ADVANCE SHEETS, 2 ISSUED JULY 15, 1918

UNITED STATES DEPARTMENT OF AGRICULTURE
OFFICE OF FARM MANAGEMENT
W. J. SPILLMAN, CHIEF

# ATLAS
OF
# AMERICAN AGRICULTURE

PREPARED UNDER THE SUPERVISION OF O. E. BAKER, AGRICULTURIST

PART II
## CLIMATE

CONTRIBUTION FROM THE U. S. WEATHER BUREAU
CHARLES F. MARVIN, CHIEF

SECTION I
## FROST AND THE GROWING SEASON

BY
WILLIAM GARDNER REED
ASSISTANT IN AGRICULTURAL GEOGRAPHY, OFFICE OF FARM MANAGEMENT

PREPARED UNDER THE JOINT DIRECTION OF P. C. DAY, CLIMATOLOGIST
U. S. WEATHER BUREAU, AND O. E. BAKER, AGRICULTURIST
OFFICE OF FARM MANAGEMENT

WASHINGTON
GOVERNMENT PRINTING OFFICE
1918

Advance Sheets, 2 Issued July 15, 1918

UNITED STATES DEPARTMENT OF AGRICULTURE
OFFICE OF FARM MANAGEMENT
W. J. SPILLMAN, Chief

# ATLAS

OF

# AMERICAN AGRICULTURE

Prepared under the Supervision of O. E. BAKER, Agriculturist

PART II

## CLIMATE

Contribution from the U. S. Weather Bureau
CHARLES F. MARVIN, Chief

SECTION I

## FROST AND THE GROWING SEASON

BY
WILLIAM GARDNER REED
Assistant in Agricultural Geography, Office of Farm Management

Prepared under the joint direction of P. C. Day, Climatologist
U. S. Weather Bureau, and O. E. Baker, Agriculturist
Office of Farm Management

WASHINGTON
Government Printing Office
1918

# SELECTED REFERENCES ON FROST

NOTE: References marked with asterisks (*) contain discussions of methods of frost protection.


**Ballantyne, A. B.**: Blooming periods and yields of fruit in relation to minimum temperatures. Utah Agr. Exp. Sta. Bul. 128, p.245–261, 10 figs. Logan, 1913.

**Batchelor, L. D., & West, F. L.**: Variation in minimum temperatures due to the topography of a mountain valley in its relation to fruit growing. Utah Agr. Exp. Sta. Bul. 141, 27 p., 20 figs. Logan, 1915.

**Chandler, W. H.**: The killing of plant tissues by low temperature. Missouri Agr. Exp. Sta. Research Bul. 8, p.143–309, 3 pls., chart. Columbia, 1913.

**Cox, Henry J.**, & others: Frost warnings. *In* U. S. Weather Bur., Weather forecasting in the United States, p.177–215, figs.97–124. Washington, 1916.

**Day, P. C.**: Frost data of the United States. U. S. Weather Bur., Bul. V, 5 p., 5 maps. Washington, 1911. *This bulletin is superseded by the section on* FROST AND THE GROWING SEASON *in this* ATLAS.

**Fassig, Oliver L.**: The period of safe plant growth in Maryland and Delaware. U. S. Weather Bur., Mo. Weather Rev., vol. 42, p.152–158, table, 10 figs. (incl. maps). Washington, 1914.

***Frost.** By various authors *in* The encyclopedia of practical horticulture, Granville Lowther, editor, vol. 2, p.1006–1029, incl. maps, ills. North Yakima, 1914.

**Garriott, Edward B.**: Cold waves and frosts in the United States. U. S. Weather Bur., Bul. P, 22 p., 328 charts. Washington, 1906.

***Garriott, E[dward] B.**: Notes on frost. U. S. Dept. Agr., Farmers' Bul. 104, 35 p., 4 figs. Revised by Alexander G. McAdie, August, 1911. Washington, 1911.

**Henry, Alfred J.**: [Mountain and valley temperatures] *6 papers under various titles.* U. S. Weather Bur., Bul. Mt. Weather Observ., vol. 3, p.201–225, incl. tables, 5 figs. (1910); vol. 4, p.103–114, incl. tables, 1 fig. (1911); vol. 4, p.305–306, incl. table (1912); vol. 4, p.310–341, incl. tables, 10 figs. (1912); vol. 5, p.1–18, incl. tables, 5 figs. (1912); vol. 6, p.35–37, incl. tables (1913). Washington, 1910–1914.

***McAdie, Alexander [G.]**: Temperature inversions in relation to frost. Annals, Harvard College Observ., vol. 73, p.168–177, 4 pls. Cambridge, 1915.

***McAdie, Alexander [G.]**: The theory and practise of frost fighting. Scientific Mo., vol. 1, p.292–301, 6 figs. New York, 1915.

***Reed, William Gardner**: Frost in the United States. *In* Second Pan American Scientific Cong., Proc., vol. 2, incl. tables, 13 figs. *In press.* Washington, 1917.

**Reed, William Gardner**: The probable growing season. U. S. Weather Bur., Mo. Weather Rev., vol. 44, p.509–512, 4 figs. Washington, 1916.

**Reed, William Gardner, & Tolley, Howard R.**: Weather as a business risk in farming. Geog. Rev., vol. 2, p.48–53, incl. tables, 4 figs. New York, 1916. *Abstract in* U. S. Weather Bur., Mo. Weather Rev., vol. 44, p.354–355. Washington, 1916.

**Smith, J. Warren**: Predicting minimum temperatures for frost protection. Ohio Naturalist, vol. 15, p.405–408, 1 fig. Columbus, 1915.

**Spillman, W. J.**, & others: The average interval curve and its application to meteorological phenomena. U. S. Weather Bur., Mo. Weather Rev., vol. 44, p.197–200, incl. tables, 2 figs. Washington, 1916.

***U. S. Weather Bureau** (Humphreys, W. J., & others): Papers on frost and frost protection in the United States. *Reprinted from* the Mo. Weather Rev., vol. 42, p.562–592, incl. tables, maps, diagr., photos. Washington, 1915.

***Wilson, Wilford M.**: Frosts in New York. New York Cornell Agr. Exp. Sta., Bul. 316, p.505–544, figs. 135–151. Ithaca, 1912.


