne from the desire in producers of canner's crops to avoid the "bunching" of vegetable crops at harvest. The latter reason is of more practical significance since such heavy accumulations of vegetables within a very short harvest period have necessitated twenty-four hour labor shifts in canning factories with resultant wear and tear on machinery due to improper maintenance schedules. In many instances an inferior product is marketed or even a complete loss of a crop is experienced because it is physically impossible for the canner to cope with the volume of produce. Unfortunately, vegetable crops deteriorate very rapidly unless properly processed, the time element therefore is very important, and if the harvest season can be lengthened it may enable the canning industry to operate more efficiently. It is imperative then to know the date of harvest considerably in advance, or in other words precisely how long it takes for a plant to reach maturity from time of seeding. In order to achieve this end, several applications of phenology have been advanced, the most familiar one being known as the Heat Unit Theory. The theory assumes temperature to be the dominant factor responsible for the various reproductive and vegetative processes in the plant and ignores the possible effect of such items as light (intensity and duration), moisture, fertilizers and fertility level in the soil, topography of the land and preceding crops. A formidable array of extremely important growth factors are therefore not considered, however, the method does give some approximation of the growth interval of the plant. Varietal records are kept, as well as local temperatures. Calculations are based on remainder indices assuming a base or unit temperature below which growth does not occur. An accumulated summation of heat units is acquired between phenological periods which may be designated as a summation of degree days if computations are made on a daily basis, or as degree hours if made on an hourly basis.

A degree day is found by subtracting a base or unit temperature from the mean of the daily maximum and minimum temperatures. That is, if the average temperature for a specific day was recorded as being 65°F. and the base temperature selected was 42°F. then the number of heat units expressed as degree days would be 23 for that day. The number of heat units for each day is accumulated for the number of days between phenological periods. In calculating degree hours the number of degree days is simply multiplied by twenty-four.

One of the difficulties experienced in the method other than that of the lack of consideration given to the related growth factors mentioned above is in the exact determination of phenological periods. With annual vegetable crops this is not vitally important as the phenological period can be taken from the time of seeding or date of emergence, to the date of maturity or of harvesting. However, with perennial plants as the deciduous fruit trees the phenological periods are extremely difficult to estimate with any degree of accuracy. That is, should the phenological period begin with the preceding harvest, with the fall of the last leaf before the winter season, with the appearance of the first bloom in the spring or the time of full bloom, or even at some later period? The end of the phenological period presents a similar problem. Obviously it should end at maturity of the fruit, but maturity indices as presently known are considered inefficient and unreliable. More precise maturity and storage tests would aid enormously in phenological investigations, however, since these maturity indices are not available it may be possible by certain manipulations of temperature and light to arrive at a good estimate of maturity. That is, certain accumulations of heat units may be relatively constant over a period of years providing a mathematical index of maturity which could be tested by the subsequent storage qualities of the fruit examined.

In the spring of the year 1952 an extensive examination of the literature on the Heat Unit Theory as applied to vegetables prompted an investigation into the possible application of the Theory in forecasting the harvest dates of apples. The formulation of a method for the accurate prediction of harvest dates was the main purpose of the study, but in order to facilitate the examination of the problem certain related factors of growth and climatic environment had to be considered. These included possible effects of duration of light, light intensity, night temperature and of differences in the location of the study medium.

Review of Literature.

Most of the early studies in phenological and heat summation problems were made in Europe in the countries of Austria, France, Belgium, Russia and Germany where the subject attracted the interest and excited the imagination of biologists and plant students for many years. In 1905 Professor Cleveland Abbe (1) published a report which was essentially a summary of the views of the best experimentalists and observers that had been published up to 1891. Much of his subject matter is reproduced here in order that a comparison may be made between investigations carried out during that period and those being done at the present time.

In his report Abbe stated that in 1735 Reaumur made an exact comparison of the different quantities of heat required to bring a plant up to a given stage of maturity. From observations made in France, Reaumur adopted the sum of the mean daily temperature of the air recorded by a thermometer in the shade and counting from any given phenological epoch to any other epoch. He employed the average of the daily maximum and minimum temperatures as being a sufficiently close approximation to the average daily temperature. Even at that time Reaumur was interested in making a comparison of the sum of temperatures for growing periods between years and between latitudes.

Another worker mentioned by Abbe was Adamson, who in 1750 disregarded all temperatures below °C and took only the sums of the positive temperatures. Gasparin (1) in 1844 selected 5°C as the base temperature.

In order to arrive at a constant heat product, Boussingault (1) in 1834 computed the total quantity of heat required to ripen grain by multiplying the mean daily temperature of the air in the shade in centigrade degrees by the duration in days of the process of vegetation. The product was known as the number of day degrees the plant required from sowing to maturity.

The problem of discriminating between phenological periods was hotly debated. Quetelet (1849) working in Belgium thought there were three great growth periods: leafing, flowering and ripening. He concluded that the progress of vegetation was in proportion to the sum of the temperatures or the sum of the squares of temperature calculated above freezing point starting with the awakening of vegetation. However, Karl Fritsch (1881) after ten years of study at Vienna was more explicit as to his definition of the phenological periods. His phenological epochs were: 1. The first visibility of the upper surface of the leaf. 2. The complete development of the first flower. 3. The complete ripening of the first fruit. 4. The date at which a tree or bush lost all its foliage. Fritsch used as his starting point January first for both annuals and perennials. He calculated his thermal constants by the sums of the mean daily temperature above zero degrees Reaumur.

At about 1850 there were three hypotheses being postulated in respect to phenology and temperature summations. The first hypothesis was that for the same plant the same stage of vegetation occurred from year to year on the attainment of the same mean daily temperatures. The second was that the same stage of vegetation was attained when in the course of any year the sum total of the mean daily temperatures above freezing attained the same value. The third was to the effect that the same stage of vegetation was attained when in the course of any year the sum of the squares of these positive temperatures attained a certain constant value.

Each hypothesis had its own group of supporters but no hypothesis was demonstrated as being completely satisfactory.

At the time of Karl Linsser (1867, St. Petersburg) the base temperature accepted was 6°C. Linsser employed base temperatures of 1°, 2°, 3°, 4°, 5° and 6°C. He found none that gave any more uniform constant than the original 6°C. Linsser thought that in general, at different places the same phase of development of vegetation required different mean daily temperatures, different sums of temperatures and different sums of squares of temperatures. He concluded that there was no zero point that could be adopted which would make these sums equal. He formulated what was called Linsser's thermal law and which stated that in two different localities the sums of the positive daily temperatures for the same phase of vegetation is proportional to the annual sum total of all positive temperatures for the respective localities. Linsser thought that it was not the absolute quantities of heat or nourishing material but rather the relative distribution during the period of vegetation that was significant.

Tisserand (1875) introduced sunshine into the discussions and adopted the rule that the work done by a plant was represented by the product of the mean temperature and the number of hours of sunshine only rejecting useless night time. He, nevertheless, experienced considerable variation in locality and between plants in his calculations.

Angot (1882, France) used a base temperature of 6°C. and three methods of calculations: observation of the daily maximum and minimum temperature; the daily means; and lastly by maximum temperature alone. He later changed to a base temperature of 5°C. because he thought 6°C. too high. But no decision was reached as to which was the best method. The difficulty in fixing the epoch from which the summation should begin was emphasized. He observed that date of sowing (in this instance the crop was wheat) was generally taken as the starting point but he recognized that the date of emergence would be better since temperatures of the soil and those of the sky were different.

That soil played an active part in the growth of the plant was demonstrated by Marie Davy in 1881. According to him, heat was needed in the soil in the early part of the growth of the plant but after the flower was formed or during the process of perfecting the fruit sunlight was needed. He thought that any formula which considered temperature alone was a very imperfect presentation of the growth. He demonstrated that in wheat when the temperature of the soil during the last phase of growth, earing to maturity, fell below 58° and 60°F., no progress was made in growth and unless 60°F. was exceeded the crop never ripened properly.

Cleveland Abbe summarized his own views and those of the workers mentioned above by noting that in order to study the influences of climate upon crops one should know the facts about such variables as: the mean temperature of the air in the shade; the mean temperature of a thermometer exposed to full sunshine and wind and placed amid the foliage of the crop to be studied; the temperature of the soil at depths of 1 - 6"; the hydrometric condition of the free air; the velocity of the wind or its daily movement; the cloudiness of the sky; the total effective radiation from the sun and sky; the actual evaporation from the plants and soils; and also the total rainfall as measured by ordinary rain gauges in the experimental field. He emphasized the great need for a laboratory where the vagaries of climate might be reproduced in order that plant responses to changes in temperature and light might be studied more precisely.

From 1905 there appeared to be a general disinterest in phenological investigations until modern impetus was given to the Heat Unit Theory because of its apparent value in the forecasting of harvesting dates for vegetables (2, 5, 26, 28, 35, 46) and fruits such as grapes, pears, peaches, apricots and apples (7, 8, 11, 12, 14, 61, 68, 69). The many climatic aspects which affect plant growth are now being investigated. The summation theory has been particularly useful in forecasting the harvesting dates of vegetables. Bomalaski (10), working with peas, found that the temperature summation for the same variety of plants varied under different growing conditions. Generally, the summation was lower in cooler seasons, due primarily, to the length of the daylight factor. In peas the maturing process was approximately double in rate for any 18°F. (10°C.) rise in temperature. According to Bomalaski, growth was slow at the minimum point, but from above minimum to optimum the rate of growth followed Van't Hoff's Law. Above the optimum point growth fell off rapidly until the maximum was reached, beyond which growth stopped. The optimum and maximum were closer than the minimum and optimum. In addition, peas that were planted early when the soil was cold matured with a lower number of growing degree days than those planted late in the season and grown during the warmer temperatures. Bomalaski believed that hours of light was the prime factor in the rate of maturity per degree of temperature.

Sayre (51), also working with peas, found that the heat unit system was the most accurate system yet devised for forecasting the maturity of peas because the total heat summation was the dominant factor affecting the rate of maturity of field grown peas. Also it was possible to achieve a more rapid rate of maturity with less heat units due to greater light intensity and drought conditions.

As an interesting practical aspect of the Heat Summation Theory Young (70) reported that the heat unit system was helpful in forecasting the time of development of the corn borer stages. The degree hours were recorded throughout the season beginning in winter, using a base of 49°F. Apparently the method could be used in insecticidal programs to some advantage.

In addition to supporting the Heat Unit Theory Phillips (45) suggested the use of 50°F. as a base temperature for sweet corn, 35°F. for spinach, 50°F. for snap beans, 40°F. for lima beans and for peas and 55°F. for pumpkins.

Livingston (33) outlined the two general classes of temperature efficiency indices, one the remainder indices and the other the exponential indices. The remainder indices was derived by subtracting a constant quantity, a daily mean at which growth rate was regarded as unity, from each of the temperature data to be employed. The exponential method was based on the supposition that plant growth rates follow the chemical principle of Van't Hoff which is that a chemical reaction is about double with increase in temperature of $10^{o}C.$ or $18^{o}F.$ He illustrated by Lehenbauer's work with maize that there was a minimum, maximum and optimum temperature for plant growth and that optimum temperature would vary with the duration of the temperature conditions. He advocated the use of physiology and growth measurements in relation to climatic factors as the best possible index of growth.

Nuttonson (42) used a base temperature or zero temperature of $35^{o}F.$ for wheat and flax and $40^{o}F.$ for peas and egg plants. He found that a multiple of the average day length and the summation of day degrees was the least variable numerical expression. He suggested that the use of days or day degrees alone as a unit of measurement provided mathematical expressions of greater variability than that of the multiple. In other words Nuttonson believed that the transition from vegetative to the reproductive stage, as well as the transition from the initiation of growth to market maturity, could occur with some plant varieties under a number of combinations of temperature and day length conditions. He further noted that in his investigations the summation of day degrees required by all horticultural varieties appeared to increase in a southward direction, that is, with the decrease of the average length of day duration.

Went (63, 64, 66) placed considerable emphasis on night temperatures in the study of plant growth. In his thermoperiodicity investigations the daily light cycle was given and the effects of temperature during the light and dark periods considered. He noted that development could be changed by varying temperatures during the dark period; optimal growth in most plants occurred when the temperature was lower during the night. Thermoperiodicity was the daily cycle of optimum temperature. Went wrote that in many plants the growth rate stayed constant from day to night; in others the greater part of the stem elongation occurred during the night. Therefore the night temperature could be expected to influence the growth rate of the plant as a whole.

Camus and Went (16) using three varieties of Nicotiana tabacum found that both flowering and leaf habit were affected by night temperature. They discovered that during the early stages of growth the higher the night temperature the faster the stem elongated; but as time progressed the optimal night temperature progressively decreased. They concluded that night temperature was the most critical factor governing developmental processes and that temperature thresholds should be determined for different species and their possible relationship to light intensity studied. A slow growing variety of tobacco was more sensitive to thermal treatments than faster growing varieties.

In an experiment using afternoon shading Went (65) found that some vegetables shaded in the afternoon had much higher optimal dark temperatures than those with natural night hours. The yield of lettuce and cauliflower decreased by shading but the yield of tomatoes and eggplants was increased. The optimal temperature of the tomato was 13^{o}-18^{o}C.; that of lettuce 8^{o}-13^{o}C. Beets and celery were affected very little by afternoon shading.

The effects of shading on growth and development in the vegetative phase were studied by Blackman (6) on sixteen different plant species. The relative growth rate was the product of the net assimilation rate and the leaf area ratio. Any factor which brought about a change in either the net assimilation rate or the leaf area ratio would cause a change in the relative growth rate. The net assimilation rate is highest in full sunlight. That is, on an approximately logarithmic scale the net assimilation rate was positively correlated with falling light intensity but the leaf area ratio (leaf area/total plant weight) is negatively correlated. On Helianthus annuus seedlings the relative growth was dependent on both light and temperature factors. His "relative growth rate" was defined as the overall increase in dry weight per day expressed as a fraction of the mean total plant weight as was governed by the efficiency of the assimilation per unit area of leaf and the total leaf area. Optimal light intensity ranged from 0.5 daylight for the shade plant Geum urbanum to 2.51 daylight for Medicago sativa.

Nightingale (37) grew peach and apple trees in sand at temperatures of 45°, 50°, 55°, 60° and 95°F. During the current growing season the maximum yield of roots and tops occurred at 60°F. Nightingale and Blake (39) found that at 45°F. the Baldwin variety of apple grew much more than the Stayman variety. The failure of Stayman to set fruit in the orchard under cool temperatures was attributed to insufficient nitrogen in the tops. The Baldwin variety under the same conditions set fruit abundantly. Working with peaches Nightingale and Blake (40) noted very little growth at 45°F. and a very rapid growth at 95°F. for three or four days after which growth decreased rapidly. Apparently with peaches, spring and fall temperatures are extremely important to growth processes.

In a study with Rome apple trees, Nightingale and Mitchell (41) found that the quality as well as the quantity of a plant was a product of the factors of environment. At 40 per cent humidity there was formation of terminal buds, light green foliage and an accumulation of carbohydrates. At 95 per cent humidity the leaves were a darker green, there was no formation of terminal buds and the carbohydrates were low in concentration.

