Climatic Adaptation of Fruit and Nut Crops

By J. R. Magness and H. P. Traub

THIS ARTICLE covers the climatic requirements and the effects of weather for (1) the subtropical fruits—citrus (p. 402), date (p. 404), and fig (p. 406); (2) the deciduous tree fruits (p. 406), including apples, pears, peaches, plums, and apricots; (3) grapes (p. 411); (4) the small fruits—strawberries (p. 412), and raspberries, blackberries, dewberries, currants, gooseberries, cranberries, and blueberries (beginning on p. 413); and, finally, (5) the nut crops (beginning on p. 414), including pecans, walnuts, almonds, filberts, and chestnuts.

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The distribution of fruit and nut crops in the world is determined almost entirely by climatic factors, the most important of which is temperature. These crops can be classed in three groups, based on their climatic requirements.

1. The strictly tropical fruits and nuts. This group not only fails to withstand freezing temperatures but may be injured by prolonged exposure to temperatures many degrees above freezing. Thus, the banana is reported to be well adapted only to regions where the temperature never goes below 50° F. The most important fruit crops in the group are bananas, breadfruit, mangoes, papayas, durians, annonas, sapotes, and mangosteens; the most important nut crops are coconuts, Brazil nuts, and cashews. Coffee and cacao, while not horticulturally considered fruits or nuts, are in the same group of plants from the standpoint of climatic requirements. Pineapples are adapted to only slightly cooler conditions than the other fruits listed. Space does not permit a more detailed discussion of the climatic requirement of these crops. None is grown extensively in continental United States. There is a limited production of pineapples and mangoes in Florida.

2. The subtropical fruits. Plants in this group will endure temperatures slightly below freezing without injury. Included in the group are oranges, grapefruit, lemons, limes, kumquats, cherimoyas, avocados, litchis, jaboticabas, olives, figs, and dates. These fruits will withstand more cold than those in the first group and apparently require some cool weather for proper development—they do not grow well in strictly tropical climates. The trees bearing these fruits, like those of the tropical group, are characteristically evergreen, and none of them are sufficiently hardy to withstand severe freezing. The olive is probably the hardiest, and varieties of olive grown for their fruit are injured by temperatures below 10° F.

3. The hardy fruits. These are produced on deciduous trees or bushes that during the dormant season go into a rest period, which it takes a period of cold weather to break. Most of them, while dormant, will stand temperatures far below freezing. Because of their requirement of a period of cold in order to develop normally, they are unadapted to tropical climates. The principal fruits of the group include apples, peaches, pears, cherries, plums, and prunes, grapes, apricots, blackberries, and raspberries. Strawberries are evergreen plants, only semihardy, which survive in cold latitudes because of their low growth habit and the protection of snow and other cover.

Subtropical Fruits

The climatic belt where subtropical fruits are produced, as the name indicates, is between the true Tropics, where frost never occurs, and the belt in the Temperate Zone where normally the temperature often falls below freezing and stays below for a considerable part of the winter season. This intermediate belt is not confined within exact latitude limits; its boundaries vary owing to other factors that influence climate, such as land elevation, ocean currents, large inland bodies of water, and the protection of mountain ranges. Within this belt are two general types of climate—humid and semiarid. In this brief summary the citrus fruits, the date, and the fig are considered as typical examples of subtropical fruits.
The citrus fruits, including the familiar sweet orange, grapefruit, lemon, and lime, are cultivated in both humid and semiarid regions and are interesting from the standpoint of climatic requirements for successful commercial culture.

Temperature Requirements

The reports of Girton (25), Fawcett (21), and Camp, Mowry, and Loucks (10) on temperature requirements of citrus, based mainly on seed-germination or seedling-emergence experiments, indicate that while the so-called zero growth temperature, or vital temperature, for citrus—the lowest temperature at which growth can take place at all—is in the neighborhood of 55° F., and the maximum temperature at which growth can take place is approximately 100°, the optimum for growth ranges between about 73° and 91° for sweet orange, and 79° and 91° for sour orange. On the basis of these results, Webber (62) has pointed out that 55° may be considered as the correct zero growth temperature for citrus, with slight differences for individuals, types, species, varieties, and varying physical conditions. Webber has reported average annual indices of heat units available to citrus during the growing period from March to November under California conditions, based on the sum of all the mean daily temperature readings above 55°. He points out that the Washington Navel orange reaches its best development in sections with indices from March to November of 3,000 to 3,500 degree-days, and is less satisfactory in sections with indices as low as 2,500 or as high as 5,000.

Observations by Perry and Frost over a long period in California, as reported by Webber (62), indicate that the higher the mean monthly temperatures in February and March, the earlier the midblooming period appears in any year. Apparently the actual temperatures in February and March control flowering to a considerable extent, and the annual variations in this respect will indirectly influence, at least in part, the time of ripening.

Citrus fruit types vary widely with reference to the degree of low temperature they withstand, and this largely determines where they can be most profitably grown. The hardiest of the larger types, the Satsuma orange, can withstand 18° F. without defoliation when in a dormant condition, and thus it can be grown in the northern part of the subtropical belt. On the other hand, limes may be injured at 28° and are consequently confined to the warmest locations. In between are the lemon, sweet orange, grapefruit, and tangerine. In the thoroughly dormant condition the commonly accepted minima for these types are about as follows: Lemon, 26° to 27°; sweet orange and grapefruit, 23° to 24°; and tangerine, 22° to 23°. There is variation within the type, however, as pointed out by Webber et al. (63) and Rhoads and DeBusk (53). Wright and Taylor (67) have established the average freezing point for fruits of the sweet orange, Satsuma orange, and Temple orange at 28.03°, and according to Young (68), the freezing point of ripe Washington Navel oranges is from 27° to 28°; that for half ripe, from 28° to 29°; and that for green, from 28.5° to 29.5°.

These minima must be considered in relation to other factors, particularly the condition and relative dormancy of the trees. Trees in good health, well fertilized, and free from disease and insect damage show greater resistance to low temperature than do those that are devitalized by undernourishment, disease, or insect infestation. The degree of damage is also dependent on (1) the location of the trees with reference to air drainage, (2) the minimum temperature, (3) the duration of the low-temperature period, (4) the modifying effects of winds, and (5) the conditions under which the trees thaw out and the after care (9, 53, 63, 68).