BIBLIOGRAPHY OF FROST AND FROST PROTECTION.


**Buynitzky, Eleanor**: A selection of books and papers . . . on [frost] . . . forecasting. *In* U. S. Weather Bur., Weather forecasting in the United States, p. 357–358. Washington, 1916.

**Reed, William Gardner, & Feldkamp, Cora L.**: A selected [annotated] bibliography of frost in the United States. U. S. Weather Bur., Mo. Weather Rev., vol. 43, p.512–517. Washington, 1915.

**U. S. Department of Agriculture**: Experiment Station Record, Washington, monthly. (Current.)

**U. S. Weather Bureau**: Bibliography in Monthly Weather Review. Washington. (Current.)


SOURCES OF FROST DATA.


**U. S. Weather Bureau**: Summaries of climatological data of the United States by sections (tables). Various dates. *Each section is revised and reprinted when the previous edition is exhausted.* Summaries for the whole United States were collected as U. S. Weather Bureau Bul. W. Washington, 1912.

**U. S. Weather Bureau**: Climatological data for the United States by sections (tables), 13 numbers a year (12 monthly and No. 13, annual summary) since 1914. "Printed at the several Section Centers, assembled and bound at the Washington Office for service use and exchange." (Current.)

**U. S. Weather Bureau**: Monthly Weather Review, Washington. Monthly. (Current.)

**U. S. Weather Bureau**: National Weather and Crop Bulletin, Washington, weekly during the crop-growing season (April–September), monthly during the remainder of the year. (Current.)


INSTRUCTIONS FOR REPORTING FROST.


**U. S. Weather Bureau**: Instructions for cooperative observers. Circulars B and C, Instrument Division, ed. 5. Washington, 1915.

# FROST AND THE GROWING SEASON

Definition of Frost.—The occurrence of the last frost in spring and the first in fall are especially noted by the observers of the Weather Bureau. Three distinctive frost types, based on degrees of severity, are recognized, namely, "light," "heavy," and "killing." A frost that has no destructive effect, although tender plants and vines in exposed places may be injured, is recorded as "light." The designation "heavy frost" is descriptive of a condition that in itself is more severe than a light frost—that is, the deposit of frost is heavier and the temperature falls to a lower point, although the staple products of a locality are not seriously injured. The term "killing frost" is used to define a frost, or temperature condition, of sufficient severity to be generally destructive to the staple products of the locality. The distinction between the terms "heavy frost" and "killing frost" is one that has reference more to the effect of the frost than to the amount of deposit. Two frosts may appear equally severe so far as the deposit is concerned, yet little damage may be done by one, while the other may be generally destructive to vegetation. In such cases the former is recorded "heavy frost" and the latter "killing frost."

A low temperature condition of sufficient severity to be destructive to vegetation may, in fact often does, occur without an actual deposit of frost, because of cloudiness, or other cause. Such an occurrence is considered equivalent to a "killing frost" because the effect on vegetation is much the same as that occasioned by an actual deposit of frost sufficient to cause destructive effects. It occasionally happens in spring that vegetation has not advanced sufficiently to be injured by frost at the time of its last occurrence, and in the fall the staple crops may have matured before the occurrence of the first killing frost, making it difficult to determine by direct observation the proper killing-frost dates. In such cases the last date in spring on which a temperature of 32° F. was recorded, or the first similar condition in fall, is regarded as the date of the last or the first killing frost. Frosts less severe than killing are in most cases of minor significance to agriculture, although the difference between killing frost and those less severe is often a matter of opinion of individual observers. Records of the occurrence of frosts have been kept since the establishment of the Weather Bureau in 1871 and by many people interested in agriculture or climatology for varying periods. The longest available records are those for Peoria, Ill. (see fig. 1), and St. Augustine, Fla., each of which began in 1856.

The Occurrence of Killing Frost.—Frosts are of agricultural significance only when they occur at the time of year that vegetation is active. During the winter months they are of little significance to agriculture except in limited areas in the South and Southwest; during the summer, except in some of the more elevated areas, they do not occur. Dangerous frosts in the spring are those which occur after growth has begun. Frost occurs spasmodically and large areas are subject to visitation on the same date. A period then frequently follows without frost over the whole area. Later frost may occur covering another large area generally not coextensive with the first.

Characteristic types of frost weather are shown by the three series of weather maps, figures 6 to 15. The six maps on the upper part of the page show the advance of low temperature conditions over the Gulf States and Florida for two severe frosts, one an early spring frost and the other a late fall frost. The four maps of the western part of the country show weather conditions accompanying a severe frost in southern California. These maps, selected from a large number on file at the Weather Bureau, have been introduced to show conditions favorable to the occurrence of frost. Frost conditions are complicated and the ability to recognize weather types indicating frost can be acquired only after considerable experience and a wide acquaintance with differing conditions shown by the weather maps. It is, however, often possible to foretell the occurrence of frost locally from the weather of the afternoon preceding, and many farmers are able to make successful local forecasts for frosts from casual observations of weather conditions during the day.

The thermograms (fig. 2) show the march of temperature at two stations in the Middle West at which killing frost in fall was reported on the morning of October 27, 1914. The rapid rise of temperature in the morning after a night with frost is characteristic, but the details of temperature changes during frosts are far from uniform.

Conditions Favoring Killing Frost.—The occurrence of killing frost depends upon a number of conditions, among which latitude and altitude are of primary importance; the period during which frosts occur is longer in the North and in the more elevated parts of the country, but the relations between altitude and the occurrence of frost are complex. Differences in elevation in the same region are often more important than altitude above sea level. Even in the case of comparatively small differences of elevation the distribution of frost and its relative severity often present complications owing to the tendency of the coldest air to collect in the lowest parts of the region. In more or less inclosed valleys, the hillsides, possibly even the hilltops in some cases, are less subject to frosts than the valley bottoms. The problem, however, is one of great complexity, and thermal surveys of particular regions are necessary before detailed statements as to occurrence, distribution, and severity of frosts can be made with any degree of certainty.