The importance of noting precise phenological dates was emphasized by Blake and Davidson (9) in a study of the growth status of the Delicious apple. They stated that the growth intervals to be noted were: 1. As soon as the leaves were one-half to one inch long in the spring. 2. When spur leaves had almost completed development, or about June 20 - July 1 in New Jersey; 3. At the time the fruit was ripe. 4. After the leaves had fallen. A difficulty was experienced in the infinite variation in vigor and growth between individual branches, twigs and spurs on the same tree, even with no serious weather or pest injury. Their nutritional investigations showed little top growth in Delicious apples at 45°F. but a considerable accumulation of carbohydrates. At 95°F. the variety used up carbohydrates faster than they were manufactured.

In an attempt to increase the precision by which harvesting dates of apricots and prunes might be estimated, Baker and Brooks (3) suggested three methods: 1. To consider the number of days and the probability that the number of days next year will fall within a certain interval centred at this mean. 2. The correlation of accumulated heat units with the number of days. 3. The employment of R. A. Fisher's method for estimating the relation between heat units and the number of days from full bloom to harvest throughout the season. Actually their idea was to increase the accuracy of the number of days to harvest concept by taking into consideration heat units. They used a base temperature of 45°F. to calculate the heat units. On examining data on harvesting dates available for seventeen years for apricots they found a range of nineteen days; with prunes the range was twenty days in thirteen years. Mathematically they could predict the harvest date of apricots within three days, eighty per cent of the time and for prunes fifty per cent of the time. With apricots the excess heat units shortened the number of days to harvest and this shortening was more marked early in the season.

Brooks (13) improved on the above prediction method in a later work with apricots. Here he predicted the harvest date six weeks after full bloom, using two formulae, one based on the correlation between the heat accumulated for the first six weeks after full bloom and the period between full bloom and harvest. The other formula predicted the number of days between full bloom and harvest. Actually the computations were based on records of previous years' phenological periods and appeared to be quite precise for apricots and somewhat less accurate for French prunes and Bartlett pears. It was possible to obtain an accuracy of within four days one hundred per cent of the time for apricots and within six days eighty per cent of the time for pears. The proper time to begin picking apricots was evidently more definite than it was for pears.

However, Brown (15) with the temperature, bloom and harvest records available to him on Royal (Blenheim) apricots in the district around Brentwood, California, applied the heat unit method described by Brooks (13) to the data and found it less satisfactory than might have been expected. Brown divided temperature into eight classes and worked out a multiple correlation coefficient based on the number of hours in each temperature class for 42 days after full bloom and also an estimate based on the average of the daily mean temperature for six weeks after full bloom. Both prediction methods were considered superior to that of Brooks when applied to the Brentwood data.

According to Tufts (58) in California local environment rather than latitude determined the districts suitable for fruit culture. Tufts used apricots as his study medium, employed a base unit of 35°F. and three different orchard localities. He found that the orchard having the cooler temperature had more heat units than the warmer temperature orchard. However, the orchard having the highest number of heat units had extra units collected at night with warmer night temperatures. This orchard had the earliest ripening period, whether due to greater number of heat units, the higher night temperatures or to a more equable temperature could not be determined exactly.

At the University of California, Lilleland (30) studied the effect of temperature on the growth of the apricot. Apparently there were three growth periods in the apricot, the first one being a period of rapid increase, the second characterized by much arrested rate of increase and the third by an accelerated rate of growth which continued until maturity. The length of these periods could be affected by temperature. Lilleland calculated the heat units required for each of the growth periods using three base temperatures of 35°, 42° and 50°F. He found that for the first growth period 50°F. was best, none of the base temperatures tried were suitable for the second period and for the last period 50°F. was again the most efficient base temperature. Lilleland manufactured a shelter around a branch of an apricot tree. He raised the night temperature artificially 20°F. higher in the shelter for eight weeks. In this manner he shortened the first period length by 22 days, actually lengthened the second period by five days whence the heat was discontinued. Actually the fruit in the shelter stopped rapid growth 22 days ahead of those outside, emerged from the period of depressed growth 17 days in advance of the other fruit on the rest of the tree and eventually ripened 21 days earlier.

Apparently the growth of sour cherries may also be divided into three stages. The first is a period of rapid development of the fleshy pericarp beginning at the time of full bloom. The second is a period of retarded development of the fleshy pericarp. The third is a second period of rapid development of the fleshy pericarp known as the final swell. Tukey (60) used a heating method similar to that of Lilleland (30) and by raising the night temperature of sour cherries immediately after full bloom during stage one was able to decrease the number of days to maturity. The same sort of thing was experienced in stage two. However, warm temperature late in stage three lengthened the number of days to maturity. The size of the fruit was not significantly different when mature except under the highest temperature conditions where the fruits were smaller. It was thought significant that the commercial areas of sour cherry production were located in regions having cool night temperatures during stage three.

The same periodicity of growth, that is, an early rapid growth, an interim of lesser growth and finally a period of very rapid growth was noted in sweet cherries by Lilleland and Newsome (31). Cycle growth was also reported in the plum by Lilleland (29).

According to Chandler, Kimball, etc. (17), the apple on the average required more chilling temperatures before all its buds opened in the spring than did most other kinds of fruit trees. The chilling period must be of at least two months duration with the temperature below 48°F.; if not, buds in the spring would be considerably delayed and some would open much sooner than others. The chilling requirement varied with the variety. These workers also observed that after warm winters the buds opened unevenly. Winter shade was beneficial and in high humidity the trees were less prone to shed their buds unopened or to be too greatly delayed in opening of their buds. They emphasized the importance of taking observations from full bloom. Apparently, a prolonged drought could cause apricots to be thrown completely into a rest period.

More information on the effect of winter temperatures was supplied by Eggert (19), Lamb (27) and Magoon (36). According to Eggert in New York State, the percentage of active spur and terminal buds was greater than that of the lateral buds during the winter period. There was a prolonged rest period in lateral buds. Little spur bud activity was observed in November and December but there was considerable activity by January 11. He found too that using a base temperature of 32°F. all varieties (McIntosh, Cortland, Northern Spy and Macoun) had considerable variation from season to season, but there was a better correlation between bud activity and accumulated hours below 45°F.

Ellenwood (20) in Ohio associated low temperatures in March and April with high yield. In apples he stated that bud development was rather slow at 55°F. or less. Two or three days of temperatures of 70° to 85°F. when the buds had reached the full pink stage would cause very rapid changes; the influence of the same sort of temperature two weeks earlier was not nearly as noticeable.

It is generally recognized that there should be a definite period between blossoming of fruit trees and the time at which the fruit is ready to harvest. Ryall, Smith, etc. (50), - took a base of 40°F. for pears, but experienced rather a lot of variation from year to year. They tried a maximum temperature of 90°F. as a base unit but there was no great consistency. They showed that districts not having extremely high or low temperatures had as great an accumulation of heat units as those with sharper fluctuations. Haller (24) showed that for three seasons the number of days from bloom to harvest for each variety of apple was rather consistent under middle Atlantic conditions. Tukey (59) working with several varieties of apple as well as pears, peaches and cherries found that the interval of elapsed time between blossoming and maturity was more constant for the apple than for other fruits studied.

At Michigan, Gardner, Merrill and Toenges (22) in an investigation using the Delicious apple found that environmental conditions during the short period immediately following full bloom were controlling factors in fruit setting. The first week or ten days was shown to be the critical period. They stressed the importance of sunshine during the blossoming period. Lu and Roberts (34) at Madison, Wisconsin, found the setting of fruit through temperature fluctuations varied with variety. Delicious blossoms dropped heavily in warm temperatures above 70°F. but the same temperature did not affect the Wealthy variety. A five day warm period at full bloom caused heavy early dropping; a cool temperature at this time delayed dropping in the Delicious variety. Using trees in the greenhouse, they found that day temperatures as well as night temperatures greatly affected setting; warm days reduced set, cool days tended to increase it.

A United States Department of Agriculture publication (25) reported an investigation by Philips wherein the length of the period between full bloom and ripening depended upon the amount of heat received by the tree. This period was longest in the Pacific Coast, shortest in the Atlantic Coast and intermediate in the Central States. Also the period was longer in the south where it was warmer, than in the north. The more rapid maturation in the colder north was attributed to greater insolation. However, the evidence was contradictory and generally the publication decided that the number of days from full bloom to maturity was the most reliable index to maturity. Their data indicated that the length of period from bloom to maturity was not influenced by growing season temperatures except with the variety Jonathan where the period was shortened by high temperatures in the early part of the growing season. An early bloom followed by a cool growing season lengthened the time required to mature fruit.

Maturity studies in the apple reported by Haller (25) showed that there were three important factors which might be considered: 1. The change in the ground color. 2. The firmness of the fruit. 3. The way the fruit is holding to the tree or the ease of separation and dropping. However, Haller objected to the use of these maturity indices for several reasons, the most important being the extreme variability experienced between season and between apples on a single tree. Even the size of the crop affected maturity as a light crop matured 5 - 10 days earlier than a heavy crop. Haller divided maturity into five stages, immaturity, early maturity, optimum maturity, late maturity and overmaturity with a range of no more than five days for each stage of maturity. That is, one could not be in an error of more than five days in a prediction or the apples would be in an unsatisfactory stage of maturity. According to Haller temperature differences had a greater influence during certain periods than in others, for instance, early in the season and late in the season. Very cold weather, particularly during the first part of the growing season, could delay maturity.

Smith (53) did considerable research with growth as affected by climatic factors and found that all expressions of growth which could be measured quantitatively while the plants were quite young had their maximum in the twenty-four hour day, but as the plants grew older, the maximum gradually was displaced in the direction of the shorter day lengths. Smith evolved a complete growth formula, using multiple correlation with time as the independent variable and the factors of length of day; mean air temperature in degrees C.; mean daily light as dependent variables. His growth constants enabled him to calculate the growth intensity of any combination of light, day length and temperature corresponding to any geographical position and season.

A similar method to that of Smith was used by Clements, Shigeura and Akamine at the University of Hawaii (18) in a sugar cane investigation. They used a growth unit defined as "the daily increase in cane volume, a correlated value of it obtained by multiplying the daily elongation rate in centimetres and the green weight of the sheaths per stalk of cane". The growth unit was a better measure of growth than a simple linear elongation since it tended to be a measure of volume growth. After considerable work with partial regressions involving such factors as: green weight of sheaths, age, sheath moisture, relative humidity, wind velocity, maximum temperature, minimum temperature and light, they concluded that wind velocity, humidity and sheath moisture could be disregarded without destroying the efficiency of the prediction equation. They, like Smith (53), developed a growth formula, only their formula was applicable to sugar cane.

Thornthwaite (57), working at Seabrook, New Jersey, evolved a growth unit defined as "the amount of development that would occur in a plant while a unit amount of water was being transpired". The units were given in the metric system; 100 growth units corresponded to 1.0 cm. of water (about 0.4 inches). He believed that the water need of a plant and the growth index were the same and consequently the curve of the mean daily water need also showed the daily growth index. Throughout the year growth units accumulated slowly at first, more and more rapidly until midsummer and finally more and more slowly until the end of the season. The curve related growth and development with time and translated the civil calendar into the climatic calendar. Hours and days became growth units. He employed an instrument known as the evapotranspirometer for measuring evaporation and transpiration. Through a detailed observation of peas and by the use of a transpirometer he found a relationship between climate and the plant's water needs. That is, since transpiration, growth and development were all proportional to each other and were all affected by temperature in the same way he was able to work out a crop calendar in a slide rule whereby he could predict harvest dates from any planting date or vice versa.

In general it would appear that phenology and its practical applications have been and are being examined with considerable interest and determination. The difficulties inherent in the study of such a subject are fully appreciated. For one thing there is the complexity of factors, physical, chemical and environmental, which contribute to the growth processes within the plant. Then there is the matter of combining or correlating all these factors into a mathematical expression which will result in a coherent, reproducible and accurate formula for practical prediction purposes. Suggested methods of computation range from the involved multiple correlation concept to the very simple remainder indices, and each may be able to contribute something toward a final, successful solution. Finally, there is the indisputable fact that the problem concerns living material, with all its countless variations and individual idiosyncracies, tremendous obstacles to any investigation. However, being able to recognize and name the troublesome characters is in itself an advantage and if one can judge by the accumulation of literature on the various phases of study, phenology has an important place in biological research.

Materials and Methods

The procedure of the investigation lent itself readily to a division into three parts. The first one, preliminary in nature, involved the simple calculation of degree days and the compilation of hours of sunshine for several important apple varieties and covering a period of four years. The second part was an intensification of the investigation followed in the first part but with certain simplifications and additions. Here, only one variety and root, namely McIntosh on East Malling I, was studied. The entire scope of the project was enlarged to include data from the year 1952. Various combinations of several base temperatures were examined, together with refinements in the starting point and duration of the phenological period. Sunshine records were again tabulated as well as minimum and night temperatures. Solar radiation was introduced as a new factor. The third and final phase increased the range of years for which degree days were calculated and restricted the study to temperature effects alone. It also brought in the effect of location by utilizing data from the Experimental Station at Summerland, B. C. Under actual field conditions a study was made on the growth of apples during the season of active growth and its possible relation to the average temperature.

Part I

A series of calculations were made beginning with an examination and subsequent compilation of meteorological data for the years 1948-1951 available from the records of the Division of Field Husbandry at the Central Experimental Farm, Ottawa, Ontario. Averages of the daily maximum and minimum temperatures recorded at Ottawa were calculated and then using the simple remainder indices described by Livingston (33), with unit or base temperatures of 42°F. and 50°F. respectively, degree days were calculated for each month of the growth period of apples. Precise phenological data on the dates of blooming and harvesting were taken from the records at the Division of Horticulture for the years 1948-1951. The beginning of the phenological period was taken as being the date of first bloom, the end of the period being the day previous to the actual harvesting of the fruit. Several of the more important and useful varieties, such as Melba, Hume, McIntosh, Lawfam and Sandow, grown at the Farm were selected. The phenological dates chosen were an average computed from two to thirteen trees depending upon the number of trees available for the variety and root concerned. Trees were taken from Section I of the Standard Orchard at Ottawa, as that Section had had fairly uniform cultural treatment since it was planted in 1936.

From the records of the daily hours of sunshine, the total hours of sunshine were compiled for the phenological periods of the McIntosh variety in the years 1948-1951 and tabulated with the number of degree days for the same period.

Statistics on the hours of sunshine and degree days were calculated for harvest dates of the McIntosh variety kept by the Record Section of the Horticultural Division and also for harvest dates recorded in maturity tests made by the Cold Storage Research Section.

Part II

Since the material covered in the preliminary investigation seemed inadequate it was decided to extend the study to include the factors of solar radiation, night temperatures and minimum temperatures. A single variety and root, that of McIntosh on East Malling I, was selected. Thirteen trees from Section I of the Standard Orchard were used for this investigation.

In addition to the use of base temperatures of 42°F. and 50°F. already employed in the previous work, degree days in this investigation were calculated with base temperatures of 34°F. and 38°F. for the growing season of the apple during the years 1948-1952. The above base temperatures were selected from suggestions in the literature. Various combinations of these base temperatures were employed throughout each growing season to ascertain whether (as is apparently true of other fruits) there are optimum temperatures for certain stages of plant growth. In the apple, for instance, during the month of May a base temperature of 50°F. might be selected from which to calculate the degree days; the assumption being that temperatures above 50°F. are the optimum for that stage in the development of the apple. In the month of June, assuming a different growth temperature optimum, a base of 42°F. might be used. The same or different base temperatures could be employed in the remaining months of the growing season. In this manner a system of dividing the growth period into a series of possible optimum temperatures levels was derived. An example of this combination of several base temperatures is illustrated in Table 3, which shows the degree days by month for the years 1950 and 1952. Each combination of base temperature is given a series letter, A, B, C, D, etc. In series G, 50°F. is used as a base temperature throughout the phenological period.