Since critical low temperatures occur in most areas of the United States where citrus is grown commercially, grove heating is employed during cold periods when it is economically feasible. The method of warming the atmosphere by lighting a large number of small fires throughout the grove area is generally used as a means of frost prevention in the Southwest, where it has been put on a systematic basis (68). The temperature is thus made to rise 8° F. or more, which is usually sufficient to prevent damage to trees and fruit. Frost prevention by heating is most efficient when the air near the ground is calm. When frosts are accompanied by winds, heat from the fires is continually carried away, and the fuel consumption...
and consequently the cost are relatively greater. In the Southeast, although frosts are often accompanied by high winds, grove heating is gradually increasing. Trees under 6 years old are more susceptible to low-temperature damage than older ones and are usually mounded with earth well above the bud union during the winter season. If the top is frozen, a new one may be grown from the uninjured scion portion above the bud union. Attempts have been made to select varieties that are relatively hardy. The grapefruit variety Marsh may be cited as an illustration. It is definitely less susceptible to low temperature damage than Duncan and other varieties. Crosses of various citrus types that have been made in attempts to secure greater hardiness in the progeny are described in detail in the 1937 Yearbook of Agriculture.

Another effect of temperature on citrus remains to be noted. In tropical climates the rind of citrus fruits in a great measure retains the green or yellowish-green color even at maturity. By contrast, the rind of citrus in subtropical climates takes on a deep yellow or orange color, depending on the type. Within the subtropical belt a similar though less marked difference in rind color is noted between the warmer and colder areas.

**Moisture Supply**

It is estimated that 35 inches of water a year is needed for the production of normal citrus crops. In a humid climate like that of Florida, as pointed out by Hume (32), there is usually sufficient moisture from rainfall during the growing season from February to November. During the winter season, however, the rainfall is relatively scarce, and the application of irrigation water would be beneficial from “February when trees are in bloom, through June.” According to Friend (24) the annual rainfall is approximately 23 inches in the semiarid lower Rio Grande Valley, and this deficit must be made up by the application of irrigation water. Fortunately, most of the rainfall occurs during the summer season, when it is most needed. In the semiarid Southwest, citrus trees require irrigation water, in addition to the rainfall. The amount to be supplied depends upon the amount of rainfall, the character of the soil, and the age and type of the trees (14, 55). Vaile (59) has shown that in general less water is used and the intervals between irrigations are longer in the cooler coastal districts than in the interior.

Under California conditions, according to Webber (62), there is apparently no correlation between rainfall and the date of flowering of citrus trees.

**Effects of Humidity and Winds**

The work of Hodgson (31) indicates that hot, dry winds are the chief cause of June drop of immature Washington Navel orange fruits in southern California. Wager (61) reports similar results from South Africa. In the interior valleys of the arid Southwest, abscission of immature fruits, according to Coit and Hodgson (15), is due to the daily water deficits in the young developing fruits resulting from high temperature and low relative humidity.

According to Webber (62), under California conditions, where there is wide variation in average daily relative humidity—coastal sections 63 to 72 percent, Interior Valley section 50 to 52 percent, and Salton Basin section 37 to 39 percent—“fruits tend to be smoother, thinner skinned, and in general more juicy and richer in quality when grown in an atmosphere of fairly high relative humidity.” He also points out that the shape, skin texture, relative development of navel, and depth of color may be affected by the climatic complex, of which the atmospheric humidity is apparently the dominating factor.

Coit and Hodgson (15) have shown that within limits the relative humidity can be raised considerably over that of the desert by windbreaks, the trees themselves, and cover crops. Reed and Bartholomew (52) have summarized the literature on the effects of desiccating winds on citrus trees and reported their own field observations and experiments. They conclude that desiccating winds cause defoliation, death of twigs, and loss of fruit owing to excessive transpiration during windstorms as well as the mechanical force of the wind.
Light Requirements

According to Palmer (45), the earlier ripening of oranges in the northern end of the Central Valley of California, as contrasted with that in the citrus districts 400 miles farther south, is in a great measure due to the longer day during the growing season, although the protection from cool night winds afforded by the surrounding mountains is partly responsible.

After weighing the available evidence from various citrus-producing regions, using as his measure the time of maturity, which is influenced to some extent by the time of flowering, Webber (62) concludes that length of day probably has no effect or only a minor one in causing flowering.

Harding et al. (28) have reported significantly higher ascorbic acid (vitamin C) values in the juice of oranges picked from outside branches that were well exposed to sunlight as contrasted with fruit from inside, shaded branches.

Effect of Climate on Citrus Diseases and Pests

As an example of the close relationship between climate and the prevalence of diseases, the work of Peltier and Frederich (46) with citrus scab may be cited. They found that "any environmental factor or factors inducing a slight spring growth and rapid maturation or late starting, favors scab escape; while any environmental factor or factors inducing a large amount of spring growth and slow maturation favors scab susceptibility." Similar generalizations may be made with reference to citrus diseases caused by other plant pathogens. Fawcett (22) points out that certain citrus diseases that have had ample time and opportunity for wide distribution in citrus areas of the world are confined by climatic conditions to definite areas. The various semiarid citrus areas have, in general, the same citrus insect pests, in some cases the same species or different species of the same genus. In general, the important citrus insects in humid climates differ from those of semiarid areas, as pointed out by Quayle (50).

Dates

Although the date palm, Phoenix dactylifera, will grow in most parts of the subtropical belt, it does not ripen fruit of commercial quality except under certain conditions of temperature and aridity.

Mason (39) studied the temperature changes in the interior of the date palm and reported that the temperature at the center of the tree ranged from 26° F. warmer than the surrounding air on the coldest mornings observed to 32° cooler on the hottest day. This stabilization of temperature is apparently due, according to Mason, to the protective insulating leaf bases and the ascending sap current, which has a temperature acquired from the soil; and it would explain at least in part the resistance of the date palm to extremes of temperature.