Frost Records.—Because the period available for plant growth is largely confined to the time between the last killing frost in spring and the first in fall, the dates of these frosts and the periods between them are the most significant statements of frost occurrence which can be recorded. These dates in any locality are subject to wide variations from year to year; figure 1 shows them for Peoria, Ill., for each year of the record. The shaded area shows the time of year when killing frosts occur and the unshaded area the time free from killing frosts; agriculturally these may be regarded, respectively, as the time not suitable for plant growth and the time available for the growth of crops.

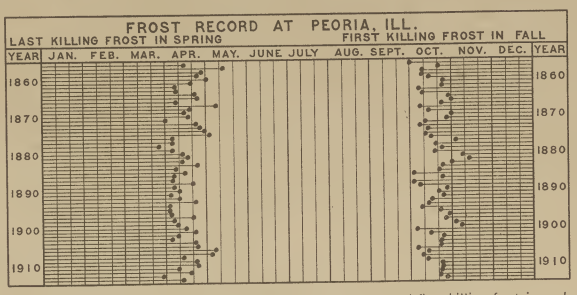



Figure 1. The dots represent the dates of occurrence of last and first killing frost in each year; the blank portion of the diagram is the time free from killing frost.

Frost records are available from about 4,000 regular and cooperative stations of the Weather Bureau. Of these records about 600 cover the full period of 20 years (1895–1914), adopted for most of the climatic material in this Atlas. About 1,800 cover more than 10 but less than 20 years; the other 1,600 are for shorter periods, but none less than 5 years. The records were all made under the direction of the Climatological Service of the Weather Bureau and have been carefully verified by officials of the bureau familiar with the districts and the locations of the stations. The data represent as nearly as possible the exact occurrence of the frost dates in the years of record.

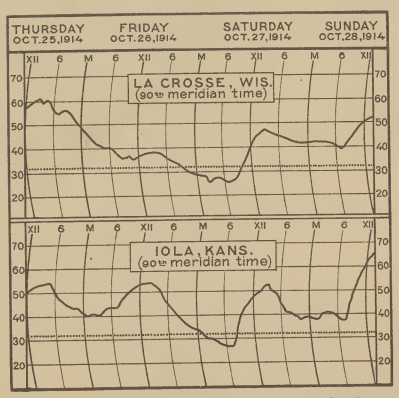



Figure 2. March of temperature at the time of killing frost at representative stations in the Middle West. Killing frost occurred on the morning of October 27.

Dispersion of Frost Dates.—The most noteworthy fact regarding these critical frost dates is their extreme irregularity. This may be seen by examining the Peoria record (fig. 1) and the records for other stations (see figs. 5, 17, 19, 22, 24, and 26). These diagrams show for selected stations the actual occurrence of frost in all the years of the record for each station, 59 years in the case of Peoria. The stations were selected from those having the longest records to illustrate different dispersions. The dates of these critical frosts are of agricultural significance in that they show in each year the time between which no injurious frosts occurred. As different crops require periods of varying length to reach maturity, a knowledge of the length of the season without killing frost is of importance in the selection of regions suitable for particular crops. Figure 1 shows by the blank space in the middle the length of the frostless period for each year at Peoria. Figures 28, 31, and 33 give similar information for other stations. In these diagrams the length of the line shows the period without killing frost for each year.

The irregularities are so great that some method of summarizing critical frost dates and the lengths of the periods without killing frost must be adopted when any considerable number of records are under consideration. In the case of a single station the complete record showing the dates in each year furnishes detailed information. The record at Peoria (fig. 1) shows that in the 59 years no killing frost in spring occurred after May 11 and none in fall before October 1, giving a period of 143 days during which no frost occurred in the entire 59 years. In very many years the period is longer, however, and many days available for plant growth will generally not be used if these dates are taken as the extreme limits of the growing season. The question the farmer must decide is the degree of risk he is able to incur in order to make use of this longer period. The risk involved in planting at different dates must be determined by means of the mathematical summaries which can be made on the basis of the detailed information contained in the record.

Average Dates.—The simplest of all summaries is the arithmetical average. In the case of frost the average date of last killing frost in spring is the time when the chance of killing frost falls to one in two; that is, in about half the years it will occur on or after the average date and in other years it will be earlier. For records covering less than 20 years the average is the only type of summary which can be obtained with usable accuracy. The double-page maps of average dates of last killing frost in spring and of first killing frost in fall show for the 20-year period 1895–1914 the summarized frost conditions of the United States. It should be noted, however, that on the average dates the chance of killing frost is large, crops growing on these dates being subject to frost damage one year in two on the average.

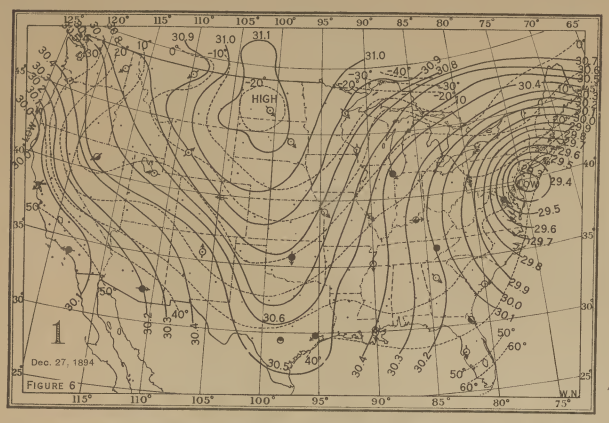
Last Killing Frost in Spring.—The average dates of last killing frost in spring are shown by figure 3. East of the Rocky Mountains lines have been drawn for the 1st, 11th, and 21st day of each month from March 1 to June 1, and from the Rocky Mountains westward for the 1st of each month only. Over the eastern section the lines trend east and west in general, although they bend more or less northerly in the proximity of bodies of water and large river valleys, while the bend is southerly in the vicinity of highlands. In the East latitude is the more general control of frost occurrence, while in the West altitude, modified by oceanic influence along the Pacific coast, is the more influential factor. This makes mapping of the western third of the United States on a small scale exceedingly difficult, and this difficulty is increased by the fact that habitations (the only places where continuous records can readily be obtained) are as a rule restricted to the lower slopes where frost conditions are less severe than in the mountains. The result is that only very general conditions can be shown for this western portion of the country, as each station presents problems peculiar to itself, and in any given area of small extent the occurrence of frost may vary considerably from that shown by the map. The complications introduced by the high mountains and deep valleys and the exceedingly irregular character of the surface have made it impossible to draw lines at intervals of less than one month.