To illustrate the refinements possible by selecting a beginning of the phenological period other than full bloom on the total number of degree days, a table was set up to make a comparison between the total degree days as calculated from full bloom and the total degree days as calculated from ten days before full bloom.

Some conjecture as to the possibility of the employment of minimum temperatures rather than average temperatures prompted the construction of a table (Table 6) in which 42°F. was subtracted from the minimum daily temperature during the phenological periods for the years 1948-1952. This is precisely the same as the normal degree day calculation, but the result is tabulated here simply as 'X' units to differentiate from the degree days.

In order to estimate the importance of night temperature on the growth and maturity of the apple, the night temperatures for the growth periods during the years 1948-1952 were calculated after Went's formula (62). That is, the night temperature was found by adding one-quarter of the difference between maximum and minimum temperatures to the minimum temperature. It was assumed that a higher night temperature is more conducive to growth of deciduous fruits, therefore a base of 50°F. was subtracted from the daily night temperature. For example, if the average night temperature was 60°F., then after subtracting a base of 50°F. the resulting 10°F. could be interpreted as being 10 'Night' units. These units were accumulated for the growing season in the ordinary way. The total 'Night' units were calculated by month for the years 1948-1952. The 'Night' units were then listed with the total degree days for the same years in order that a comparison might be made of the efficiency of each method in the prediction of harvest dates.

The average calculated night temperature was subtracted from the average daily temperature and the totals found for each growing season in the years 1948-1952. This was intended as a measurement of the fluctuation existing between day and night temperatures. The units here were not calculated using base temperatures. That is, if the calculated night temperature was 60°F. and the average daily temperature 85°F., then when the night temperature was subtracted from the average temperature, the resulting 25°F. was interpreted as being 25 'Y' units. These units were again accumulated for the growth season as in the calculation of the total number of degree days.

The hours of sunshine were compiled by month for the years 1948-1952 and the total hours of sunshine tabulated for each growing year. The dates of full bloom and of harvest, the total number of days in each phenological period and the average number of hours of sunshine per day were included in this series. Sunshine was taken as a measurement of light intensity.

Solar radiation was next considered and a table drawn up showing the amount of radiation per month for the years 1950-1952. No solar radiation data are available before June 1949. In some instances the data for individual days were missing. Accordingly the radiation was calculated after a method suggested by Mr. G. W. Robertson, Meteorologist at the Central Experimental Farm. The method involved the use of the formula $Rc = R_A\ (a - b\frac{n}{N})$ where Rc is the measured radiation, R_A is a theoretical maximum total daily radiation at the top of the atmosphere. a and b are unknown constants which were calculated as being 0.27 and 0.54 respectively for the Ottawa latitude; n is the total hours of sunshine, and N is the maximum possible hours of sunshine. Table 10 lists the maximum hours of daylight and the theoretical maximum total radiation at the top of the atmosphere at Ottawa for the specific dates shown. From these data the solar radiation units for the missing days were calculated. Solar radiation units are expressed in Langleys, a Langley being the unit used to denote one gram calorie per square centimetre of normal surface.

Part III

In the spring of 1953 it was decided to intensify the investigation with regard to temperature alone. Here the main purpose was not so much to predict the harvest date but rather to study the growth processes of the apple as affected by temperature. It was thought that in this manner it might be possible to arrive at a more accurate base temperature or temperatures from which to calculate degree days and ultimately predict the harvest date.

However, before this experiment was begun the previous year's temperature investigation was broadened to include the years 1940-1952 at Ottawa. The possible differences due to location were also to be noted by having similar data examined from Summerland, B. C. The Summerland data were incomplete as harvest dates were not recorded during the War. Data were available for the years 1940 and 1941 and continuously from 1946-1952.

Temperature and phenological data from both Ottawa and Summerland were compiled at Ottawa. The study medium was again McIntosh on East Malling I. Degree days were calculated using base temperatures of 50°F., 46°F., 42°F. and 34°F. for both Stations. Dates of full bloom and harvest, total number of days in the phenological period as well as the total degree days were included in the tables constructed. The beginning of the phenological period was taken as ten days before full bloom in all instances.

Upon completion of this work a comparison of the total number of degree days at Ottawa and at Summerland was made by years and by base or unit temperature.

The investigation into growth and temperatures in the field was initiated on the first of June 1953. At this time the bloom on early and late varieties had disappeared and small apples were being initiated.

A tree of an Ottawa selection, O-277, which is a cross between the variety Melba and the variety Crimson

Beauty and consequently an early maturing variety, was set aside for observation purposes. Four different spurs selected at random around the tree were labelled on June 1, well after the non-fertilized blossoms had fallen. The number of immature apples varied from one to five on each spur. Actually a total of seventeen apples were measured in the initial phase. However, by June 17, all but seven of these had been eliminated by the June drop. A vernier caliper manufactured by the Central Scientific Company and graduated in millimetres was used to measure the equatorial diameter of the apple. It was possible by means of the vernier scale to achieve an accuracy of measurement up to one one hundredth of a centimetre. Measurements were taken around noon each Monday, Wednesday and Friday of the week.

On July 26, the O-277 tree was attacked by children who filched four of the apples which had been labelled. The apples at this time were quite ripe, but the tree was not picked completely until August 4th. Growth measurements were made up to an including August 3rd on two apples. Of the data collected from the O-277 seedling only those measurements beginning on June 5 and continuing to July 24 were included in this study. These data represent statistics gathered on seven apples.

Three trees of the variety McIntosh on East Malling I were also marked for observation purposes and four spurs on each tree labelled in a similar manner to that employed with the O-277 seedling variety. A total of forty apples were examined in the initial phase. Unfortunately with the McIntosh variety most of the apples marked fell off during the June drop. In fact only one apple of all those examined on each tree survived the drop. However, on June 24, the date at which the June drop appeared to be over, three new apples on each tree were selected at random and labelled, making a total of four apples marked for study on each tree. Equatorial measurements on the twelve apples were taken throughout the summer and autumn around noon every Monday, Wednesday and Friday. On September 25 the labelled apples on one tree were accidently picked by harvesting crews. Therefore complete data on twelve apples were available only from June 26 to September 23, although the last labelled apple did not drop off the tree until October 5.

The average temperature per day was calculated from records supplied by the Meteorological Section of the Division of Field Husbandry, C. E. F., Ottawa, for the active growth period of the O-277 seedling and of the McIntosh on East Malling I apples. The average growth or increase in equatorial diameter was determined from the field observations. Two coefficients of correlation were calculated for the relationship between average increase in size and average temperature. In one instance, the coefficient of correlation was based on a study of the 0-277 seedling with seven apples and twenty-two observations; while in the other the coefficient of correlation was based on measurements taken on the McIntosh on East Malling I variety with twelve apples and thirty-nine observations.

Results of the Investigation

Part I

Four years temperature data collected during the active growing season at Ottawa, Ontario, are presented below in Table No. 1.

Table I

Average Monthly Temperatures For The Years 1948-1951 at Ottawa

Degrees Fahrenheit

Month	1948	1949	1950	1951	Average
May	53.6	54.9	55.1	56.7	55.1
June	62.9	68.3	64.1	62.7	64.5
July	69.1	71.5	68.3	68.5	69.4
August	68.9	69.9	64.1	64.2	66.8
September	61.3	56.2	57.8	54.9	57.6
Average	63.2	64.2	61.9	61.4	62.7

The above table shows that monthly temperatures ranged from an average of 55.1°F. in May to 69.4°F. in July. In all years July was the warmest month. The grand average for the four year period was $\overline{62.7}^{\circ}$F.

Table I(a)

Average Degree Days From First Bloom to Harvest By Variety at Ottawa

(Record Section)

Base 42°F.

Variety	1948	1949	1950	1951	Average
Melba	2172	2188	1995	1960	2079
Hume	2586	2918	2568	2559	2658
McIntosh	2919	3072	2672	2812	2869
Linda	3019	2984	2710	2844	2889
Edgar	3072	3254	2779	2907	3003
Lawfam	3071	3254	2732	2966	3006
Fameuse	3075	3248	2698	3067	3008
Sandow	3142	3204	2812	2910	3031
Niobe	3143	3334	2903	3052	3108

Base 50°F.

Variety	1948	1949	1950	1951	Average
Melba	1427	1496	1329	1274	1382
Hume	1748	1999	1680	1657	1771
McIntosh	1930	2075	1716	1804	1881
Linda	1976	2020	1732	1824	1888
Edgar	2021	2141	1765	1861	1947
Lawfam	2020	2141	1737	1884	1946
Fameuse	2022	2130	1719	1905	1944
Sandow	2031	2119	1781	1883	1954
Niobe	2030	2183	1812	1918	1986

The average number of degree days calculated from base temperatures of 42°F. and 50°F. as given in Table No. I(a) shows that the early varieties Melba and Hume required fewer degree days to mature than did the later varieties Fameuse and Niobe. Using a base of 42°F., Melba required an average of 2,079 degree days for the four years 1948-1951 to bring it to harvest maturity; while for the same period Niobe required an average of 3,108 degree days, a difference of 1,029 degree days. With a base temperature of 50°F. a similar trend was shown except the difference between the two varieties was only 604 degree days. The varieties Edgar, Lawfam and Fameuse required almost the same number of degree days to bring them to harvest maturity.

Table I(b)

Degree Days by Month for the Years 1948-1951
Base 42°F.

	Month											
Year	May		June		July		August		September		October	
1948	357	11*	636	21	850	27	838	27	588	20	158	5
1949	399	13	796	27	913	29	871	28	427	14	302	10
1950	415	13	671	22	822	27	698	23	391	13	232	7
1951	469	15	631	21	828	27	705	22	483	16	230	7

* Average number of degree days per day

Table I(b) shows that as far as the total number of degree days per month was concerned there was a rise in the number to a peak in the month of July, whence the degree days dropped off again. Of particular interest for harvest prediction work was the average number of degree days per day in the month of September. During September this average ranged from thirteen degree days in the year 1950 to twenty degree days in the year 1948. The average number of degree days per day during September over the four years 1948-1951 was sixteen.

Table 2 shows phenological data arranged from records kept by the Low Temperature Storage Section.

Table 2

Low Temperature Storage Maturity Records, Variety McIntosh, Base Temperature 42°F.

Year	Date of First Bloom	Date of Harvest	No. of Days in Phenological Period	Total Degree Days	Hours of Sunshine
1948	May 20	Sept. 21	123	2902	1006.8
1949	May 13	Sept. 21	130	3143	1070.3
1950	May 24	Sept. 26	124	2685	918.3
1951	May 16	Sept. 26	132	2945	920.2
Average			127	2919	978.9

It can be seen that for the variety McIntosh the total number of degree days varied from 2,685 in 1950 to 3,143 in 1949, a difference of 458 degree days.

The difference in the actual number of days from first bloom to harvest for the years 1950 and 1949 was only six days. From the average this deviation was only three days for each year.

There appears to be no consistent relationship between the hours of sunlight and either the total number of degree days or the total number of days between first bloom and harvest.

Part II

The several combinations of base temperature upon which degree days were calculated is outlined in Table 3 for the two years 1950 and 1952. This table shows that a high base temperature in the spring followed by a low summer base temperature and ending the season with a comparatively low base temperature (Series A) was not effective in increasing the precision of the total number of degree days from year to year. Nor did the low base temperatures used in Series C increase the precision. In Series F a base temperature of 50°F. in May, followed by a base temperature of 42°F. in June, 34°F. in July and August and 50°F. in September reduced the difference between the total degree days for the two years to 364, the same as that found using a straight base temperature of 50°F. throughout the season.

Table 3

Degree Days From Full Bloom to Harvest With Various Combinations of Base Temperatures in Degrees F. By Month for Years 1950 and 1952 at Ottawa

Series	Year 1950 Month: May	June	July	August	September	Total	Year 1952 Month: May	June	July	August	September	Total
A	50°	50°	34°	42°	42°		50°	50°	34°	42°	42°	
	38	431	1070	698	285	2522	82	467	1157	768	459	2933
Difference between years 411												
B	34°	50°	34°	42°	42°		34°	50°	34°	42°	42°	
	102	431	1070	698	285	2586	242	467	1157	768	459	3093
Difference between years 507												
C	34°	38°	34°	42°	42°		34°	38°	34°	42°	42°	
	102	791	1070	698	285	2946	242	822	1157	768	459	3448
Difference between years 502												
D	50°	50°	34°	34°	42°		50°	50°	34°	34°	42°	
	38	431	1070	946	285	2770	82	467	1157	1016	459	3181
Difference between years 411												

Table 3 (Continued)

Series	Year 1950 Month May	June	July	August	September	Total	Year 1952 Month May	June	July	August	September	Total
E	50°	42°	34°	34°	42°		50°	42°	34°	34°	42°	
	38	671	1070	946	285	3010	82	702	1157	1016	459	3421
Difference between years 411												
F	50°	42°	34°	34°	50°		50°	42°	34°	34°	50°	
	38	671	1070	946	148	2873	82	702	1157	1016	275	3237
Difference between years 364												
G	50°	50°	50°	50°	50°		50°	50°	50°	50°	50°	
	38	431	574	450	148	1641	82	467	661	520	275	2005
Difference between years 364												

Table 4

Total Degree Days by Years (1948-1952) From Full Bloom to Harvest With Different Base Temperatures (Ottawa)

Year	Base 34°F.	Deviation From Average	Base 38°F.	Deviation From Average	Base 42°F.	Deviation From Average	Base 50°F.	Deviation From Average	Series F	Deviation From Average
1948	3807	30	3332	33	2855	35	1904	39	3136	39
1949	3905	128	3433	134	2961	141	2016	151	3248	151
1950	3458	319	3002	297	2546	274	1641	224	2873	224
1951	3710	67	3214	85	2734	86	1758	107	2990	107
1952	4005	228	3515	216	3005	185	2005	140	3237	140
Average	3777		3299		2820		1865		3097	

Table 4 shows that when the number of years examined was extended to include the years 1948-1952 the deviation from the average shows that there is little to choose between the employment of one temperature base throughout the season and the combination, Series F, as shown in Table 3. The deviations from the average were exactly the same for the base temperature of 50°F. and the Series F temperatures. Actually the base temperature of 42°F. appears to be most satisfactory for all years, but considerable variation from the average was noted from year to year even with that base temperature.

Tables 5 and 5(a) show that starting the phenological period ten days before full bloom rather than at full bloom increased the precision of the total degree days. In 1948 with a base temperature of 34°F. there is a deviation of thirty degree days from the average when the phenological period was started at full bloom. Starting the growing season ten days before full bloom results in a deviation of only six degree days from the average using a base temperature of 34°F. A similar trend is shown for Series F base temperatures and for the other years tabulated.