The date palm can endure lower temperatures than most types of citrus, and when in the dormant condition, according to Swingle (58), it is rarely injured at 20° F. and is able to survive in regions where the temperature occasionally falls to 12°. He indicates four different limits: (1) Young palms in active growth would be injured at several degrees below freezing; (2) young palms not in active growth and old palms, if nearly dormant, would be severely injured at 15°; (3) old and dormant palms could withstand temperatures down to 12°; and (4) most date palms would be killed and all would be seriously injured at 10°, and the culture of dates would be impracticable in regions where such temperatures were experienced more than once in a decade. According to Albert and Hilgeman (1, 2) mature palms may be seriously injured at 12° F. in the date-growing region of Arizona, but varieties differ in resistance to low temperature. Young palms will be seriously injured at 20°, and 24° to 26° will cause noticeable injury to lower leaves. According to Nixon and Moore (44) leaves of mature palms are injured by prolonged exposure to a temperature of 20°.

According to De Candolle (11), temperatures as low as 64.4° F. have no influence on the flowering and fruiting of the date, and Swingle (58) reports that this is confirmed by his observations. Although Swingle does not set a maximum at which growth will cease, he does state that the high air temperatures (up to 110° and higher) experienced during the growing season in some semiarid regions where dates are grown commercially are beneficial. Nixon and Moore (44) state that
in the Coachella Valley of California the air temperature frequently exceeds 110° and has exceeded 122° but that it is not known whether such temperatures are desirable for the date. Albert and Hilgeman (2) report that there is no record of injury to date palms by high temperatures in Arizona.

According to Swingle (58), at least 3,632 summation heat units during the growing season, with 64.4° F. as zero, are required to ripen a high-quality date such as the Deglet Noor. Later Vinson (60) reported that the date palm ceases to grow at 50°. Using this as zero, Albert and Hilgeman (2) have classified date varieties on the basis of summation heat units required to reach commercial maturity as (1) early ripening, about 4,000 to 4,200 units; (2) midseason, 4,600 to 4,800 units; and (3) late, 5,200 to 5,300 units.

Mason (39) reports that the growth of the date palm may be continuous during the day provided the temperatures are favorable and there is an ample water supply. Even when the minimum air temperature of the day is several degrees below the freezing point, growth may continue provided the maximum temperature during the day is well above the zero growth point, 50° F. Albert and Hilgeman (2) report that winter temperatures have a direct influence on the growth of the spathe and the time of blossoming, and that temperatures after blossoming apparently have more effect on the time of ripening than does the date of blossoming.

In the case of the Deglet Noor date, according to Aldrich and his coworkers, it appears that if enough heat units accumulate to cause fruit from inflorescences pollinated in late February or March to ripen during the hot period of late August and September, the fruit is very much inferior to fruit on the same palm maturing during the cooler weather of October or November. The late August and September fruit has a greater shrivel and a darker color at time of picking, or the darker color appears during storage; and it is lacking in flavor as compared with fruit ripening later.

An essential in date culture is a minimum of rainfall and low relative humidity during the fruit-maturing season (2, 41, 44, 49). A regular supply of irrigation water must be provided to compensate for the lack of rain. Excessive rainfall or high humidity adversely affects dates by providing conditions favorable for the development of disease and also by causing souring or other spoilage of the fruit. There is a considerable range of resistance to spoilage from rain and humidity among date varieties, and this influences the choice of varieties for specific localities (2, 44).

Humid weather during the ripening season favors the growth of several fungi on the fruit and causes spotting, shattering, and rotting of fruits (23, 44). Nixon (42, 43) and Fawcett and Klotz (23), Haas and Bliss (27), and Albert and Hilgeman (2) have reported on water damage to dates. The injuries last named are not due to plant pathogens but to both weather and physiological conditions in the plant. Aldrich and coworkers have classified water injury to date fruits in three general groups: (1) Checking, or blacknose, due to high humidity or light rains when the fruit is changing from light green to the first pink tints (usually between mid-July and mid-August); (2) splitting (also called tearing by Haas and Bliss), which is due to excess rainfall or prolonged wetting of the fruit while it is pink or turning brownish; and (3) excessive hydration, which seems to be related to the loosening of the fruit at the calyx. Whether the entrance of pathogens causes or follows the loosening of the calyx is not known.

Rains in winter may be helpful, but spring precipitation may interfere with date pollination and the fertilization of the flowers.

According to Mason (40), who correlated weather conditions with vital activity in date seedlings, "Normal growth, as manifested by the pushing up of the leaves from the growth center, is made chiefly in the time between sunset and sunrise, but also at a reduced rate in daylight, when direct sunlight is cut off by clouds. In full sunlight date palm leaf elongation entirely ceases." With reference to the cause of inhibition of growth, Mason concludes, on the basis of experiments with artificial light, "that the inhibiting of the date-palm leaf growth in intense sunlight of the desert regions is due chiefly to the action of rays of wave length from about 0.57 μ in the yellow to about 0.405 μ in the violet end of the visible spectrum, but invisible ultra-violet rays probably assist in stopping growth." More recent work on other plants seems to indicate that this checking in growth is at least partly due to the inactivation of growth substance by radiation of short wave lengths (47, 49).

3 Unpublished results at the United States Date Garden, Indio, Calif.
Figs

The common cultivated fig, *Ficus carica*, can withstand lower winter temperatures than either citrus or dates. Condit (16) reports that the dormant mature fig tree can be expected to withstand winter temperatures of 15° F. without injury; young trees are much more susceptible to low-temperature injury, and in the semiarid Southwest spring frosts cause the most serious damage, though fortunately not frequently. Serious injury may also occur during October and November before the leaves fall. Gould (26) points out that in addition, in the southeastern humid region, serious injury may result when low-temperature periods follow exceptionally warm periods of considerable duration that bring trees out of the winter dormant condition.

Figs for preserving or canning are being grown with maximum daily temperatures below 100° F. in humid regions of summer rains (26, 57), and also in semiarid areas with similar temperatures and fairly high relative humidity due to rains and fog (16). Figs for drying, however, are most successfully produced in regions with long sunny days, maximum daily temperatures around 100° F., and low relative humidity. With temperatures considerably higher than 100°, the fruits ripen prematurely, or the skin is toughened and the proportion of fruits deficient in pulp increased. On the other hand, with a small number of heat units and greater relative humidity, splitting of the fruit and other spoilage troubles are more prevalent (16, 57).