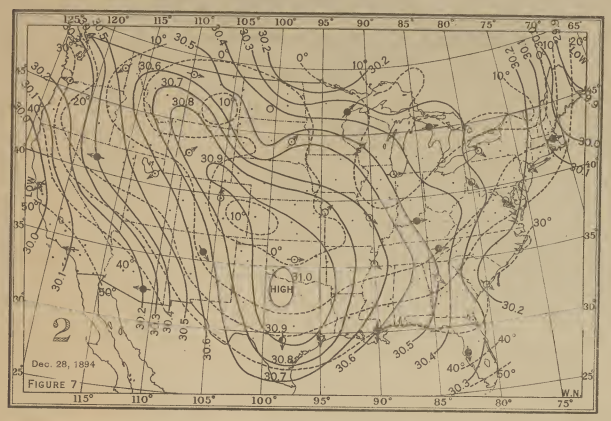
The earliest date line shown is that of March 1. This line skirts the coast of South Carolina and of Georgia, crosses northern Florida, and extends westward through the Gulf States. Southwestern Arizona, the greater part of the Colorado Desert, the coast of southern California, and other favored regions in the West also have their last killing frost in spring before March 1. In these regions frost conditions are irregular, but killing frost occurs every year except at places having exceptionally favored locations. A line has been drawn marking off that portion of the country in which killing frost is liable to occur annually. North of this line it may be expected every year, although there is an occasional winter without it. The area south of this line, in which frost does not occur annually, includes the

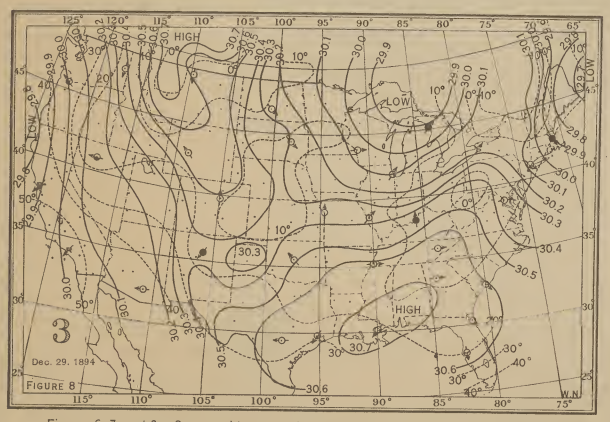

Figure 3 shows the average of the dates on which the last killing frost in spring has occurred. In the East and Middle West the lines are drawn for the 1st, 11th, and 21st of each month; from the Rocky Mountains westward for the 1st of each month only. The only Weather Bureau station in the United States where killing frost does not occur is Key West, Fla. Except for the peninsula of Florida, the coast of the Gulf of Mexico, and favored localities in Arizona and California frost occurs every winter. These localities in California are situated mostly in the foothills and along the coast of southern California and in the San Francisco Bay region. The earliest date for which it is possible to draw a line showing the average time of last killing frost in the spring is March 1, while the latest date is June 1. Occurrences of the last killing frost before March 1 and after June 1 are too irregular to permit the drawing of average date lines. Along the northern margin of the cotton belt the last killing frost in spring occurs usually about April 11, along the northern margin of the corn belt about May 11, and in northern Maine, in the Green Mountains of Vermont, in the Adirondacks, in the Iron Ranges of upper Michigan, and in northeastern Minnesota about June 1. At the higher elevations in the West there are large areas, utilized mainly for summer grazing for sheep and cattle, in which frost occurs after June 1. The dates of last killing frost vary year by year from the 20-year average date indicated on the map. The insert map (figure 4) shows the dates for one year—1914. In other years the dates and the areas covered may be different. The graph (figure 5) for five representative stations shows, by means of a dot for each year of the record, the dates of occurrence of the last killing frost in spring with reference to the average date for the station.

# WEATHER MAPS SHOWING CONDITIONS FAVORABLE FOR FROST

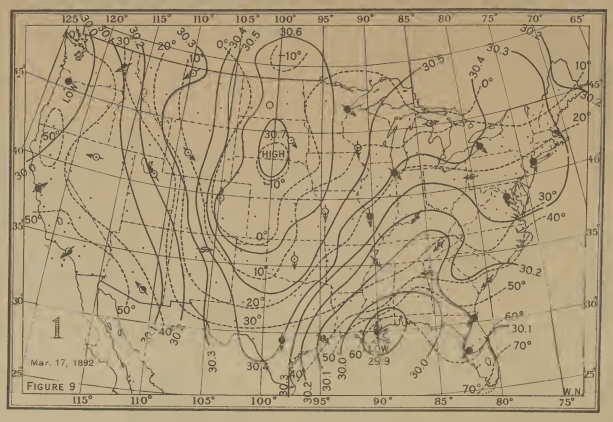
Observations taken at 8 a. m., 75th meridian time. Air pressure reduced to sea level. ISOBARS (continuous lines) pass through points of equal air pressure. ISOTHERMS (dotted lines) pass through points of equal temperature; they are drawn for every 10 degrees. SYMBOLS indicate state of the weather: ○ clear, ◑ partly cloudy, ● cloudy, R rain, S snow. Arrows fly with the wind.