Table 5

Deviation of Total Degree Days From the Average, Five Different Base Temperatures, Years 1948-1952 at Ottawa

Year	Base Temp. 34°F.	Deviation	Base Temp. 38°F.	Deviation	Base Temp. 42°F.	Deviation	Base Temp. 46°F.	Deviation	Base Temp. 50°F.	Deviation
1948	3982	6	3467	18	2950	1	2434	1	1931	9
1949	4115	127	3677	192	3091	140	2581	148	2067	145
1950	3740	248	3244	241	2748	203	2251	182	1763	159
1951	3927	61	3391	94	2871	80	2346	87	1826	96
1952	4174	186	3644	159	3094	143	2554	121	2022	100
Average	3988		3485		2951		2433		1922	

Phenological period begins 10 days before full bloom.

Table 5(a)

Total Degree Days by Years for Two Periods at Ottawa
1. Full Bloom to Harvest
2. 10 Days Before Full Bloom to Harvest

	Full Bloom to Harvest				10 Days Before Full Bloom to Harvest			
Year	Base 34°F.	Deviation From Average	Series F	Deviation From Average	Base 34°F.	Deviation From Average	Series F	Deviation From Average
1948	3807	30	3136	39	3982	6	3163	9
1949	3905	128	3248	151	4115	127	3289	135
1950	3458	319	2873	224	3740	248	2995	159
1951	3710	67	2990	107	3927	61	3068	86
1952	4005	228	3237	140	4174	186	3254	100
Average	3777		3097		3988		3154	

Table 6 was compiled by using the minimum temperature instead of the average temperature from which to subtract a base temperature.

Table 6

Minimum Temperature Minus Base of 42°F.
By Month for the Years 1948-1952 - Ottawa

Year	May	June	July	August	September	Total 'X' Units	Deviation From Average
1948	43	292	485	495	221	1536	32
1949	73	474	537	477	116	1677	109
1950	118	365	505	371	126	1485	83
1951	141	339	499	347	154	1480	88
1952	91	363	553	419	235	1661	93
Average						1568	

Period is from 10 days before full bloom to harvest.

The calculated night temperature as shown in Table 7 reveals no consistency over a five year period except in 1950 and 1951 when there was a difference of only two 'Night' units.

Table 7

Night Temperature Minus Base 50°F. By Month and Year - Ottawa

Year	April	May	June	July	August	September	Total 'Night' Units	Deviation From Average	Total Degree Days Base 50°F.	Deviation From Average
1948		16	227	417	412	161	1233	3	1931	9
1949		47	397	475	418	74	1411	175	2067	145
1950		77	279	409	281	69	1115	121	1763	159
1951		99	240	408	273	97	1117	119	1826	96
1952		33	284	477	338	173	1305	69	2022	98
Average							1236		1922	

Period is from 10 days before full bloom to harvest.

Table 8

Average Twenty-Four Hour Temperature Minus Calculated Night Temperature By Month and Year - Ottawa

Year	May	June	July	August	Sept.	Total 'Y' Units	Deviation From Average	Average For Last 5 Days
	Month							
1948	73	172	185	178	129	737	1	5.2
1949	119	167	200	205	75	766	30	5.2
1950	86	161	165	171	97	680	56	4.6
1951	142	159	172	176	103	752	16	5.2
1952	93	183	163	182	122	743	7	5.0
Average						736		

Period is from 10 days before full bloom to harvest.

In Table 8 the calculated night temperatures are subtracted from the average daily temperature and originally were aimed at some sort of measurement of the fluctuation between night and day temperatures. Actually this procedure may be reduced to simply a summation of one-quarter of the daily maximum minus the daily minimum temperatures for the phenological period and gives the range between maximum and minimum temperatures. The total number of 'Y' units calculated in this manner for each year shows less deviation from the five year average than any other system yet attempted. The deviation from the average varied from fifty-six in 1950 to one in 1948.

Table 9

Hours of Sunshine by Month for the Years 1948-1952 - Ottawa

Year	Date of Full Bloom	May	June	July	August	September	Harvest Date	Total	No. of Days	Average Per Day (Hours)
		Month								
1948	May 28	113.2	210.9	299.5	257.1	156.5	Sept. 24	1037.2	129	8.04
1949	May 21	160.6	233.9	309.7	278.9	92.5	Sept. 16	1075.6	118	9.12
1950	May 28	97.8	242.9	249.6	223.6	110.4	Sept. 19	924.3	124	7.45
1951	May 21	175.7	167.9	263.6	202.9	126.9	Sept. 20	937.0	132	7.10
1952	May 22	115.3	284.8	300.3	273.9	121.1	Sept. 24	1095.4	135	8.11

Period is from 10 days before full bloom to harvest.

Table 9 indicates that there is apparently little relationship between the total hours of sunshine and the total number of days in the phenological period. In 1951 there were a total of 937.0 hours of sunshine in the growing period which consisted of 132 days, but in 1949 the actual records showed a total of 1075.6 hours of sunshine with only 118 days in the active growth period. The year 1949 had the largest average number of hours of sunshine per day of the years listed, and matured apples in the shortest time. The year 1951 had the lowest average hours of sunshine per day but only three days less were required to harvest mature the apples than did the year 1952 during which almost an hour of sunshine more per day was recorded during the active growth of the apple.

The data in Table 10 represents basic calculations of the maximum possible hours of sunshine and the theoretical maximum total radiation for Ottawa. From these data a curve can be constructed which will give the maximum possible hours of sunshine and theoretical total radiation for any day of the year. Once these data have been computed it is possible using the formula, $Rc = R_A (a - b\frac{n}{N})$, suggested by Mr. Robertson to arrive at the number of solar radiation units for that day.

Table 10

Date	Maximum Hours of Daylight at Ottawa Latitude 45° - 24' N	Theoretical Maximum Total Radiation At Top of Atmosphere R_A
March 21	12.20	626
April 13	13.38	767
May 6	14.48	887
May 29	15.32	964
June 22	15.63	990
July 15	15.30	960
August 8	14.40	878
August 31	13.43	759
September 23	12.15	618
October 16	10.95	474
November 8	9.87	352
November 30	9.07	270
December 22	8.75	241
January 13	9.10	272
February 4	9.91	356
February 26	10.98	481

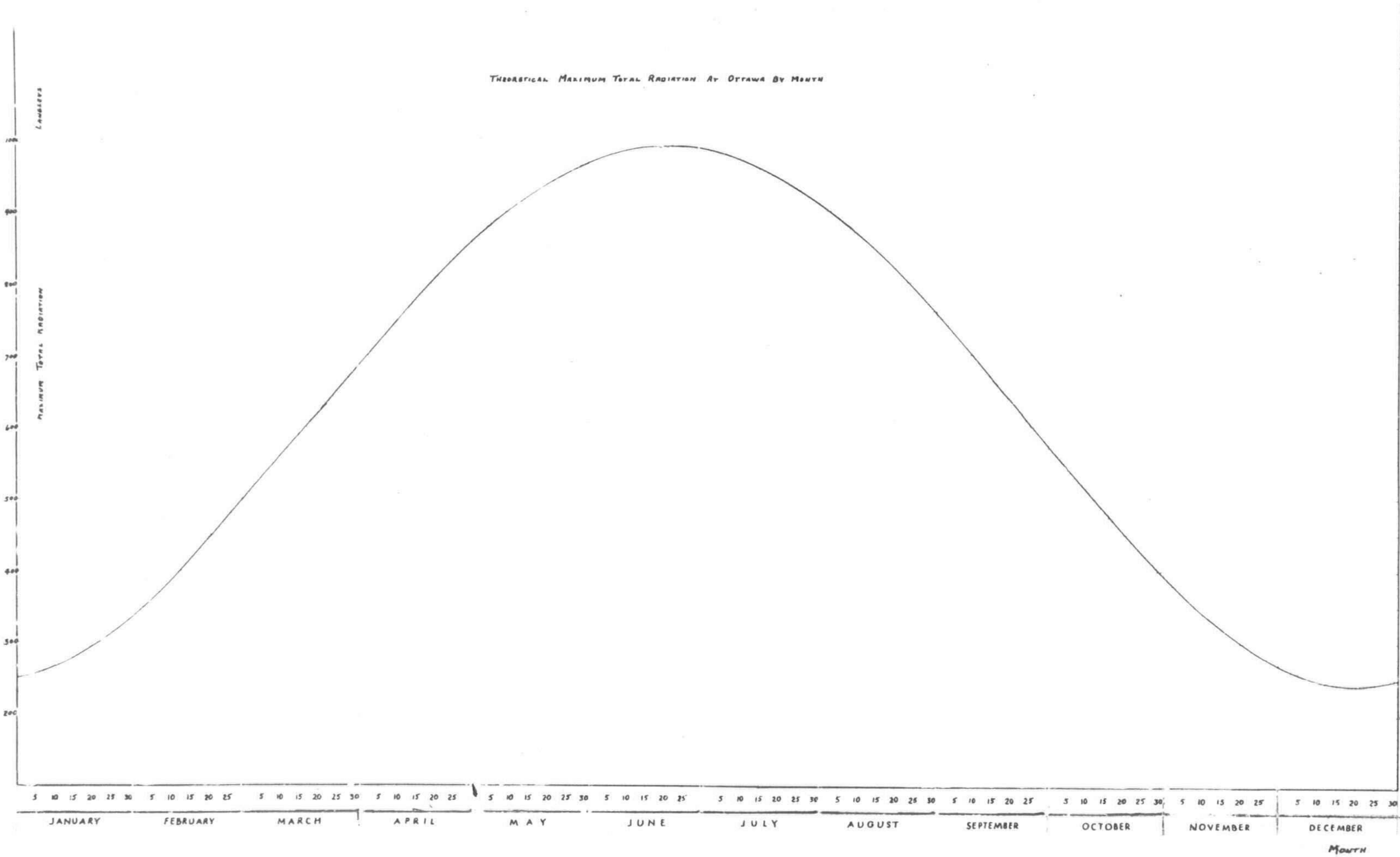

Figure I Theoretical Maximum Total Radiation at Ottawa by Month

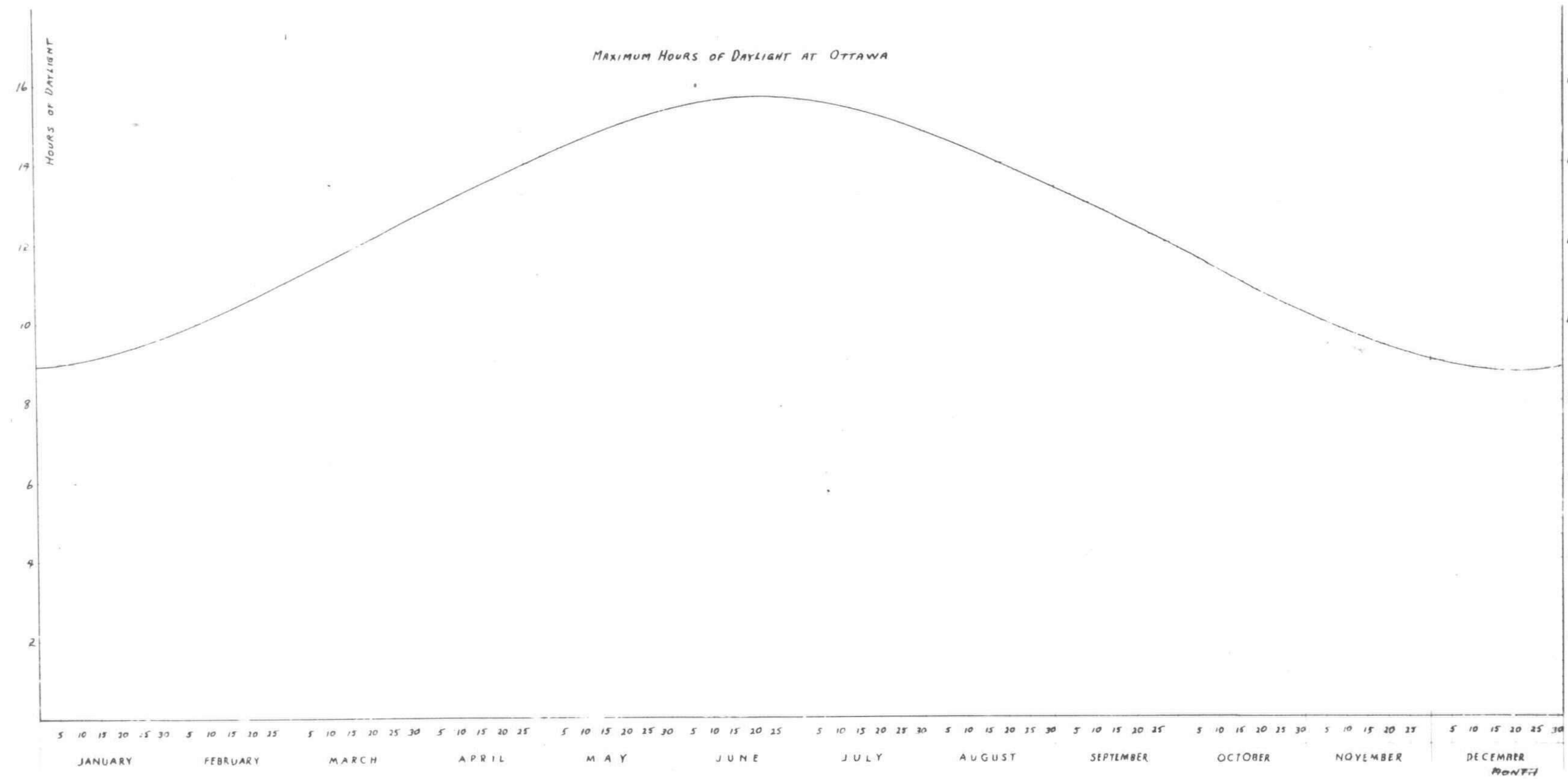

Figure II Maximum Hours of Daylight at Ottawa

Table 11

Solar Radiation By Month for Years 1950-1952
At Ottawa

				Month			
Year	April	May	June	July	August	September	Total
1950		6685	16027	17120	13020	7061	59913
1951		11661	14620	16621	13592	7578	64072
1952		9245	18364	18008	15483	8559	69659

Period is from 10 days before full bloom to harvest.

A tabulation of the solar radiation by month at Ottawa as recorded in Table 11 shows considerable variation between years and between the same month in different years. In May, 1950, there were 6,685 Langleys recorded; 11,661 Langleys in May of 1951 and 9,245 Langleys were observed in May of 1952. Other months were similar in their variance. The total number of Langleys varied from 59,913 in 1950 to 69,659 Langleys in 1952.

Table 12

Climatological and Phenological Data Gathered at Ottawa For Years 1948-1952

Year	Date of Full Bloom	Harvest Date	No. of Days	Total Degree Days Base 50°F.	Total Hours of Sunshine	Total Solar Radiation	Total Night Temperature Minus 50°F.
1948	May 28	Sept. 24	129	1931	1037.2		1233
1949	May 21	Sept. 16	118	2067	1075.6		1411
1950	May 28	Sept. 19	124	1763	924.3	59913	1115
1951	May 21	Sept. 20	132	1826	937.0	64072	1117
1952	May 22	Sept. 24	135	2022	1095.4	69659	1305

Period is from 10 days before full bloom to harvest.