In semiarid regions sufficient irrigation water must be supplied to make good any moisture deficiency from lack of natural rainfall, since attempts to grow the fig under dry-land culture have failed. However, rains at the time of caprification (fertilizing of the fig blossoms) are unwelcome, and they are especially serious during the drying season, when figs may be either completely ruined or considerably injured in commercial quality (16).

In the semiarid Southwest, some varieties are subject to splitting of immature fresh figs. According to Smith and Hansen (56), "this is caused by atmospheric humidity or sudden changes in humidity rather than by soil moisture as was formerly thought." In the humid Southeast, the most common disease is fig rust, *Uredo fici*. It attacks both leaves and fruit, is confined to humid regions, and can be controlled by spraying (26, 57, 64). On the Texas Gulf coast, where the Magnolia—a variety that carries the fruits upright on the branches and has a more open eye than some varieties—is chiefly grown, there is a tendency for fruits to sour during damp weather (57).

Strong winds at the season of ripening whip the foliage and cause scarring of fruit, especially of such canning varieties as Kadota, thus lowering the grade. Windy weather during the season of caprification may seriously interfere with the normal flight of blastophagas (wasps that fertilize the blossoms) and a poor setting of figs of the Smyrna type may result (16, 50).

Since figs ripen very rapidly in the humid sections of the Texas Gulf coast, the fruit must be picked daily to decrease loss from spoilage after picking. To minimize this loss, figs are usually picked before they are soft ripe (57).

Condit (16) reports that the fruit characters of the fig may be affected by climatic differences. In the hot interior valleys with low relative humidity, second-crop Kadota figs have a very slight neck or none at all, a golden-yellow skin, and an amber pulp, while those grown in moister coastal regions have a distinct neck, green skin, and violet-tinted pulp. Similarly, second-crop Mission figs, in the interior valleys, are smaller, less elongated, and sweeter than those grown along the coast.

DECIDUOUS TREE FRUITS

The climatic adaptation of the group of deciduous tree fruits including apples, pears, peaches, cherries, plums, and apricots is similar for the entire group in that all require a winter dormant period for proper development and fruit production and therefore are limited to temperate regions having sufficient winter cold to break the natural rest period. In their distribution northward they are limited by the duration and intensity of winter cold.

Exposure to 600–900 hours below 45° F. is necessary to fully
break the rest period of the commonly grown American peach varieties. Apples apparently require about the same amount of cold as the more slowly responding varieties of peaches, or about 900 to 1,000 hours below 45° (figs. 1 and 2). Pears derived from oriental species have a relatively short cold requirement, while varieties of European origin require about the same amount of cold as peaches.

If the trees are not exposed to sufficient cold, the buds do not open in the spring. With most fruits the blossom buds require slightly less cold than the leaf buds, and frequently in southern latitudes blossom buds will open before the leaf buds begin to grow. Unless the leaf system develops with or shortly after blossom opening, fruit fails to set owing to lack of a food supply from the leaves. Insufficient winter cold to break the rest period is the most important limiting factor in the growing of such fruits as apples in those parts of the United States within 150 miles of the Gulf of Mexico. Peaches can be grown somewhat farther south, while pears derived from Asiatic species are grown even farther south than peaches. Chandler et al. (18) have discussed in detail the chilling requirement for these fruits in California.

**LOW-TEMPERATURE INJURY**

While lack of winter cold prevents the successful culture of these fruits in tropical and subtropical areas, excessive cold is destructive in the colder parts of the world.

The most tender part of the tree during the dormant season is the root system. Experiments indicate that the roots of this group of trees may be injured at any time they reach a temperature below about 20° F. Temperatures ranging from 15° to 20° have been found to injure the roots of apples severely (12, 37, 48). It

![Figure 1](image)

*Figure 1.—Apples require considerable winter cold to break the rest period and are not well adapted where summer temperatures are high. Thus few apple trees are grown within 200 miles of the Gulf coast. Principal centers of commercial production are south and east of large bodies of water, as in Michigan and New York, or east of mountain ranges which afford some protection from severe cold. Distribution of apple trees of bearing age as of April 1, 1930, is shown.*
is probable that the range of root injury is not greatly different with the other species.

Fortunately the soil protects the root system so that root injury actually occurs less frequently than injury to the tops of trees. A grass sod or a heavy cover crop reduces the rate of cold penetration, and a heavy snow cover is generally sufficient to prevent root injury. In moderately heavy soils that are well supplied with moisture, penetration of cold downward is much less rapid than in more open, drier soils, owing to the release of heat as a result of the freezing of the greater amount of water present. Root injury is most likely to be serious in relatively open soils when prolonged periods of below-zero weather occur with relatively little snow or other cover on the ground. Under these conditions root injury may be severe and may result in the death of the trees even though the tops are not directly injured.

The tenderest of the above-ground portions of the tree is generally the collar, or crown (the portion immediately above the ground line). Very frequently the bark in this region is killed by temperatures that do not injure other portions (57). This is likely to occur when sharp freezes follow periods of moderate temperature. Such hardy fruits as apples may be so badly injured as to result in the death of the tree when such sharp freezes occur, although the temperatures do not go below 0° F. Peach trees, particularly in the Southern States, may be injured by temperatures of 15°. Not only is the collar particularly subject to injury, but temperatures are usually lower on the surface of the ground than they are a few feet above.

The fruit buds are usually the next most sensitive. Frequently they are killed by low winter temperatures that do not injure the wood, bark, and leaf buds (17, 34).

Fruits of this group, in common with those of other plants, are more seriously injured if severe freezing weather occurs without a previous period of hardening by moderately cold weather. Thus, Bradford and Cardinell (6) state that the greatest injury to fruit trees in Michigan since the establishment of the fruit industry there occurred as the result of a freeze in October 1906, when the temperature remained well above zero. The trees had not been previously exposed to sufficient cold to harden them. Similarly, severe freezes even during midwinter are more damaging if a period of warm weather has preceded the cold.