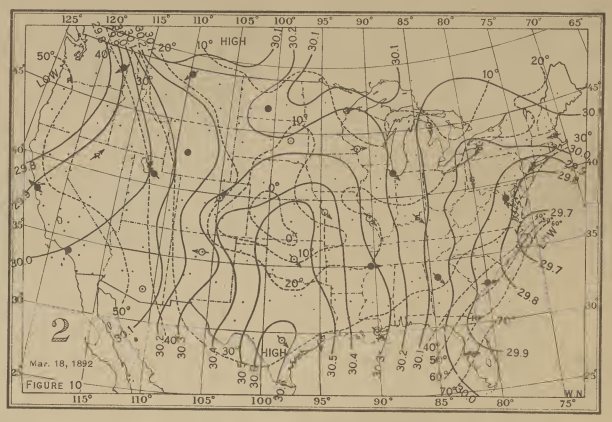


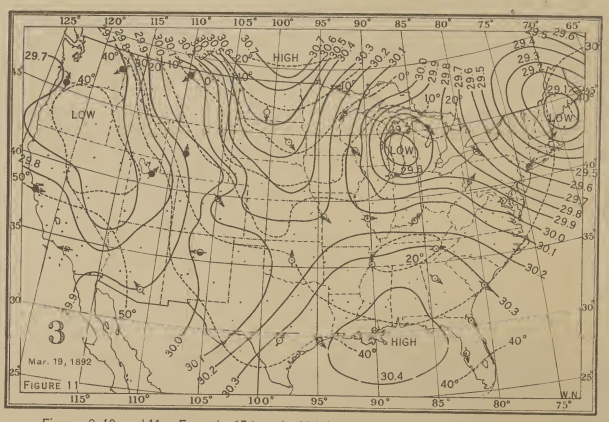



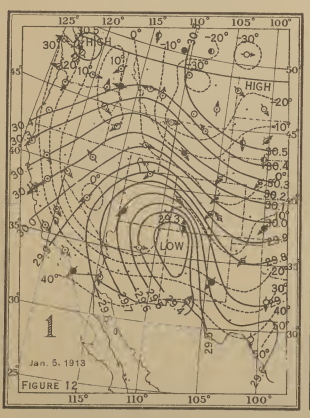

Figures 6, 7, and 8. Severe cold wave and freeze in the Gulf States. Temperatures on the 29th: Mobile 16°, Jacksonville 14°, Tampa 19°, Jupiter 24°, and Key West 44°.

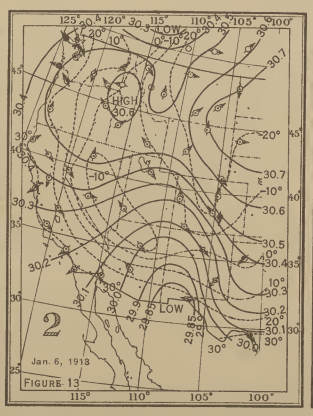


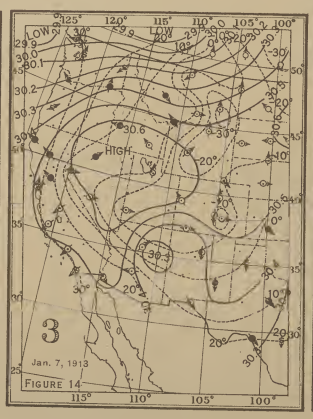



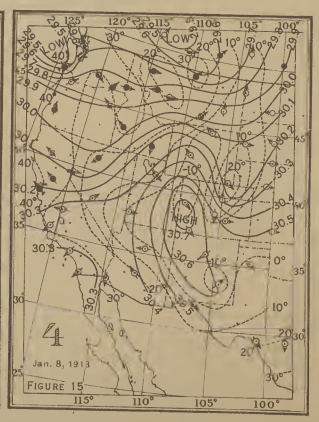




Figures 9, 10, and 11. From the 17th to the 19th low temperatures and frost seriously injured crops and early vegetation from the southeastern slope of the Rocky Mountains over the Gulf and South Atlantic States and the northern half of the Florida Peninsula.




Figures 12, 13, 14, and 15. This pressure distribution is typical for frost in southern California. During the midday hours the temperature did not rise much above 50°. Citrus fruit was subjected to temperatures below freezing for four successive periods averaging 4 hours for the first, 4 hours for the second, 13 hours for the third, and 9 hours for the fourth. The temperature was generally below freezing for a total of 30 hours, below 25° for 12 hours, and below 20° for 2 hours.