In Table 12 the various climatological and phenological factors are grouped for purposes of comparison. There appears to be a relationship between total solar radiation, hours of sunshine, and total degree days for the years 1950-1952. The year 1952 had more solar radiation units, hours of sunshine and total degree days than any of the other years tabulated with the exception of 1949 which had a larger total number of degree days. That year (1952) required the greatest number of days to mature the McIntosh apple. The warmest night temperatures were recorded in 1949 and also the least number of days to maturity were required, but this trend was not followed in all years. For instance, the year 1950 had the coldest nights but yet required only 124 days to mature the apples, while in 1952 the warmer nights required 135 days to mature the McIntosh variety of apple sufficiently to harvest the crop.

Part III

Table 13

McIntosh on East Malling I

Degree Days By Month, Years 1940-1952 - Base 50°F.
At Ottawa, Ontario

Year	Date of Full Bloom	May	June	July	August	September	October	Date of Harvest	Total No. of Days	Total Degree Days
		Month								
1940	May 29	155	368	544	516	116		Sept. 13	117	1699
1941	May 16	157	517	642	426	185		Sept. 17	134	1927
1942	May 15	182	447	555	490	247		Sept. 26	144	1921
1943	May 31	109	474	602	471	167		Sept. 23	125	1823
1944	May 22	245	455	644	637	319		Sept. 29	140	2300
1945	May 21	80	389	555	520	287		Sept. 28	140	1831
1946	May 25	140	395	568	427	265		Sept. 25	133	1795
1947	June 6	16	388	611	665	325	1	Oct. 2	138	2006
1948	May 28	70	396	602	590	273		Sept. 24	129	1931
1949	May 21	80	556	675	623	133		Sept. 16	118	2067
1950	May 28	160	431	574	450	148		Sept. 19	124	1763
1951	May 21	216	391	580	447	192		Sept. 20	132	1826
1952	May 22	99	467	661	520	275		Sept. 24	135	2022
Average									131	1916

Period begins 10 days before full bloom.

Table 13 (Continued)

Degree Days By Month, Years 1940-1952 - Base 46°F.
At Ottawa, Ontario

Year	Date of Full Bloom	May	June	July	August	September	October	Date of Harvest	Total No. of Days	Total Degree Days
					Month					
1940	May 29	207	488	668	640	164		Sept. 13	117	2167
1941	May 16	252	637	766	550	248		Sept. 17	134	2453
1942	May 15	278	567	679	614	339		Sept. 26	144	2477
1943	May 31	153	594	726	595	247		Sept. 23	125	2315
1944	May 22	317	575	768	761	414		Sept. 29	140	2835
1945	May 21	134	502	679	644	384		Sept. 28	140	2343
1946	May 25	205	515	692	551	357		Sept. 25	133	2320
1947	June 6	30	508	735	789	412	5	Oct. 2	138	2479
1948	May 28	114	516	726	714	364		Sept. 24	129	2434
1949	May 21	158	676	799	747	201		Sept. 16	118	2581
1950	May 28	216	551	698	574	212		Sept. 19	124	2251
1951	May 21	292	511	704	571	268		Sept. 20	132	2346
1952	May 22	171	587	785	644	367		Sept. 24	135	2554
Average									131	2427

Table 13 (Continued)

Degree Days By Month, Years 1940-1952 - Base 42°F.
At Ottawa, Ontario.

Year	Date of Full Bloom	May	June	July	August	September	October	Date of Harvest	Total No. of Days	Total Degree Days
1940	May 29	259	608	792	764	212		Sept. 13	117	2635
1941	May 16	355	757	890	674	312		Sept. 17	134	2988
1942	May 15	384	687	803	738	438		Sept. 26	144	3050
1943	May 31	197	714	850	719	334		Sept. 23	125	2814
1944	May 22	393	695	892	885	516		Sept. 29	140	3381
1945	May 21	206	622	803	768	489		Sept. 28	140	2888
1946	May 25	270	635	816	675	453		Sept. 25	133	2849
1947	June 6	46	628	859	913	507	9	Oct. 2	138	2962
1948	May 28	170	636	850	838	456		Sept. 24	129	2950
1949	May 21	240	796	923	871	261		Sept. 16	118	3091
1950	May 28	272	671	822	698	285		Sept. 19	124	2748
1951	May 21	373	631	828	695	344		Sept. 20	132	2871
1952	May 22	251	707	909	768	459		Sept. 24	135	3094
Average									131	2948

Table 13 (Continued)

Degree Days By Month, Years 1940-1952 - Base 34°F.
At Ottawa, Ontario

Year	Date of Full Bloom	Month: May	June	July	August	September	October	Date of Harvest	Total No. of Days	Total Degree Days
1940	May 29	363	848	1040	1012	308		Sept. 13	117	3571
1941	May 16	563	997	1138	922	440		Sept. 17	134	4060
1942	May 15	600	927	1051	986	638		Sept. 26	144	4202
1943	May 31	285	954	1098	967	510		Sept. 23	125	3814
1944	May 22	551	935	1140	1133	735		Sept. 29	140	4494
1945	May 21	373	862	1051	1016	705		Sept. 28	140	4007
1946	May 25	406	875	1064	923	645		Sept. 25	133	3913
1947	June 6	78	868	1107	1161	740	22	Oct. 2	138	3976
1948	May 28	282	876	1098	1086	640		Sept. 24	129	3982
1949	May 21	408	1036	1171	1119	381		Sept. 16	118	4115
1950	May 28	384	911	1070	946	429		Sept. 19	124	3740
1951	May 21	541	871	1076	943	496		Sept. 20	132	3927
1952	May 22	411	947	1157	1016	643		Sept. 24	135	4174
Average									131	3998

The foregoing table shows that in the thirteen year period 1940-1952 at Ottawa some variation was noted from year to year in the total number of degree days and also in the number of degree days for the same month in different years.

Table 14

The Deviation of the Total Number of Degree Days From The Average for Six Base Temperatures at Ottawa, Years 1940-1952

Year	Base 50°F.	Base 46°F.	Base 42°F.	Base 34°F.	Series K	Series L
1940	-217	-260	-313	-427	-217	-249
1941	11	26	40	62	11	-6
1942	5	50	102	204	5	17
1943	-93	-112	-134	-184	-93	-93
1944	384	408	433	496	384	399
1945	-85	-84	-60	9	-92	-75
1946	-121	-107	-99	-85	-121	-109
1947	90	52	14	-22	90	101
1948	15	7	2	-16	15	26
1949	151	154	143	117	151	139
1950	-153	-176	-200	-258	-153	-169
1951	-90	-81	-77	-71	-90	-94
1952	106	127	146	176	106	118

Series K - Base temperature of 50°F. in May, 42°F. in June, 34°F. in July and August and 50°F. in September.

Series L - Base temperature of 50°F. in May, 42°F. in June, 34°F. in July and August and 46°F. in September.

The deviation from the thirteen year average for each of the six base temperatures given in Table 14 shows that no one base temperature was consistently better than any other. The base 42°F. occupied a medial position while 34°F. seemed to be least suitable. Series K except for the year 1945 was exactly the same as base 50°F. Small deviations from the average were the rule for year rather than for base temperature.

Extreme years were selected and the range in degree days between those years were calculated by month as in Table 15 below.

Table 15

The Range in Total Degree Days Between Extreme Years By Month During the Period 1940-1952 at Ottawa

	Base Temperature							
	50°F.		46°F.		42°F.		34°F.	
Month	Range	Extreme Years	Range	Extreme Years	Range	Extreme Years	Range	Extreme Years
May	229	1944, 1947	287	1944, 1947	338	1944, 1947	522	1942, 1947
June	188	1940, 1949	188	1940, 1949	188	1940, 1949	188	1940, 1949
July	131	1940, 1949	131	1940, 1949	131	1940, 1949	131	1940, 1949
August	239	1941, 1947	239	1941, 1947	239	1941, 1947	239	1941, 1947
September	209	1940, 1947	250	1940, 1944	304	1940, 1944	432	1940, 1947

The above table shows that there was some fluctuation in the extreme years for May and September and also shows the uneven range with decreasing base temperatures. Besides temperature fluctuations there was the factor of an indefinite, very variable number of days in May and September on which degree day determinations were made. The years 1949 and 1940 were extremes for the months of June and July but 1947 and 1941 were the extreme years for August. The range in June (188 degree days) was the same for all base temperatures. The same was true of July and August except that the range was 131 and 239 degree days respectively. These data indicated that the average daily temperature did not drop below 50°F. in June, July and August at Ottawa for those years. May and September were critical months in the selection of base temperatures.

Table 16

A Comparison of the Total Degree Day Averages Based on a Five Year Period and on a Thirteen Year Period at Ottawa, Four Base Temperatures

Base Temperature 34°F.		Base Temperature 42°F.	
5 Year Av.	13 Year Av.	5 Year Av.	13 Year Av.
3988	3998	2951	2948

Base Temperature 46°F.		Base Temperature 50°F.	
5 Year Av.	13 Year Av.	5 Year Av.	13 Year Av.
2433	2427	1922	1916

The five year average for the total degree days as is shown in Table 16 differed but slightly from the thirteen year average for all base temperatures. The greatest difference was shown using a base of 34°F. but even here the difference was only ten degree days.

Table 17

Average Monthly Temperature for Years 1948-1951 At Summerland

Month	1948	1949	1950	1951	Average
May	55.5	59.6	55.1	58.8	57.3
June	67.9	62.5	65.3	63.8	64.9
July	66.5	68.2	70.4	71.2	69.1
August	64.5	66.8	68.7	68.6	67.2
September	58.1	60.1	62.7	61.6	60.6
Average	62.5	63.4	64.4	64.8	63.8

Table 17 indicates that the average monthly temperature for the growing season or phenological period at Summerland, B. C., varied from 57.3°F. in May to 69.1°F. in July. Unlike the temperature at Ottawa the month of July was not the warmest month in all years. In 1948 the average temperature in June exceeded that of the month of July. However, the average temperature for July was higher than any other month for the years observed. The grand average was 63.8°F., slightly higher than that of Ottawa.

Table 18

McIntosh on East Malling I

Degree Days By Month, Years 1940, 1941, 1946-1952 - Base 50°F.
At Summerland, British Columbia

Year	Date of Full Bloom	April	May	June	July	August	September	Date of Harvest	Total No. of Days	Total Degree Days
					Month					
1940	April 30	39	289	532	692	586	269	Sept. 15	148	2407
1941	April 25	103	228	415	731	584	119	Sept. 15	153	2180
1946	May 7	5	313	316	585	567	283	Sept. 27	153	2069
1947	May 1	57	329	360	573	494	150	Sept. 19	151	1963
1948	May 21		177	537	512	450	253	Sept. 28	140	1929
1949	May 8		316	375	564	520	216	Sept. 22	147	1991
1950	May 19		177	458	633	580	388	Sept. 29	143	2236
1951	May 12		271	415	656	576	222	Sept. 17	138	2140
1952	May 10		242	337	588	591	223	Sept. 20	142	1981
Average									146	2100

Period begins 10 days before Full Bloom.

Table 18 (Continued)

Degree Days By Month, Years 1940, 1941, 1946-1952 - Base 46°F.
At Summerland, British Columbia

Year	Date of Full Bloom	Month: April	May	June	July	August	September	Date of Harvest	Total No. of Days	Total Degree Days
1940	April 30	78	408	652	816	710	325	Sept. 15	148	2989
1941	April 25	160	351	535	855	708	175	Sept. 15	153	2784
1946	May 7	14	435	436	709	691	387	Sept. 27	153	2672
1947	May 1	95	453	480	697	618	218	Sept. 19	151	2561
1948	May 21		258	657	636	574	355	Sept. 28	140	2480
1949	May 8	5	426	495	688	644	300	Sept. 22	147	2558
1950	May 19		265	578	757	704	499	Sept. 29	143	2803
1951	May 12		391	535	780	700	286	Sept. 17	138	2692
1952	May 10		353	456	712	715	299	Sept. 20	142	2535
Average									146	2675

Table 18 (Continued)

Degree Days By Month, Years 1940, 1941, 1946-1952 - Base $42^{o}F$.
At Summerland, British Columbia

Year	Date of Full Bloom	April	May	June	July	August	September	Date of Harvest	Total No. of Days	Total Degree Days
					Month					
1940	April 30	120	532	772	940	834	381	Sept. 15	148	3579
1941	April 25	224	475	655	979	832	231	Sept. 15	153	3396
1946	May 7	26	559	556	833	815	491	Sept. 27	153	3280
1947	May 1	135	577	600	821	742	290	Sept. 19	151	3165
1948	May 21		342	777	760	698	463	Sept. 28	140	3040
1949	May 8	13	549	615	812	768	384	Sept. 22	147	3141
1950	May 19		356	698	881	828	611	Sept. 29	143	3374
1951	May 12		511	655	904	824	350	Sept. 17	138	3244
1952	May 10		476	576	836	839	375	Sept. 20	142	3102
Average									146	3258

Table 18 (Continued)

Degree Days By Month, Years 1940, 1941, 1946-1952 - Base 34°F.
At Summerland, British Columbia

Year	Date of Full Bloom	April	May	June	July	August	September	Date of Harvest	Total No. of Days	Total Degree Days
					Month					
1940	April 30	208	780	1012	1188	1082	493	Sept. 15	148	4763
1941	April 25	352	723	895	1227	1080	343	Sept. 15	153	4620
1946	May 7	50	807	796	1081	1063	699	Sept. 27	153	4496
1947	May 1	215	825	840	1069	990	434	Sept. 19	151	4373
1948	May 21		510	1017	1008	946	679	Sept. 28	140	4160
1949	May 8	29	797	855	1060	1016	552	Sept. 22	147	4309
1950	May 19		540	938	1129	1076	835	Sept. 29	143	4518
1951	May 12		751	895	1152	1072	478	Sept. 17	138	4348
1952	May 10		724	816	1084	1087	527	Sept. 20	142	4238
Average									146	4425

Table 18 shows that the variation in total degree days for a nine year period at Summerland was similar to that shown in the thirteen years at Ottawa (Table 13). The four base temperatures 50°F., 46°F., 42°F. and 34°F., all showed variations from year to year.

Table 19

The Deviation of the Total Number of Degree Days From the Average For Six Base Temperatures at Summerland, B.C., Years 1940-1941, 1946-1952

Year	Base 50°F.	Base 46°F.	Base 42°F.	Base 34°F.	Series K	Series L
1940	307	314	321	338	308	283
1941	80	109	138	195	81	56
1946	-31	-3	22	71	-30	-7
1947	-137	-114	-93	-52	-136	-149
1948	-171	-195	-218	-265	-170	-149
1949	-109	-117	117	-116	-108	-105
1950	136	128	116	93	137	167
1951	40	17	-14	-77	41	24
1952	-119	-140	-156	-187	-119	-124

Series K and L as in Table 14

Table 19 shows that again no one base temperature appeared to be entirely satisfactory. Series K was almost the same as the base temperature of 50°F. On the whole Series L was better than Series K or the base temperature of 50°F. and may have been slightly better than the continuous base temperatures of 46°F. and 42°F. Series L had the smallest deviation from the individual yearly average for 56 per cent of the years included in the study. Calculations based on a base temperature of 42°F. showed the same medial tendency as with the Ottawa data, and 34°F. gave the largest deviations from the average.