![Figure 2](image_url)

**Figure 2.**—The peach tree thrives well under higher summer temperatures than the apple, requires somewhat less cold to break the rest period, and is more subject to injury from low temperatures. Thus principal centers of peach production are south of the principal centers of apple production. Distribution of peach trees of bearing age as of April 1, 1930, is shown.
While the effects of any freeze will vary greatly, depending on the varieties and preliminary hardening, some generalizations may be made concerning the temperatures that these fruits will normally stand in the colder parts of the country when thoroughly hardened. Thus apples, sour cherries, and American plums under these conditions usually stand temperatures as low as —30° F. without severe injury. Pears, sweet cherries, and Japanese and European plums usually stand —20°. Peaches and apricots are likely to be severely injured by a temperature of —15°. The fruit buds of all of these fruits may be injured at temperatures somewhat above the limits for severe tree injury. Fruit buds of peaches particularly are frequently killed at temperatures of —10° even in midwinter.

Thus the location of commercial plantings in the northern districts is largely determined by the minimum temperatures the trees will survive. Apples and sour cherries can be grown in the northern part of the Eastern States, particularly in protected locations. Peaches, pears, and European plums are somewhat less hardy and are grown in the northern sections only where protected by large bodies of water or by the topography. None of these fruits thrive in the northern Great Plains, where minimum temperatures below —30° F. are likely to occur.

With the onset of warmer weather and the beginning of growth, all these fruits become less resistant to low temperatures. They differ markedly in the total amount of "growing" weather required to expose the vital floral parts (5, 13). Thus apples brought into greenhouses when dormant but with the rest period broken and maintained at a uniform temperature of about 70° F. require approximately 25 days before the blooms open. Blossoms of most peach varieties under similar conditions will open in 15 to 20 days. With apricots and some varieties of plums an even shorter period is required. This factor is of tremendous importance in determining the susceptibility of these fruits to spring frosts. Because the apricot requires the fewest hours of warm weather to open its flower buds, it is the earliest blooming and consequently the most exposed to killing by frost of the blossoms or young fruits. Certain plum varieties and oriental types of pear are also very early blooming. Peaches, sweet cherries, European plums, sour cherries, and apples follow in that order. Thus the apple, requiring the greatest amount of warm weather to bring it into bloom, is the most likely to escape spring freezing.

The actual temperatures that will cause injury to the blossoms of these fruits are apparently not significantly different. Any temperature sufficiently low to cause appreciable ice formation in the pistil of the blossom, the part that ultimately develops into the fruit, apparently results in killing.

The following data on the relation of stage of development in apple buds to temperatures causing killing of a portion of the blossoms are from Ellison and Close (20):

<table>
<thead>
<tr>
<th>Stage of development of fruit buds:</th>
<th>Temperatures that result in some flower killing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buds breaking, &quot;green tip stage&quot;</td>
<td>0-10</td>
</tr>
<tr>
<td>Buds packed in cluster, &quot;delayed dormant&quot;</td>
<td>10-20</td>
</tr>
<tr>
<td>Buds separated in cluster, &quot;pre-pink&quot;</td>
<td>124-26</td>
</tr>
<tr>
<td>Center bud pink—others no color</td>
<td></td>
</tr>
<tr>
<td>All buds showing color—&quot;pink stage&quot;</td>
<td></td>
</tr>
<tr>
<td>Center bud open, others &quot;balloon stage&quot;</td>
<td>25-27</td>
</tr>
<tr>
<td>All buds full open</td>
<td></td>
</tr>
<tr>
<td>Petals fallen</td>
<td>27-28</td>
</tr>
<tr>
<td>Small green fruits</td>
<td></td>
</tr>
</tbody>
</table>

^1 For several hours.

**MOISTURE REQUIREMENTS**

For best growth conditions and production, all of the fruits in this group require ample available moisture in the soil of their root zone throughout the growing season. Since the trees develop large leaf areas, the total water requirement is relatively high. A minimum of 30 inches of precipitation, or a combination of precipitation and irrigation, should be available in any part of the United States where commercial culture is attempted. Somewhat larger quantities of water are essential in the hotter and drier regions (30, 35, 37).

Under natural rainfall, where prolonged periods of limited rainfall may occur, it is particularly important to select soils that will retain a large amount of available water to carry the trees through periods of drought.
Fruits that ripen early, such as cherries and apricots, apparently can be grown with somewhat less water than late-maturing kinds such as late peaches, apples, and pears. Some of the American-type plums also are highly drought-resistant.

**Light Conditions**

It is not known that any of the deciduous fruits considered here respond to specific light durations for the initiation of fruitfulness, as is true of many other plant species. All of them appear to develop and function best under conditions of relatively high light intensity. Thus in the Western States, under irrigation and with high light intensities the production of fruits is relatively greater than under eastern conditions. The work of Heinicke and Childers (29) has shown that in apple, maximum photosynthesis (manufacture of carbohydrates) is correlated with maximum light intensity—at least under New York conditions. Thus the areas of most intense light, other factors being equal, seem to be preferable for apples and probably for the other fruits of this group.

**Summer Temperatures**

All these fruits will thrive under widely fluctuating summer temperatures. However, it is possible to make some generalizations concerning the conditions under which the highest production and best quality of fruit are secured.

Sour cherries appear to be adapted to cooler summer temperatures than the other fruits of the group. The main centers of sour cherry production in the United States are where the June, July, and August mean temperatures are about 65° F.

The principal areas for apple production and the areas in which the apple seems to thrive best have mean temperatures for these months of 65° to 75° F. Areas in which the mean temperatures range above 75° appear to be poorly adapted to apple production (8). The best pear districts in the Western States appear to have temperatures slightly higher than those found best for apples. With certain varieties of pears, at least, the best dessert and storage quality is secured where the temperatures are relatively high during the growing season.

Peaches, on the whole, seem well adapted to somewhat warmer conditions than apples. Peaches grown where mean summer temperatures are as low as 65° F. usually are not of so high a quality as those grown at warmer temperatures. On the other hand, excellent peach production and quality are secured in some sections having mean summer temperatures above 75°. Most of the present cling peach production in California is in sections having high growing-season temperatures.