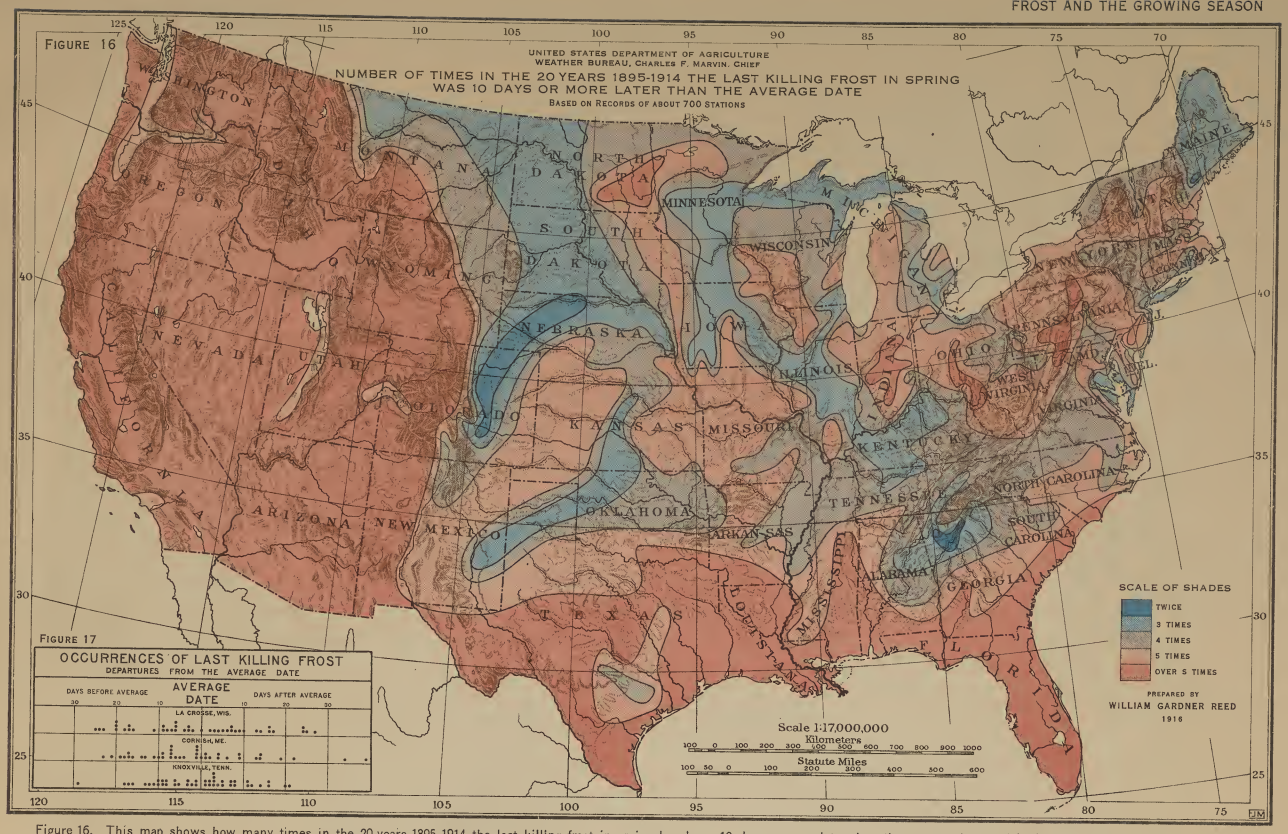
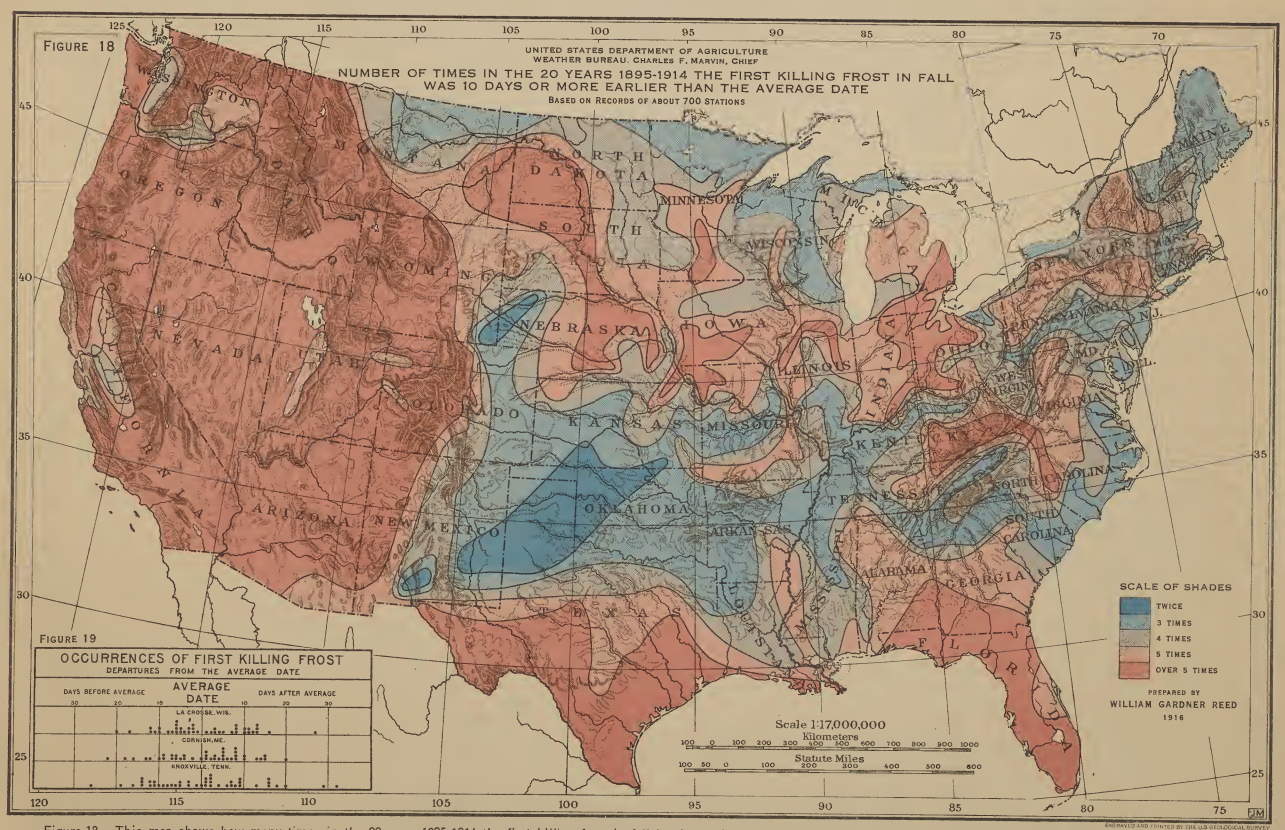



Figure 16. This map shows how many times in the 20 years 1895-1914 the last killing frost in spring has been 10 days or more later than the average date, and indicates the relative dependability of the different portions of the map of average dates of last killing frost in spring (figure 3). The variations are wide in the western part of the country, but owing to the differences in local conditions exact mapping is impracticable. The Gulf States and the portion of the United States west of the Rocky Mountains experience the most frequent variations of considerable amount in the date of last killing frost in spring, while areas in northern Georgia and in eastern Colorado and western Nebraska show the least frequent variations. The graph (figure 17) shows for each year of the record at three representative stations the actual date of the last killing frost in spring with reference to the average date.




ENGRAVED AND PRINTED BY THE U.S. GEOLOGICAL SURVEY

Figure 18. This map shows how many times in the 20 years 1895-1914 the first killing frost in fall has been 10 days or more earlier than the average date, and indicates the relative dependability of the different portions of the map of average date of first killing frost in fall (figure 20). The most frequent variations of 10 days or more are found in the Western States, southern Texas, Florida, and northwestern Ohio; the least frequent variations in the Texas Panhandle and western Oklahoma and in western Nebraska and southeastern Wyoming. The graph (figure 19) is similar to figure 17 above.