Table 20

The Range in Total Degree Days Between Extreme Years By Month in the Years 1940, 1941, 1946-1952, At Summerland, B. C.

	Base Temperature							
	50°F.		46°F.		42°F.		34°F.	
Month	Range	Extreme Years	Range	Extreme Years	Range	Extreme Years	Range	Extreme Years
May	152	1947, 1948	195	1947, 1948	235	1947, 1948	315	1947, 1948
June	221	1946, 1948	221	1946, 1948	221	1946, 1948	221	1946, 1948
July	219	1941, 1948	219	1941, 1948	219	1941, 1948	219	1941, 1948
August	141	1948, 1952	141	1948, 1952	141	1948, 1952	141	1948, 1952
September	269	1941, 1950	324	1941, 1950	380	1941, 1950	492	1941, 1950

The range in total degree days between extreme years in Table 20 shows similar relationships for Summerland as were apparent at Ottawa. That is, there was the same fluctuation in May and September while the months of June, July and August had the same range in each month for all base temperatures. The range for June was 221 degree days, that for July 219 degree days and 141 degree days for August. The range for June and July was much greater at Summerland than at Ottawa, but the reverse was true for the month of August. The greatest difference between extreme years occurred in June at Summerland and in August at Ottawa.

A comparison of the total number of degree days required to mature McIntosh on East Malling I at Ottawa and at Summerland as shown in Table 21 indicates that except for four instances using a base of 50°F. and two instances using a base temperature of 46°F., the total number of degree days at Summerland exceeded that at Ottawa. The average difference in the total degree days between locations decreased as the base temperature was raised, but showed extensive variations even within base temperatures. For instance, in 1948 with a base temperature of 50°F., the difference in total degree days between Ottawa and Summerland was only two degree days. In 1940 this difference for the same base temperature was 708 degree days.

Table 21

Variety McIntosh on East Malling I

Comparison of the Total Number of Degree Days Required to Mature Apples at Summerland and at Ottawa by Base Temperature and Year

Base Temperature	1940 S.	1940 O.	1941 S.	1941 O.	1946 S.	1946 O.	1947 S.	1947 O.	1948 S.	1948 O.
50°F.	2407	1699	2180	1927	2069	1795	1963	2006	1929	1931
Difference	708		253		274		-43		-2	
46°F.	2989	2167	2784	2453	2672	2320	2561	2479	2480	2434
Difference	822		331		352		82		46	
42°F.	3579	2635	3396	2988	3280	2849	3165	2962	3040	2950
Difference	944		408		431		203		95	
34°F.	4763	3571	4620	4060	4496	3913	4373	3976	4160	3982
Difference	1192		560		583		397		178	

Base Temperature	1949 S.	1949 O.	1950 S.	1950 O.	1951 S.	1951 O.	1952 S.	1952 O.	Average Difference
50°F.	1991	2067	2236	1763	2140	1836	1981	2022	
Difference	-76		473		304		-41		243
46°F.	2558	2581	2803	2251	2692	2346	2535	2554	
Difference	-23		552		346		-19		286
42°F.	3141	3091	3374	2748	3244	2871	3102	3094	
Difference	50		626		373		8		348
34°F.	4309	4115	4518	3740	4348	3927	4238	4174	
Difference	194		778		421		64		485

Figure III Total Number of Degree Days by Years at Ottawa and Summerland, Base Temperature 50°F.

Figure IV Total Number of Degree Days by Years at Ottawa and Summerland, 34°F.

Table 22

Total Number of Days in Phenological Period For Years Indicated at Ottawa, Ontario, and Summerland, B.C., With the Deviation From the Average

	Ottawa, Ontario		Summerland, B. C.	
Year	No. of Days	Deviation From Average	No. of Days	Deviation From Average
1940	117	14	148	2
1941	134	3	153	7
1942	144	13		
1943	125	6		
1944	140	9		
1945	140	9		
1946	133	2	153	7
1947	138	7	151	5
1948	129	2	140	6
1949	118	13	147	1
1950	124	7	143	3
1951	132	1	138	8
1952	135	4	142	4
Average	131	7	146	5

Period begins 10 days before full bloom

On the average it took longer to mature the fruit at Summerland than at Ottawa when a comparison between the total number of days in the phenological period at Ottawa and the total number of days at Summerland is made. Individual years deviated from the average by as much as fourteen days at Ottawa while at Summerland the greatest deviation from the average was only eight days. The average deviation for thirteen years at Ottawa was seven days; that at Summerland for nine years only five days.

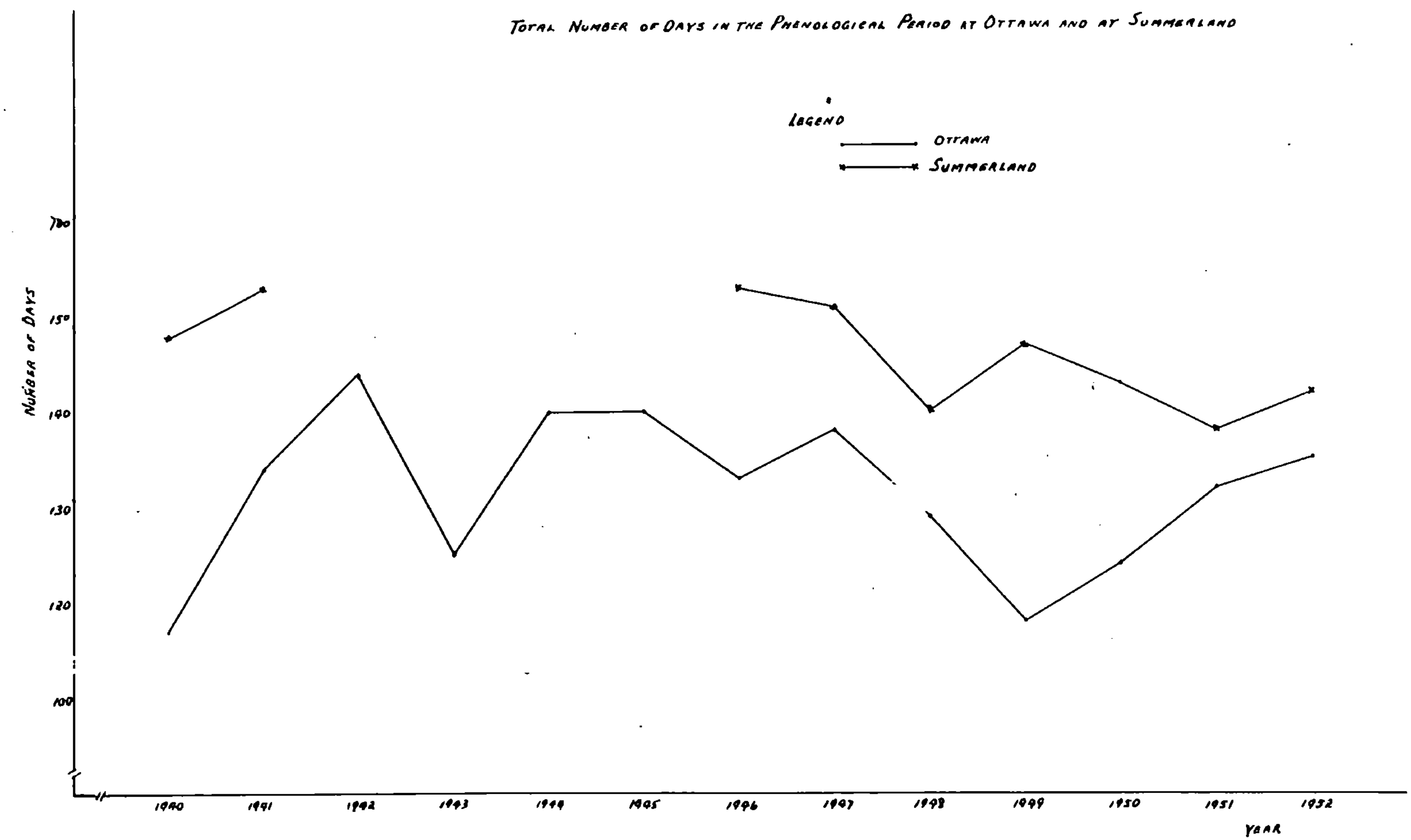

Figure V Total Number of Days in the Phenological Period at Ottawa and at Summerland

Table 23

Seedling Variety 0-277

Increase in Diameter of Apples on Spurs on Dates Indicated
Measured in Centimetres

Date	Spur 1A	Spur 1B	Spur 1C	Spur 2A	Spur 3A	Spur 4A	Spur 4B	Average	Average Growth Per Day
June 5	.22	.23	.20	.23	.18	.07	.12	.1785	.0893
June 8	.24	.20	.21	.21	.33	.25	.25	.2414	.0805
June 10	.18	.19	.27	.28	.10	.22	.21	.2071	.1036
June 12	.15	.13	.13	.14	.10	.16	.13	.1343	.0672
June 15	.32	.28	.27	.31	.29	.23	.26	.2800	.0933
June 17	.23	.14	.21	.25	.22	.19	.22	.2085	.1043
June 19	.20	.18	.28	.23	.20	.21	.24	.2200	.1100
June 22	.24	.28	.39	.26	.13	.16	.18	.2342	.0781
June 24	.07	.18	.10	.19	.07	.26	.32	.1700	.0850
June 26	.24	.10	.10	.20	.16	.16	.26	.1742	.0871
June 29	.17	.27	.23	.24	.17	.20	.18	.2085	.0695
July 1	.07	.14	.08	.14	.11	.10	.13	.1100	.0550
July 3	.06	.13	.15	.17	.13	.15	.15	.1343	.0672
July 6	.16	.16	.15	.14	.17	.18	.20	.1657	.0552
July 8	.07	.09	.11	.14	.09	.10	.05	.0929	.0465
July 10	.06	.08	.06	.15	.09	.10	.11	.0929	.0465
July 13	.10	.17	.20	.17	.15	.15	.15	.1557	.0519
July 15	.12	.09	.13	.15	.10	.14	.14	.1243	.0622
July 17	.09	.03	.02	.07	.07	.07	.07	.0600	.0300
July 20	.14	.19	.21	.19	.20	.23	.20	.1943	.0648
July 22	.00	.05	.00	.05	.04	.05	.06	.0357	.0179
July 24	.11	.14	.16	.12	.11	.10	.10	.1200	.0600

The investigation into the relation between increase in size and temperature using the Ottawa seedling O-277 as study medium and illustrated in Table 23 shows that the greatest increase in growth per day for seven apples took place from the time the measurements were started until about June 19th. The greatest average increase was eleven hundredths of a centimetre and was recorded on June 19th. From that date growth decreased slightly but fairly regularly until July 1st, from whence the growth fluctuated around the .05 centimetre mark for the remainder of the season.

Table 24

Average Growth Per Day and Average Temperature Per Day As Recorded on 0-277 at Ottawa in 1953 (Seven Apples)

Date	Average Growth Per Day (cm.)	Average Temperature For Same Period °F.
June 3		
June 5	.09	53.4
June 8	.08	64.1
June 10	.10	62.7
June 12	.07	57.7
June 15	.09	59.4
June 17	.10	65.1
June 19	.11	69.2
June 22	.08	76.2
June 24	.09	66.6
June 26	.09	63.0
June 29	.07	71.0
July 1	.06	68.1
July 3	.07	72.4
July 6	.06	64.5
July 8	.05	67.3
July 10	.05	58.9
July 13	.05	64.3
July 15	.06	68.5
July 17	.03	75.6
July 20	.06	79.3
July 22	.02	78.0
July 24	.06	75.5

An examination of the average growth per day for seven apples together with the average temperature for the same period of time as in Table 24 reveals no visible correlation. When the correlation was calculated for these data using a method outlined by Goulden (23) the coefficient of correlation was found to be -.405. The t test of significance gave a t value of 1.98 which is less than the required $t = 2.09$ for $N = 20$ at $P = .05$. Therefore the coefficient of correlation was not significant mathematically.

Table 25

Variety McIntosh on East Malling I

Date	Average Increase in Size of Apples Per Tree on Dates Indicated Measured in Centimetres				Average Growth Per Day
	Tree 1	Tree 2	Tree 3	Average	
June 24					
June 26	.24	.19	.24	.2233	.1117
June 29	.24	.29	.25	.2600	.0867
July 1	.13	.15	.14	.1400	.0700
July 3	.15	.19	.16	.1667	.0834
July 6	.19	.22	.20	.2033	.0678
July 8	.13	.17	.17	.1567	.0784
July 10	.14	.14	.12	.1333	.0667
July 13	.20	.24	.25	.2300	.0767
July 15	.13	.12	.12	.1233	.0617
July 17	.09	.10	.09	.0933	.0467
July 20	.16	.16	.17	.1633	.0544
July 22	.05	.06	.05	.0533	.0267
July 24	.13	.13	.12	.1267	.0634
July 27	.20	.22	.18	.2000	.0667
July 29	.07	.09	.09	.0833	.0417
July 31	.06	.07	.05	.0600	.0300
August 3	.07	.10	.09	.0867	.0289
August 5	.10	.13	.11	.1133	.0567
August 7	.11	.11	.07	.0967	.0484
August 10	.09	.14	.13	.1200	.0400
August 12	.13	.16	.23	.1733	.0867
August 14	.12	.10	.08	.1000	.0500
August 17	.10	.12	.12	.1133	.0378
August 19	.09	.07	.08	.0800	.0400
August 21	.07	.09	.07	.0767	.0384
August 24	.09	.10	.09	.0933	.0311
August 26	.06	.07	.07	.0667	.0334
August 28	.04	.07	.06	.0567	.0284
August 31	.05	.05	.03	.0433	.0144
September 2	.02	.02	.03	.0233	.0117
September 4	.02	.03	.04	.0333	.0167
September 7	.05	.09	.05	.0633	.0211
September 9	.05	.05	.07	.0567	.0284
September 11	.05	.05	.05	.0500	.0250
September 14	.05	.06	.07	.0600	.0200
September 16	.04	.05	.05	.0467	.0234
September 18	.02	.06	.03	.0367	.0184

Table 25 (Continued)

Date	Tree 1	Tree 2	Tree 3	Average	Average Growth Per Day
September 21	.06	.10	.08	.0800	.0267
September 23	.02	.03	.04	.0300	.0150

The above table shows irregular growth up to August 12, from whence the growth rate begins to decline. The daily increase in size of the apples was very small after August 28. The greatest growth was recorded on June 26.

Table 26

Average Apple Growth Per Day and Average Temperature Per Day As Recorded on McIntosh on East Malling I at Ottawa in 1953 (Three Trees, Twelve Apples)

Date		Average Growth Per Day (cm.)	Average Temperature For Same Period Degrees F.
June	24		—
June	26	.11	63
June	29	.09	71
July	1	.07	69
July	3	.08	73
July	6	.07	65
July	8	.08	68
July	10	.07	59
July	13	.08	65
July	15	.06	69
July	17	.05	76
July	20	.05	79
July	22	.03	78
July	24	.06	76
July	27	.07	63
July	29	.04	72
July	31	.03	75
August	3	.03	64
August	5	.06	60
August	7	.05	65
August	10	.04	67
August	12	.09	67

Table 26 (Continued)

Date	Average Growth Per Day (cm.)	Average Temperature For Same Period Degrees F.
August 14	.05	71
August 17	.04	68
August 19	.04	60
August 21	.04	57
August 24	.03	65
August 26	.03	72
August 28	.03	76
August 31	.01	82
September 2	.01	76
September 4	.02	77
September 7	.02	70
September 9	.03	61
September 11	.03	54
September 14	.02	60
September 16	.02	49
September 18	.02	52
September 21	.03	58
September 23	.02	52

A visual study of the growth and temperature data for the variety McIntosh on East Malling I shows very little correlation. This observation was verified when the correlation coefficient was calculated after Goulden (23), and found to be 0.032. The t test of significance gave a t value of 0.20 which is much less than the required $t = 2.03$ for $N = 37$ at $P = .05$. The coefficient of correlation was therefore not significant, indicating no relationship between average temperature and growth, at least for these data as presented here.