**Relation of Climatic Conditions to Diseases**

The fungus- and bacterial-disease problem is very serious with all of these fruits and is closely correlated with weather conditions. In the parts of the country having wet growing seasons, control of diseases requires expensive spray treatments and in some cases is so difficult as to make the growing of some of the fruits impracticable.

Apple scab, the most serious disease of apples, is a relatively low-temperature fungus that thrives in orchards under conditions of ample precipitation while temperatures are under about 70° F. Thus in the southern apple-growing districts, control of apple scab is primarily a spring and early-summer problem, while in northern districts scab may spread throughout the growing season. Apple scab is practically unknown in the western irrigated districts where little spring or summer rainfall occurs. Other diseases of apples, particularly bitter rot, are high-temperature fungus diseases that are prevalent only in the southern part of the Apple Belt, where temperatures are high and rainfall is likely to be abundant. In pears, the bacterial disease, fire blight, is correlated with both temperature and rainfall conditions. It attacks the trees primarily while they are in an actively growing condition and while spring temperatures are high. In areas where high spring temperatures are coupled with much rainfall, fire blight is so severe that susceptible varieties of pears cannot be grown. Thus in the United States, culture of the more blight-susceptible pear varieties is limited to dry sections in the Western States and to sections in the Eastern States having a very cool spring. The absence of rainfall in the Western States does not prevent blight infection in the trees, but dry conditions tend to reduce the rate of spread.
With peaches, such diseases as brown rot and scab are important only in sections of the country where rainfall is prevalent during the spring or summer. The most serious disease of sour cherries, caused by the leaf-spot fungus, is also dependent upon moisture supply for its spread. Thus in general, in sections having dry summers and water supplied by irrigation instead of rainfall, fungus and bacterial diseases are of minor importance in the growth of these crops, whereas they constitute a major problem in sections having abundant spring and summer rainfall.

**GRAPES**

Most of the grape production of the world consists of varieties derived from the species *Vitis vinifera*, often spoken of in the United States as Old World grapes or California grapes. In this country the vinifera varieties are grown mainly in California and to a limited extent in other Western States (fig. 3).

Since grapes of this species require a short rest period, few are grown within 20° of latitude north or south of the Equator. As they are in general very susceptible to fungus diseases, the principal producing areas are characterized by relatively dry growing seasons. Where grapes are produced for raisins, it is particularly important that the ripening season be dry and relatively hot, to facilitate the drying of the fruit. Most varieties are likely to be injured by temperatures appreciably below 0° F., even during the dormant season, though some varieties selected for hardiness will stand somewhat lower winter temperatures. Spring frosts are a hazard, as with other deciduous fruits, and growth and blossom buds are injured in the spring by about the same temperatures found injurious to peaches. Those grapes will thrive well where summer temperatures are frequently above 100°.

In the more humid parts of the United States, varieties developed from native American grapes, either alone or by hybridization with the vinifera varieties, are grown. These in general will withstand lower winter temperatures than vinifera varieties and are less susceptible to fungus diseases. Such varieties as Concord will endure temperatures that kill peach trees; they approach apples in hardiness. The most cold-resistant grapes will stand as low temperatures as will apples.

![Map of grapevine distribution in the United States](image)

**Figure 3.**—Most of the grapes of the United States are grown in California and are of varieties largely imported from the Old World. These varieties are susceptible to fungus diseases and to winter injury in the colder and more humid parts of the country. In other areas varieties derived wholly or in part from native American species, which are more resistant to cold and to fungus diseases, are grown. Distribution of grapevines of all ages as of April 1, 1930, is shown.
In the Southeastern States, varieties derived from *Vitis rotundifolia*, a native species, are grown extensively. These so-called muscadine varieties are highly resistant to fungus diseases and can be grown with little spraying in very humid climates. They are not very resistant to winter cold and are not grown where temperatures frequently fall below 0° F. They require a long, warm growing season to mature the crop.

All of the grapes are fairly resistant to drought conditions, as compared with most tree fruits. The highest quality of fruit is associated with abundant sunshine during the growing season.

**SMALL FRUITS**

**STRAWBERRIES**

Strawberries are among the most widely adapted of the fruit crops (fig. 4). Varieties have been selected that can be grown in at least the higher elevations in the Tropics, and others are grown in northern latitudes where very severe winter conditions prevail. Notwithstanding the fact that strawberries can be grown as far north as most fruits, they are not truly hardy in the sense that the plant parts withstand very low temperatures. As grown in cold climates, the vital plant parts during the winter season are at or below the ground level, where they receive the maximum protection from snow or other cover. Without such protection, the plants are very susceptible to winter killing. In commercial production, the practice of heavy mulching with straw or similar material is followed in the cold regions to insure protection if the snow cover fails.

In the United States, varieties for the most southern latitudes differ in their growth response from those adapted to severe winters. The principal fruiting in the most southerly regions of strawberry production in the United States occurs during the winter and early spring months. Varieties adapted there must grow, flower, and fruit during the relatively short, cool days of winter. With the Missionary, the principal variety in Florida, fruiting is continuous throughout the winter and spring months. Little if any rest period is required by this variety.

![Map of strawberry production in the United States](image)

_Figure 4._—Although strawberries are grown to a limited extent in every State in the Union, the principal centers of production are in the milder climates of the Southeastern States and along the Pacific coast. North of the Ohio and Potomac Rivers the plants are commonly covered with mulch during the winter months to give added protection, the depth of mulch applied being increased toward the north. Total acreage for 1929 is shown.
Where winters are somewhat more severe, with a period not too cold for plant growth but too cold for fruit production, other varieties are better adapted. Thus, north of the Missionary belt such varieties as Klondike and Blakemore, requiring a slightly longer rest period, are grown.

While relatively hardy varieties are available for still more northern latitudes, protection during the winter months is necessary for successful production. Thus, light mulching with straw or similar material is desirable in the middle latitudes of the United States. The amount of mulch that must be used increases in the more severe climates until the plants are covered several inches deep along the northern borders of the United States. The crown of the strawberry plant, from which the spring growth develops, may be killed or injured in even the hardiest varieties if its temperature falls as low as 10° F. In view of the fact that temperatures at the ground level may be several degrees colder than at a few feet above the ground, the necessity for protection can be readily realized.