Figure 20 shows the average of the dates on which the first killing frost in fall has occurred. In the East and Middle West the lines are drawn for the 1st, 11th, and 21st of each month; from the Rocky Mountains westward for the 1st of each month only. The only Weather Bureau station in the United States where killing frost does not occur is Key West, Fla. Except for the peninsula of Florida, the coast of the Gulf of Mexico, and favored localities in Arizona and California frost occurs every winter. These localities in California are situated mostly in the foothills and along the coast of southern California and in the San Francisco Bay region. The latest average date of first killing frost shown on the map is December 1. Frost usually occurs after this date in the Florida peninsula, the Texas coast, southwestern Arizona, southern California, and in a portion of the Great Valley of California. Along the northern margin of the cotton belt the first killing frost occurs on the average about October 25, along the northern margin of the corn belt about October 1, and along the northern boundary of the United States early in September. In the higher regions of the West the first killing frost occurs before September 1, in fact, is likely to occur any time during the summer. The dates of last killing frost vary year by year from the 20-year averages indicated on the map. The insert map (figure 21) shows the dates for one year—1914. In other years the dates and the areas covered may be different. The graph (figure 22) for five representative stations shows, by means of a dot for each year of the record, the dates of occurrence of the first killing frost in fall with reference to the average date for the station.

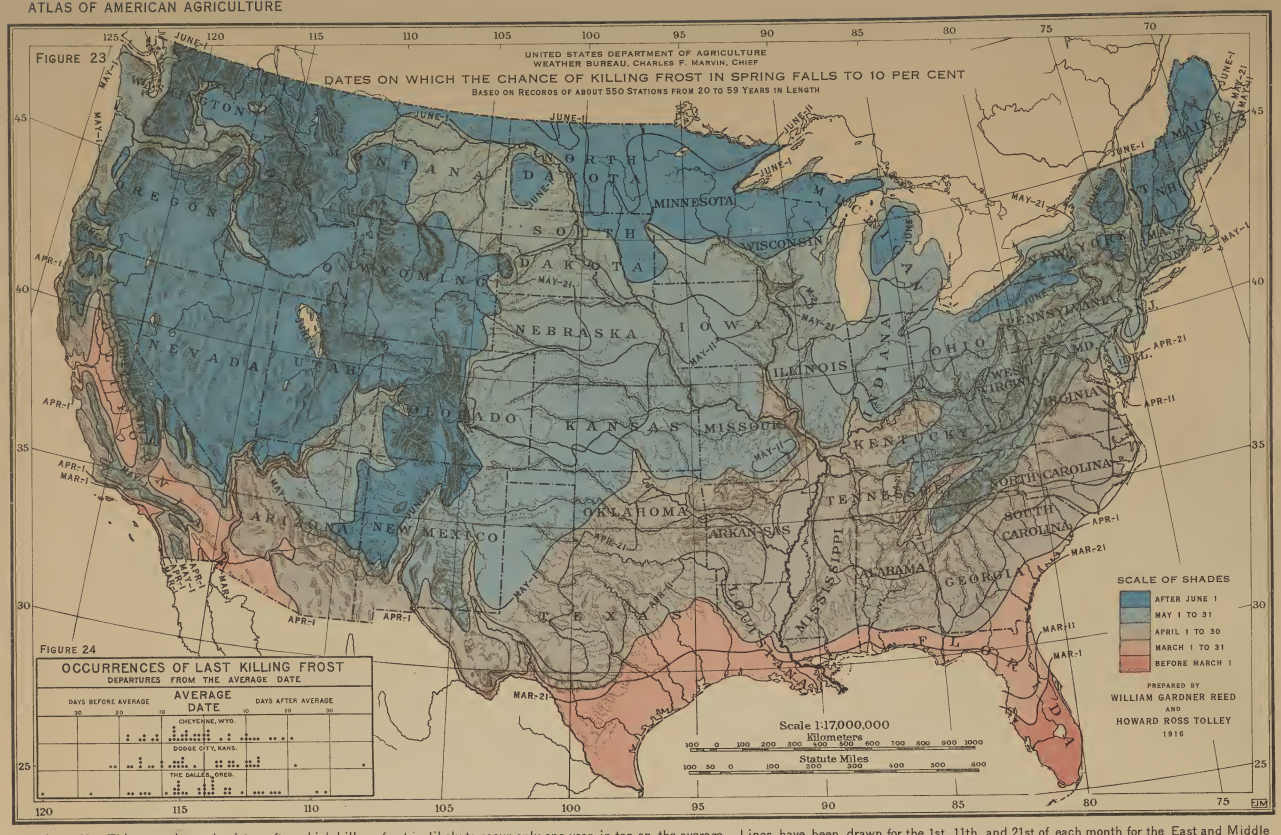



Figure 23. This map shows the dates after which killing frost is likely to occur only one year in ten on the average. Lines have been drawn for the 1st, 11th, and 21st of each month for the East and Middle West, and for the 1st of each month from the Rocky Mountains westward. At Key West, Fla., frost does not occur. The March 1 line crosses the peninsula of Florida, and in the West includes the southwestern portion of Arizona and the coast of southern California. Along the northern margin of the cotton belt only one year in ten is the last killing frost likely to occur as late as April 21, and along the northern margin of the corn belt as late as May 25. Frost occurs later than June 1 in one-tenth of the years along the northern boundary of the country and in the more elevated regions, especially in the West. The graph (figure 24) shows the actual dates of the last killing frost in spring with reference to the average date for each year of the record at three representative stations.