Discussion

There are obviously three important considerations in the science of phenology and its practical application with respect to the calculation of degree days, or the accumulation of heat units which will permit the prediction of harvest maturity of the fruit of the apple. These considerations are: the date at which the phenological period will begin, the base or unit temperatures to be employed and the maturity date of the fruit.

It would appear that in the prediction of harvest maturity of the fruits of perennial plants such as the apple, Malus pumila, (Mill.), less precision may be obtained than has been experienced with vegetable crops. In the annual plants, in which category vegetables are most generally placed, there is not the same degree of difficulty experienced in the selection of a date in which to begin the phenological period because the date of sowing or the date of emergence generally will suffice. In perennial crops this aspect of the problem is much more complicated. In these plants the two dominant phases of plant growth, vegetative and reproductive, are very closely related over a time interval which may begin during the spring or early summer of the year preceding the maturation and harvest of the fruit. Bud differentiation is an example of this sort of phenomenon. Further complications may arise due to the part played by climatic environment during the rest and dormancy periods, the latter usually limited by winter temperatures (19, 27, 36); the former may be initiated some time before the cooler temperatures begin and may be broken any time upon completion of the required accumulation of low temperatures. It is just possible that the phenological period should begin at some time during the year preceding that of the year of harvest. Undoubtedly this may account, at least in part, for the variability in total degree days found by using the date of first bloom as the beginning of the phenological period.

The minimum and optimum temperatures at which plants grow best is not easy to ascertain for according to Schilletter & Rickey (52), internal and imperceptable growth processes such as the development of floral parts and the thickening of cell walls may occur even during the dormancy period of the tree. Therefore certain internal changes are undoubtedly taking place at the very low temperatures which prohibit outward manifestations of growth. However, it is generally agreed (1, 43, 40, 30) that temperatures from 42°F. to 50°F. are most desirable for ordinary growth processes. When the extremes of this temperature range are used in calculating total degree days as in Table I(a) the same trend is observed in both base temperatures with less yearly variability in total degree days at the higher base temperature due, doubtless, to the fact that average temperatures are less variable above 50°F.

The third consideration in phenological studies is an accurate, reproducible indices of fruit maturity. In the apple no entirely satisfactory index of maturity has yet been devised (24). Harvesting dates are therefore somewhat haphazard, for in addition to the lack of a good maturity index, harvesting may be dictated by the demands of the consumer or by the size of the labor force at harvest. That is, an apple crop may be picked immature because of a good current demand for apples or on the other hand the harvest period may be extended beyond optimum maturity if few pickers are available for the work of harvesting. However, as the apples under investigation in this paper were harvested on a research farm only the factors of labor and maturity could contribute to the variability of the total degree days. In this study the maturity index as suggested by the Low Temperature Storage Research Section of the Division of Horticulture resulted in a variation of 458 degree days (base temperature, 42°F.) in the variety McIntosh between the years 1949 and 1950 while the ordinary harvest dates as recorded from the field resulted in a variation of only 400 degree days under the same conditions.

Since there cannot be an error of more than five days in apple maturity prediction dates or the fruit will have advanced to an unsatisfactory stage of maturity (24) and since the average number of degree days for September at Ottawa is sixteen for the years examined (Table I(b)) a variation of over 400 degree days would result in a variation of twenty-five days, considerably in excess of that which can be permitted in prediction work. Similarly, assuming each day in September has an average of sixteen degree days, the difference of 458 degree days indicates a possible difference of approximately twenty-eight days in the harvest dates between the years 1949 and 1950. But the employment of the average number of degree days for the four year period as a criterion of harvest date reduces the deviation of the harvest date in 1950 to fifteen days and that of the year 1949 to fourteen days (Table 2).

The total hours of sunshine as in Table 2 bears little relationship to the total number of degree days. The highest accumulation of 1070.3 hours of sunshine and the greatest number of degree days was listed in the year 1949. But in 1951 there were only 920.2 hours of sunshine with a total of 2945 degree days, only slightly higher than the 2902 degree days listed for the year 1948 which accumulated a high of 1006.8 hours of sunshine. A similar relationship or lack of relationship is shown between the total hours of sunshine and the number of days in the phenological period. The season was longest in 1951 with a total of 132 days and a relatively low accumulation of sunshine, while in 1949 the season consisted of 130 days but in this year there accumulated more hours of sunshine than in any of the other three years listed.

The number of days in the phenological period appears to be the best criterion to use in prediction work from the data in Table 2, which confirms the observations of Haller (24). The difference in the number of days between the extreme years of 1949 and 1950 was only six days and the number of days in the growing season for these years varied from the average by only three days. The greatest deviation from the average was in 1951 when the number of days in the season was five days more than the average. Using the number of days in the season may just come with the range of precision desired for prediction purposes according to the data in Table 2 but information gained in examining a longer time interval rather discourages this possibility (Please see Table 22).

From Table I(a) it would appear that since there is a general increase in the total number of degree days required to mature apples from early to late varieties, a simple classification may be drawn up using total degree days from blooming period to harvest as a criterion of maturity. Assuming a base temperature of 42°F. the classification could be arranged into three broad groups, one being from a total number of degree days of 2000 to that of 2700 degree days. Another group might be from 2700 to 3100 degree days and the last group could include those varieties ripening with an accumulation of over 3100 degree days. The extremes of the classification represent the very early varieties as Melba and the very late as Niobe. The intermediate classification of 2700 - 3100 degree days would include many of the better varieties grown at the Central Experimental Farm, that is, varieties as McIntosh, Linda, Edgar, Fameuse, Lawfam and Sandow. From the data obtained in this investigation it would appear that Fameuse matured after Lawfam. Actually, the Fameuse variety may mature a little earlier than Lawfam. However, for all practical purposes they may be said to mature at the same time as there is considerable fluctuation from year to year between varieties and within varieties.

The success or failure of a degree day classification as suggested above would depend very largely upon the accuracy with which the phenological period can be determined.

The data from the Record Section with respect to dates of harvest were used in all calculations subsequent to Table 2, since as was noted earlier in this discussion, the data from the Record Section were as good as or better than those from the Low Temperature Storage Research Section. The fact that data from the Record Section were more complete as well as more accessible also influenced that decision. This then effectively takes care of the last consideration in phenological investigations, that of fruit maturity date mentioned earlier and leaves the way clear for a study of the remaining two aspects of phenological applications; namely, the initiation of the period and the temperature bases to be employed. These should be arranged in such a manner that greater precision in yearly total degree days is achieved.

An examination of the phenological data for the years 1948-1952 at Ottawa in Table 4 indicates that the years 1950 and 1952 are extreme years of low and high total degree days respectively. This makes these years ideally suited for use as critical years upon which to try various combinations of temperatures through the growth period as suggested by Lilleland (31), Tukey (59) and Ellenwood (20). It is not unreasonable to conclude that using a single base temperature throughout the growing period may introduce a source of error as the tree may require different optimum temperatures for optimum growth during the various phases relating to the maturation of fruit.

In Table 3 several combinations of base temperatures for each month of the growing season as well as a further refinement, namely, that of starting the phenological period from full bloom rather than from first bloom, did not decrease the variation in total degree days appreciably. The Series known as F is equally as good as Series G and both are better than all the other combinations tried. Actually the only temperature base in Series F that may be said to be different from any in Series G was 42°F. in June. Since the average temperature in July and August at Ottawa rarely goes below 50°F., any base temperature selected below that would result in a constant differing only in magnitude with the base temperature selected.

That there is little to choose between the combination of base temperatures, Series F and that of Series G is further demonstrated in Table 4 where the total degree days are listed for the years 1948-1952 under the base temperatures of 34°F., 38°F., 42°F., 50°F. and Series F. Here the deviation from the average is exactly the same for Series F and the base temperature of 50°F. (Series G). Extreme variation in the total number of degree days is noted from year to year although there is a marked increase in precision when the deviation of each year's total is taken from the five year average. The precision gained by the use of the date of full bloom, rather than that of first bloom as the Period starting point is doubtful. There was a difference of 400 degree days between the total degree days in the years 1949 and 1950 in Table I(a) with the use of a 42°F. base temperature and the date of first bloom; while using full bloom this difference under the same conditions was 415 degree days. In a similar manner, for the same conditions except that a base temperature of 50°F. was used, the difference in total degree days changed from 359 using first bloom to 375 using full bloom.

When the phenological period is extended to include the period ten days before full bloom there is a marked increase in precision. For instance, with a base temperature of 34°F. and starting from full bloom in the year 1950, there was a deviation from the average of 319 degree days; but when the period was extended ten days the deviation from the average was only 248 degree days. Similar increases in precision are observable with the other base temperatures employed. It would appear, therefore, that considerable precision may be gained by starting the phenological period ten days before full bloom rather than at full bloom or even at first bloom. However, this still does not bring the total degree day variability to within the desirable eighty degree days (based on the average sixteen degree days per day found in Table I(b)).

In addition there are so many other aspects to phenological problems that should be examined such as: temperature (4, 44, 55, 21), light (38), the employment of the multiple of mean temperature and day length (1, 42), moisture and growth (57, 67, 54), multiple correlation of pertinent fa ctors (15, 18, 53), probability predictions based on past performances (13), night temperature (62, 48), nutrition (56) and plant physiological aspects (47), that it seems prudent to examine the possibilities, however briefly, of a few of these at least, and with the understanding that these factors will in no way detract from the main purpose of the investigation which concerns average temperature and the Heat Unit Theory in the prediction of apple maturity.

Obviously since the employment of the average temperature in calculating degree days apparently does not result in the necessary precision for prediction purposes from the data thus far examined it becomes imperative to try other kinds of temperature in the calculations, for instance, the minimum temperature. The compilation of the number of 'X' units as in Table 6 using the minimum temperature with a base of 42°F. and data for the years 1948-1952 reveal that further precision may be gained by using the minimum temperature rather than the average temperature. Converting the 'X' units to a daily basis similar to that employed in Table I(b) for the growth period in September it is found that the average 'X' units per day is approximately 8.5 'X' units. Multiplied by five this comes to approximately 43 'X' units. Except in one instance the deviations from the average in Table 6 are much larger than that figure indicating that substituting the minimum temperature for the average temperature will not give the required precision for prediction purposes, with respect to the data gathered in this investigation.

Another alternative to the use of average temperature in calculating heat units may be night temperature for it is considered to be the limiting factor in plant growth (62). When the night temperature calculated after a method suggested by Went (62) is substituted for the average temperature in calculating heat units the resulting units may be designated as being 'Night' units to differentiate them from the degree days found in the ordinary way. That is, the same method is employed in accumulating 'Night' units as in the standard degree procedure, except that instead of average temperature data, night temperature averages are used. In Table 7 a comparison is made between 'Night' units using a base of 50°F. and degree days using the same base temperature, data being collected for the years 1948-1952 at Ottawa. No direct comparison can be made between the deviation of 'Night' units from the average and a similar deviation for the degree days as the components making up the deviations are not the same. However, the number of 'Night' units per night for that part of the phenological period extending in the month of September works out to approximately six units. As before this number may be multiplied by five to ascertain the permissable total number of 'Night' units for maturity predictions as indicated by Haller (24). Therefore the desirable deviation should not be more than thirty 'Night' units. An examination of the material in Table 7 shows that in only one year, 1948, does the deviation come within the thirty 'Night' unit limit. Of course as already noted the deviation limit for the degree day method is eighty degree days. There does not appear to be any advantage in the employment of night temperatures as a substitute for the average daily temperature in calculating heat units.

Greater use of calculated night temperatures can be made when it is subtracted from the average temperature. The resulting statistic may be considered as a crude measure of the fluctuation between day and night temperatures but can be more accurately expressed as the range between maximum and minimum temperatures. The accumulated 'Y' units calculated in this way are not heat units as the term has been applied throughout this paper. No base or unit temperatures are involved in the calculations. The method is simply a mathematical accumulation of a range of temperatures. In Table 8 the calculated average night temperature is subtracted from the daily average and these subtractions accumulated for the phenological period as in the standard degree day method. This procedure may be simply expressed as a summation of one quarter of the daily maximum minus the daily minimum temperatures. The accumulated totals tabulated in this way are listed in Table 8. The greatest deviation from the average was fifty-six 'Y' units in the year 1950. The average number of 'Y' units per day during the growth period in the month of September for the five years listed is 5.3 and for the last five days of the same phenological period it is 5.0 'Y' units per day. If the precision of the prediction must be within five days of the actual harvest date then only a total of twenty-five 'Y' units is permissable. That is, the deviation from the average cannot be greater than twenty-five 'Y' units. The data in Table 8 are within the required limits three out of five years. The precision gained in the utilization of the phenological data in this way cannot be considered as adequate, but it is an improvement over the other methods examined in this paper. It also gives rise to the validity of the Heat Unit Theory, with its accompanying confusion of base temperatures in the prediction of apple maturity when the phenological period is of comparatively short duration.

It should be emphasized here that the use of average temperatures and the subsequent compilation of degree days, as well as using a minimum temperature with the resulting 'X' units and the night temperatures as 'Night' units are all based on the Heat Unit Theory and are an expression of various forms of that Theory. The use of the range of temperature values with its expression in 'Y' units as outlined above is definitely a departure from the Heat Unit Theory.

Yet another aspect of phenological investigations is that of the part played by the sun. Sunshine or hours of sunshine as such appears to bear but little relationship to the length of the phenological period. Table 9 shows that in 1951 there was a total of 937.0 hours of sunshine in a growing period of 132 days, while in 1949 there were 1075.6 hours of sunshine with only 118 days in the phenological period. The apparent relationship thus far indicated was shattered in 1952 when the growing season contained a total of 1095.4 hours of sunshine but required 135 days to bring the apples to harvest maturity. Similar anomalies occurred in other years. The month of May in 1950 had fewer hours of sunshine than had May of any other year listed. But this did not extend the growth period compared to years when more hours of sunshine were recorded in May as might be expected if sunny weather around blossom time affected the length of growing season of the apple. It would appear that sunny periods around blossoming time do not have a consistent effect on the length of the phenological period.

A substitution of solar radiation for sunshine data would not seem to be justified from the work done in this investigation. Solar radiation units are available for only the three years 1950-1952 as interest in this approach to the growth problem is of relatively recent origin. The data in Table 11 indicates that an accumulation of solar radiation units would not be useful in predicting harvest maturities of the apple. Too much variability in the total number of Langleys exists from year to year. There does appear to be some relationship or at least a similar trend, between the number of days in the phenological period, the total degree days, total hours of sunshine and total solar radiation units for the years 1950-1952. Unfortunately, there are no solar radiation figures available for the growing periods in 1948 and 1949. One can only conjecture as to how the radiation for these years would fit in with the trend established in the years 1950-1952. Certainly the other factors as the total degree days, hours of sunshine, and number of days in the growth period for the years 1948 and 1949 tend to destroy any relationship between each other once the data from these years are examined.