Most strawberry varieties are short-day plants in that the fruit buds are initiated while the days are of medium or below-medium length. In northern latitudes this occurs in September and early October, and all fruit buds are formed at that season. In southern latitudes also fruit-bud formation takes place in the fall, but growth may be resumed sufficiently early in the spring to have additional fruit-bud formation during the first relatively short days; thus the early crop is produced from fruit buds formed in the fall, while the somewhat later crop is produced from spring-formed buds. This results in a much longer fruit-ripening period in such areas as the Carolinas and Louisiana than in the more northerly latitudes, where spring fruit-bud formation does not occur.

Under the moist humid conditions of the Eastern States, the varieties grown must be resistant to fungus diseases. In the drier regions of the Pacific Coast States, this is less important, and also in this milder climate, winter mulching is not commonly practiced.

In all parts of the country, susceptibility of the blossoms to spring frost injury may result in severe losses. The open blossoms will withstand temperatures only slightly below freezing, and because of the low growth habit of the plant they are very subject to frost injury. Partly grown berries are much more resistant to low temperatures than are the newly opened blossoms.

The strawberry is a relatively shallow-rooted crop and very subject to injury from an insufficient moisture supply. If drought occurs before the crop matures, total production will be seriously curtailed. Dry weather during midsummer interferes with the production of runner plants, but unless it is so severe as to result in the death of the plants or severely restrict runner-plant production, it apparently does not seriously damage the production for the following season. It is extremely important, however, that ample moisture and good growing conditions be present during the fall season, when fruit-bud formation for the following year occurs, otherwise production will be greatly reduced.

A few varieties—the everbearers—have been selected that will develop flower buds and fruit in the relatively long days of midsummer in the more northerly latitudes. If the spring crop is removed by pinching off the blossoms, these varieties will grow and fruit in the long days of midsummer and late summer.

Thus there are strawberry varieties that are adapted to a wide range of climatic conditions, extending from the equable temperature and day length of the Tropics to the extreme cold of the northern latitudes.

**Raspberries**

Raspberries are best adapted to parts of the United States with relatively cool summers. Under the hot, humid conditions of the Southeastern States, they are subject to leaf and cane diseases, which make commercial production difficult if not impracticable. Although the raspberry apparently requires about as much winter rest as do most of the deciduous tree fruits, it is the prevalence of disease rather than lack of winter cold that limits its production southward in the eastern part of the United States.

Of the two types of raspberries, the red varieties will stand somewhat more severe winter conditions than will the black. Black raspberries are hardy in the Northeastern States but are frequently winter-killed in the upper Mississippi Valley, where some red varieties will survive. Where temperatures are very low, production is made possible by laying down the canes and covering them during the winter months.
BLACKBERRIES AND DEWBERRIES

The cultivated blackberries and dewberries are derived from a number of different species and consequently they show a wide range of adaptation. Varieties have been selected that thrive satisfactorily under the warm, humid summer conditions of the Gulf States, while others are too susceptible to fungus diseases to be grown in that section. In general the blackberries are less resistant to winter cold than are raspberries. Even the hardiest, such as Eldorado and Snyder, do not endure continued cold much below 0° F., and may be killed by relatively short exposures to temperatures of −20° to −30°. For this reason and because of greater tolerance of warm, humid conditions, the principal blackberry regions of the Eastern States are south of the principal raspberry areas. Many varieties thrive well under the cool and relatively equable climatic conditions of the Pacific Coast States.

Currants and gooseberries are very resistant to low winter temperatures but susceptible to leaf and cane diseases under warm, humid summer conditions. They are hardy throughout the northern part of the United States and well into Canada, but are little grown south and west of the Potomac and Ohio Rivers.

CRANBERRIES

The cranberry plant is evergreen, and in common with other evergreen fruit plants it is not truly hardy, although it is grown commercially in such northern districts as Massachusetts and Wisconsin. The plant is a native of swamp areas and stands submergence under water for long periods without injury. These conditions are simulated under commercial culture, the plants being grown on bog fields so arranged that they can be covered with water during the winter months. Although ice may freeze deeply over the fields, the temperatures to which the plants are exposed are not severe. The cranberry thrives best where the summers are relatively cool. Fungus diseases are more serious in the warmer areas. Cranberries are not grown commercially south of New Jersey both because of their poor adaptation to warm conditions and the fact that bog areas are limited in hotter climates.

BLUEBERRIES

The common cultivated blueberries are derived chiefly from the high-bush swamp species. Their northern limit is determined by low winter temperatures. They are not hardy in northern Michigan and northern New England, resembling the peach in resistance to winter cold. The range southward is determined by their need for a certain degree of winter cold. Apparently they are poorly adapted south of the Piedmont region in Georgia. They thrive well under relatively cool, moist summer conditions.

The rabbiteye group of high-bush blueberries is native to northern Florida and southern Georgia. Varieties of this species require a very short period of winter cold. They grow vigorously in the hot summers of the Southern States. Their cold hardiness is not well known, but they are probably not hardy north of the Potomac River.

NUT CROPS

Three of the important nut crops of the world—coconut, Brazil nut, and cashew—appear to be strictly tropical in their climatic requirements. The most important of these, the coconut, is believed to have originated in the American Tropics, but it was distributed throughout the tropical regions of the world prior to the exploration of these regions by white men. It appears to be adapted only to regions having a mean yearly temperature above 70° F., with no freezing at
any time. An equable temperature throughout the year and at least 40 inches of well-distributed rainfall—except in locations where the roots can reach subterranean water—appears necessary for its best development (3). Plantings have been made largely near coasts in practically all tropical countries of the world.

The Brazil nut is native in the river valleys of tropical South America, particularly those of the Amazon and its tributaries. Practically all of the Brazil nuts of commerce come from native trees, and to date the nut has not been cultivated to an appreciable extent either in South America or in other tropical countries. Cultivation would appear possible in regions adapted to the banana, but because of the slowness of the trees to come into production and the rather limited production per tree, the growing of the Brazil nut as a horticultural crop has not been encouraging.