The apparent lack of significance attached to sunlight and solar radiation expressed above should not be construed as meaning these factors have no effect on plant growth. The effect of light and duration of light are widely known and recognized as being extremely important to the growth processes of plants (38, 42, 46, 53). For instance, very recent work by Liverman and Bonner (32) suggest that visible red light activates a particular protein in plant tissue in order that it may combine with the essential plant hormone, auxin, to produce growth. The auxin and protein are combined with the help of light during the day and the union is broken down during the night. Thus the role of light and darkness in plant growth cannot be emphasized too much. However, the data on sunlight and solar radiation are compiled in this investigation in a manner purported to show that an accumulation of these units alone are of doubtful value in prediction work. It may be that a correlation of many factors as light, moisture, temperature, wind velocity, etc., in a manner similar to that suggested by Clements (18) and Smith (53) is a more efficient method of attacking the problem of plant growth than the study of only one such factor alone.

The brief discussion of the different temperature statistics, sunshine and solar radiation units as outlined above is far from complete but serves to illustrate their importance as individual factors in maturity prediction studies. However, our main interest in this paper is the statistic of average temperature and its relation to growth in the plant. So far the examination has been directed to four and five years' data. It becomes necessary to see whether data collected over a longer period of time will introduce any new aspects of the problem.

Degree days calculated for the years 1940-1952 at

Ottawa as in Table 13 reveal the same fluctuations that were observed in the data from only five years. In other words there is considerable variability in the total degree days for all base temperatures and all years. Contrary to what may have been expected there is no increase in precision gained by taking the deviation from a thirteen year average rather than a deviation from a five year average. Actually the reverse is true, for upon examining the deviations from the thirteen year average for the base of 50°F. as in Table 14 and comparing it with the information given in Table 5 it may be observed that the range of deviation in Table 5 varies from plus 145 to minus 159 degree days; while in Table 14 the range varies from plus 384 to minus 217. That is, the inclusion of more years into the survey merely introduced abnormal years as 1940 and 1944 which were very much out of line with other years. However, it does stress the necessity for the inclusion of as many years' data as possible in order that a more complete picture of the problem may be obtained. Obviously no one base temperature (at least of those base temperatures used in this investigation) appears to give a consistent increase in precision over the other. But the base temperature of 42°F. occupies a medial position. Years such as 1941 and 1948 appear to be "average" years and all base temperatures work reasonably well in those years. That is, precision is gained in individual years rather than for individual base temperatures.

It is interesting to note that the selection of the actual base temperatures for summer months is relatively unimportant as long as it is 50°F. or lower. Table 15 shows that for the summer months of June, July and August there is no change in the range of extreme years for all base temperatures. But the selection of base temperatures for the months of May and September may be much more important as it is in these months when the temperature fluctuates rapidly. Therefore, it becomes imperative that the selction of base temperatures for those months be carefully chosen with due regard to minimum or optimum growth temperatures for a specific location.

Some additional rather interesting information may be gathered from Table 16. Here the total degree averages are listed for five years' data and for thirteen years' data at Ottawa, using four different base temperatures. There is a remarkably close agreement between the two averages for each base temperature leading to the conclusion that if one is interested only in an average for data on phenology, a five year time interval may suffice. However, as earlier observed in this paper, if it is desirable to ascertain the range of yearly variability then it may be necessary to include ten or more years' climatological and growth data in the investigation.

The inclusion of data from Summerland, B. C., serves to illustrate the effects of geographical position on phenological investigations. For instance, Ottawa is situated at a latitude of 45°24'; Summerland is located at a latitude of 49°34'. A comparison between Table 17 and Table I shows that in general, Summerland has warmer average temperatures than are experienced at Ottawa. The grand average for the growing season at Summerland is 63.8°F. while at Ottawa it is 62.7°F. The warmer temperatures at Summerland resulted in a longer phenological period with a subsequent larger total number of degree days than was experienced at Ottawa. Comparable figures are not available for Summerland and Ottawa for the thirteen year period of 1940-1952 since records at Summerland were not complete for the war years of 1942-1945. However, the data for nine years as listed in Table 18 shows similar yearly variations to that of data recorded at Ottawa. The deviations from the average in Table 19 show that at Summerland there is the same tendency for "average" years as at Ottawa. But the years are not necessarily the same and indeed are not in these data. At Ottawa the "average" years were in 1941 and 1948; while at Summerland the "average" years were 1946 and 1951.

A similar conclusion with regard to base temperatures was observed at Summerland as at Ottawa. That is, no one base temperature appeared to be very much better than the others with the possible exception of the Series L combination of temperatures. This series, which consists of the employment of a base temperature of 50°F. for May, 42°F. in June, 34°F. in July and August and 46°F. in September, appeared to be best suited to the conditions at Summerland. A base temperature of 42°F. occupied a medial position and the base temperature of 34°F. was least satisfactory at Summerland.

The same sort of information is obtained at Summerland with regard to the range in total degree days between extreme years (Table 20) as was observed at Ottawa. That is, the months of June, July and August are not critical months in the selection of base temperatures but careful consideration should be given to base temperatures selected for the months of May and September.

From Table 21 it would appear that with very few exceptions more degree days were required to mature fruit at Summerland than at Ottawa, despite the fact that temperatures were generally warmer at Summerland than at Ottawa. However, this is in accordance with the observations made by others (19, 25, 31, 60), that is, under certain conditions of higher temperature, maturation of fruits and vegetables may be actually retarded. It may be that the range of fluctuation between night and day temperatures at Summerland is greater than at Ottawa and this greater fluctuation has an adverse effect on growth and ripening. In addition, geographical position and its effect in length of day has not been explored fully in this investigation. But whatever the reason, there is a definite increase in the total degree days accumulated at Summerland over those accumulated at Ottawa and this is reflected in the length of the growth period as is shown in Table 22. The average number of days to mature fruit at Ottawa over a period of thirteen years was 131 while at Summerland the average for a nine year period was 146 days. It therefore takes fruit an average of fifteen days longer to mature at Summerland than at Ottawa. Under the climatological conditions existing at Ottawa there is considerably more yearly fluctuation in the length of the phenological period than at Summerland. Phenological periods in individual years at Ottawa may deviate as much as 14 days but at Summerland the greatest deviation of the years listed in this investigation is only 8 days. The data from Summerland are not quite comparable to those of Ottawa because of the missing years, 1942-1945. However, it would appear that using the toal number of days as a criterion for prediction purposes would be more satisfactory at Summerland than at Ottawa. Further, and with respect to the data gathered in the present investigation it is doubtful whether, as has been suggested by Haller (25) the number of days in the phenological period could serve as a method for predicting the harvest dates of apples.

The work thus far examined has indicated that average daily temperature may not be the correct factor to use in the prediction of harvest dates of apples. Actual measurements of growth related to average temperature were not available for the years observed. Information of this kind was supplied using the Ottawa seedling 277 and the McIntosh variety on East Malling I.

From the measurements taken on seven individual apples on the O-277 seedling and listed with average temperatures as in Table 24 it is not possible to observe the cyclic growth that has been noted in the literature (30, 31, 59). Nor does there appear to be much correlation between average temperature and average growth. For instance, during the period June 3 to June 5 the average growth per day was 0.0893 cm. with an average temperature of 53.4°F. During the period June 5 - 8 the average growth was 0.0805 cm. with an average temperature of 64.1°F. The growth is about the same although the average temperatures are quite different. The argument of cyclic growth with different optimum temperatures would not account for this phenomenon as the temperature differences were recorded in what could only be one phase of the cyclic growth. A similar sort of thing occurred from July 6 to July 10. However, there does appear to be a fairly rapid increase in the rate of growth up to June 19 and then a slightly lower rate of growth until July 1 whence the growth hovered about the .05 cm. mark until the end of the season. The first two periods would agree with those observations in the literature, but instead of the last phase increasing in rate of growth this investigation found the rate to decrease.

Cyclic growth may be present in the data as found in this investigation but it appears difficult to associate these periods with any optimum average temperature.

It is interesting to note that the correlation coefficient calculated for the data in Table 24 is negative. That would lead to the conclusion that growth decreases with increasing temperature. Unfortunately, with an early variety of apple, cessation of growth or fruit maturation coincides with the arrival of warmer summer temperatures. It is therefore difficult to disassociate the effects of temperature from the natural processes of maturation. The coefficient of correlation calculated here is -0.405 which proves to be insignificant according to the t test as in Goulden (23). However, it is very nearly significant and it may be that if more data had been available the results would have been significant.

Since the data on the early seedling variety 0-277 may be influenced by factors other than climatological, one might expect the data on growth and temperature as collected from the McIntosh variety to be much more satisfactory. That is, observations are made over a longer period of time embracing a greater range of temperatures. However, on examination the McIntosh data as recorded in Tables 25 and 26 are even more difficult to interpret than those observed with the 0-277 seedling. The average rate of growth in the McIntosh variety was maintained in excess of .06 cm. up to August 12, from whence the rate of growth declined but never actually stopped. Rather steady growth took place from June 26 to July 15, but the average temperature varied from 59°F. to 73°F.

Evidence of cyclic growth is not readily observable in the McIntosh apple. But one might say that there is a period of rapid growth from bloom to July 15, then a period of irregular growth follows ending about August 15 and finally there is a period during which very little growth takes place and which does not end until the apple is removed from the tree. There is no reason to suspect a flush of growth toward the end of the season. But in this respect it would be well to remember that during the summer and autumn of the year 1953, moisture was definitely a limiting factor in the experimental orchard. A good rain which fell from August 10 to August 12 is no doubt responsible for the increase in rate of growth shown for that period of time.

The correlation coefficient for the data recorded on the McIntosh variety was 0.032 indicating no relation between average growth and average temperature. One should have a correlation coefficient of at least 0.8 before one could state positively that for a given average temperature a specific rate of growth will be obtained.

From the data in this investigation it would appear that the growth or maturation of the apple fruit is not related to average temperature but it must not be assumed that these results are conclusive. Further work should be done, particularly in regard to the actual measurement of apple growth.

Summary

The application of the Heat Unit Theory in the forecasting of harvest dates of vegetables in commercial plantings throughout Canada prompted an investigation to study the possible use of the Theory in the prediction of harvest maturity in apples at the Central Experimental Farm at Ottawa.

The primary purpose of the investigation was the accurate prediction of harvest maturity of the apples through the medium of an accumulation of heat units, commonly known as degree days, for each of the years studied. Only the climatological factors of temperature, sunshine and solar radiation were considered in the study and of these temperature was the factor most critically analyzed.

In the preliminary inquiry four years phenological data for the period 1948-1951 were arranged in a manner calculated to show the variability in total degree days existing between years and between apple varieties. Several of the more important varieties grown at the Central Experimental Farm such as Melba, Hume, McIntosh and Niobe were selected as study mediums. The beginning of the phenological period of each variety was taken as being that of the date of first bloom of the variety. Maturity indices were taken from data gathered by the Record Section and from those of the Low Temperature Storage Research Section. It was found that harvest dates as recorded in the field were as good as, if not better than, optimum harvest dates selected through storage research.

No relation could be observed between the accumulated hours of sunshine and total degree days or the length of the phenological period.

In the next phase of the work, phenological data from the year 1952 were added to the four years examined previously. Only one variety, that of McIntosh on the root

East Malling I was used as the study medium in this phase and throughout the rest of the investigation. Refinements in the phenological period were made by starting the period at full bloom and at ten days before full bloom of the McIntosh variety. Beginning the period ten days before full bloom achieved maximum precision in the total degree days for the five years examined.

Base temperatures of 34°F., 42°F., 46°F., 50°F., constantly maintained throughout the period were tested, as well as certain combinations of these base temperatures. No one base temperature or combination of temperatures appeared more efficient than any other, although the base temperature of 42°F. maintained throughout the period occupied a medial position.

The possible substitution of temperature statistics other than the average in the calculation of heat units was explored. It was found that the substitution of either the minimum temperature or the night temperature for average temperature did not materially aid in the precision of a prediction based on heat units. However, an accumulation of a range of temperatures, which bears no relation to the Heat Unit Theory, being a departure from the assumption of base temperatures, gave the most consistent results of all methods attempted.

The inclusion of the climatological data on sunshine and solar radiation from the year 1952 into the investigation did not appear to improve the relationship between the accumulated hours of sunshine or the accumulated solar radiation units and the total degree days or the length of the phenological period.

The time interval at Ottawa in the last phase of the investigation was lengthened to include data from the thirteen years 1940-1952. In addition, nine years data from the Summerland Experiment Station were included in order that the effect of geographical position could be noted. Irrespective of base temperature, the deviation in total degree days for each year from the average was not consistently low enough for prediction purposes at either Station. Precision was acquired within individual years rather than for individual base temperatures. That is, "average" years were noted during which all base temperatures resulted in good precision. These "average" years were not necessarily common to both Stations.

The critical months for the establishment of a base temperature were found to be May and September. The selection of base temperatures for the months of June, July and August was relatively unimportant to the prediction as long as the base temperature selected was below 50°F.

The average daily temperature at Summerland was somewhat warmer than that at Ottawa; yet more degree days were required to mature the apple fruit at Summerland than at Ottawa.

At Ottawa there was little difference in the average total degree days computed from five years' data and the average calculated from thirteen years' data.

In a study designed to note the effect of average temperature on the rate of increase in size of the apple fruit it was found that for the early Ottawa seedling 277 and for the McIntosh variety very little correlation could be established between growth of the fruit and average temperature.

The total number of days contained within the phenological period was found to give more precise predictions than the employment of the Heat Unit Theory based on an accumulation of degree days.

Conclusion

A study of the practical application of phenology in predicting harvest dates of the apple through the medium of the Heat Unit Theory indicates that:

Starting the phenological period ten days before full bloom results in greater precision than when it is begun at full bloom or even at first bloom.

No one base temperature or combination of base temperatures appears to be better than any other. Critical months for the establishment of base temperatures are May and September as long as these temperatures are 50°F. or lower.

Precision of harvest predictions is acquired within individual years rather than for particular base temperatures. That is, "average" years occur during which all base temperatures result in good precision. This is true for both Ottawa, Ontario, and Summerland, B. C., although the years are not necessarily the same for these Stations.

Ordinary picking or harvest dates when used as a point at which to end the phenological period are as good as optimum dates procured through maturity indices studies in cold storage.

The average daily temperature at Summerland is somewhat warmer than at Ottawa, yet more degree days are required to mature the apple fruit at Summerland than at Ottawa.

Very little relation can be observed between the accumulated hours of sunshine and the total number of degree days or the length of the phenological period.

In this investigation no relationship can be shown between average temperature and average growth in either the Ottawa seedling 277 or the McIntosh variety on East Malling I root.

An accumulation of a range of temperatures gives more consistent results in harvest predictions than does an accumulation of heat units based on minimum, average or night temperature statistics.

The total number of days contained within the phenological period gives a more precise prediction than an accumulation of degree days, particularly at Summerland, B. C.

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