The cashew nut, also native to tropical America, has been grown mainly in the tropical parts of India. In common with the Brazil nut, it is limited to strictly tropical conditions. With improved methods of handling the nut kernels its popularity in world commerce has increased greatly in recent years, although its culture has not yet spread widely through the Tropics, mainly because of difficulty in shelling.

There are no important nut crops that would be considered subtropical in their adaptation. The principal nut crops of the world fall into two classes—tropical and hardy or semihardy.

**Deciduous Hardy or Semihardy Nut Crops**

The most important nut crops in the deciduous or semihardy group include the walnuts, pecans, chestnuts, almonds, and filberts. All are produced on deciduous trees, in contrast to the evergreens on which tropical nuts are produced, and require some winter cold for the best development. They vary widely both in the amount of winter cold required to break their rest period and in the minimum winter temperature they will endure.

The growth in size of all the nuts is normally completed fairly early in the summer, while the latter part of the growing season is the period of filling, or kernel development. Thus a water shortage in the first half of the season will be reflected in small-sized nuts, and a water shortage, defoliation, or other unfavorable factors during the latter part of the season result in poor filling.

**Pecans**

The pecan is native to the southern part of the United States and northern Mexico, the native habitat ranging from the Mississippi Valley to west Texas and north to Missouri, southern Illinois, and Indiana. The cultivated varieties have been developed largely from selected seedlings found in the wild or in planted seedling groves. About two-thirds of the present crop in the United States is derived from native seedling trees and about one-third from the improved cultivated varieties. The pecan is not grown commercially outside the United States, though test plantings have been made in several countries. Native nuts are harvested in Mexico.

Most of the pecans in the United States are grown where there is a season of more than 200 frost-free days. A long hot growing season is necessary for maturing the nut. Though the trees appear hardy in such northern latitudes as New York and Michigan, no nuts are matured on trees in those locations.
The pecan apparently requires a smaller amount of winter cold than most deciduous fruits. Thus pecans can be grown successfully along the Gulf coast from northern Florida to Texas. In the regions immediately adjacent to the Gulf, however, spring growth does not start as early as somewhat farther north—an indication that in that area the amount of winter cold is about the minimum required.

The pecan is more resistant to fungus diseases than such other nut trees as the Persian walnut and the filbert. Under the humid conditions prevailing in the Southeastern States, however, fungicide spraying to protect the foliage is generally necessary. In the drier western districts fungus diseases are much less serious. Because of the long growing season and the large foliage system, the pecan is a heavy user of water. In Texas it is normally found along streams where the root system can tap subsurface water supplies. Under cultivation, 40 to 50 inches of water a year in well-distributed rainfall, or a similar amount applied as irrigation, appears desirable for a mature orchard.

Walnuts

Though several types of walnut are used as food in different parts of the world, the Persian, or so-called English, walnut is the type principally cultivated. In the United States, production is mainly in California and Oregon. There is extensive production in practically all of the countries surrounding the Mediterranean Sea. Varieties of the Persian walnut vary greatly in their cold requirement and also in the minimum temperatures they will stand. The hardier varieties, when well hardened, will stand temperatures of $-10^\circ$ to $-15^\circ$ F. Growth starts early in the spring, and spring frosts, where prevalent, are a serious hazard. In humid climates the trees seem very susceptible to fungus diseases, so that the culture of the nut outside of areas having dry summer climates has not been successful.

The Persian walnut requires considerable winter cold to break the rest period (13, 65). Certain varieties need as much cold as apples, or even more; others require less cold than peaches. In the coastal districts of southern California production is frequently curtailed because of lack of sufficient winter cold. Varieties requiring the least cold have been planted in the area, and even these sometimes have very late and prolonged blooming seasons.

Very high summer temperatures are likely to be injurious (4). The nuts may be sunburned and the meats darkened when they are exposed to temperatures much above 100° F. Thus the crop is best adapted to regions having a moderate-to-cool but dry summer climate. Abundant moisture, however, particularly during the latter part of the growing season, is necessary for the best filling of the nuts.

The black, or American, walnut is a native tree in the United States and apparently is well adapted to all parts of the country except the coldest and the southernmost areas. Though many nuts are gathered, cracked, and sold, commercial culture is negligible.

Almonds

The almond is quite similar to the apricot in its climatic requirements. Only a limited amount of winter cold is necessary to break the rest period. Because of the short rest period and the fact that a relatively low total heat-unit requirement is necessary to bring the trees into bloom, the almond is one of the earliest blooming of the fruit and nut trees. Thus it is extremely subject to damage in sections of the country where moderately late spring frosts are prevalent. This characteristic has limited the commercial production in the United States to California, with a few local plantings in some of the other Western States (66). Almonds are extensively grown in the countries surrounding the Mediterranean Sea.

Ample moisture is necessary for the almond as for other nut crops for maximum production and large-sized, well-filled nuts (66), but since the trees will survive and produce some nuts with a limited amount of moisture, they have been planted in many areas where water supplies are insufficient for other fruit and nut crops.
Filberts

Commercial filbert production was formerly confined mainly to the Mediterranean countries, although production in Europe occurs northward as far as England. During the past 20 years extensive filbert plantings have been made in western Oregon and western Washington, where conditions are apparently favorable for the European-type filbert.

The filbert, in common with the walnut and the almond, seems best adapted to regions having a relatively dry growing season with only moderate summer temperatures. The trees of European varieties will apparently withstand temperatures down to −10° to −15° F. without serious injury. Very severe freezes in the late winter are likely to kill the catkins or the pistillate flowers, which results in poor sets of nuts, but ordinary frosts rarely cause injury. Many of the European varieties are grown as garden plants in the Eastern States, but productiveness has not been sufficiently high to warrant commercial planting. Trees may be injured by severe winter temperatures in the middle latitudes of the East.

Chestnuts

The extensive chestnut forests formerly found in the eastern part of the United States have been largely killed by the fungus disease known as chestnut blight. The European chestnut is widely grown in the Mediterranean countries, where its climatic requirements are apparently similar to those of the Persian walnut. The oriental chestnuts, from China, are being widely tested in the United States. Their climatic requirements appear to be similar to those of the black walnut, except that their range is farther south. Thus they should be adapted to many areas in the Eastern States as well as on the Pacific coast.

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