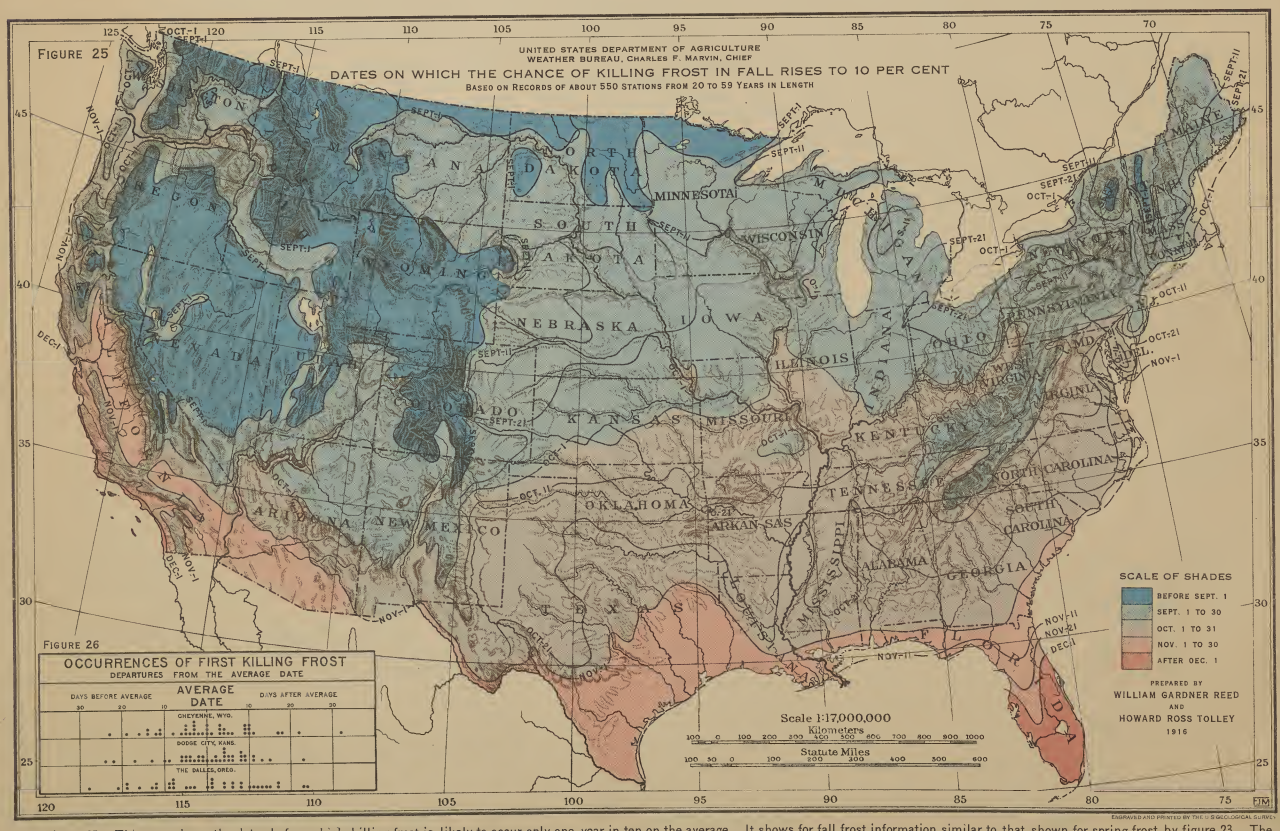



Figure 25. This map shows the dates before which killing frost is likely to occur only one year in ten on the average. It shows for fall frost information similar to that shown for spring frost by figure 23. The line for December 1 follows more or less closely the corresponding line for March 1 in figure 23; and the line for September 1 that for June 1. Along the northern margin of the cotton belt the first killing frost in fall is likely to occur as early as October 11 only one year in ten, while along the northern margin of the corn belt it is likely to occur one year in ten as early as September 11. The graph (figure 26) is similar to figure 24 above.

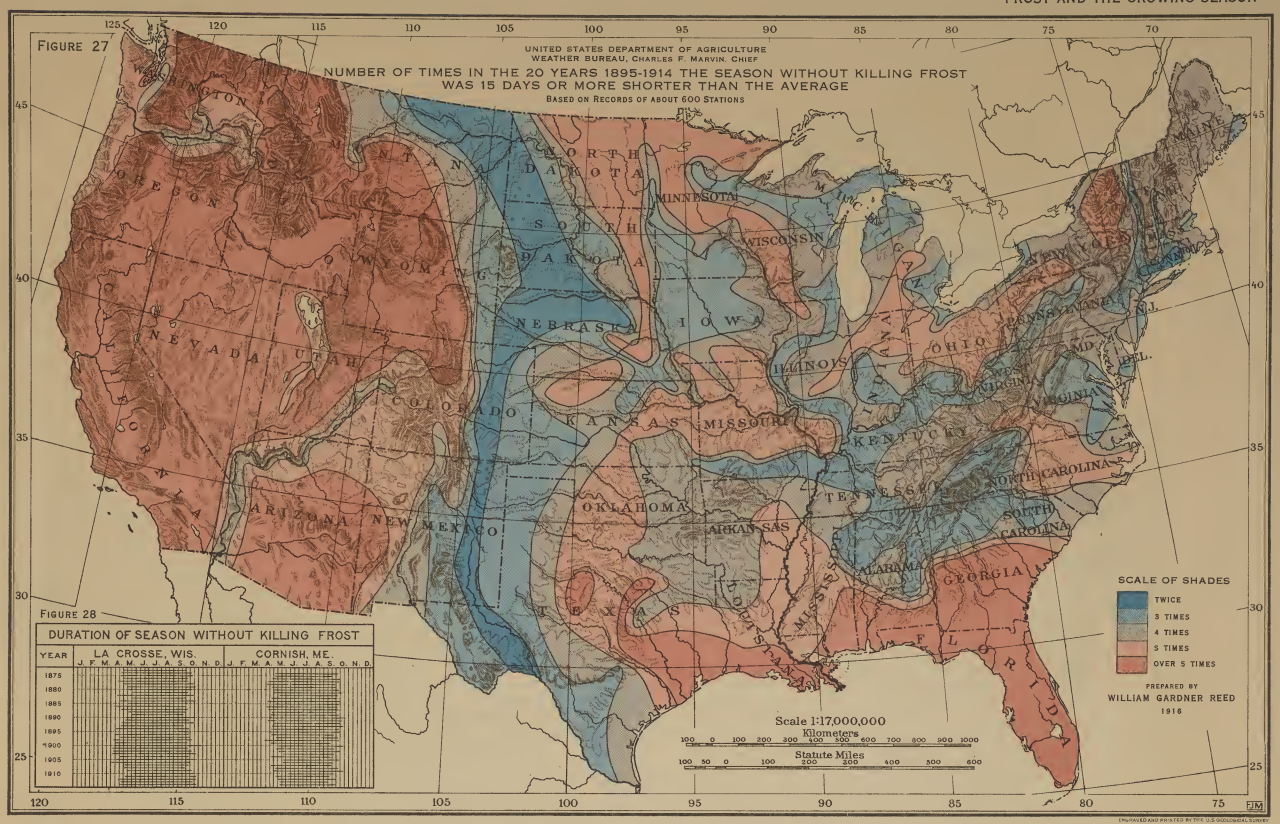



Figure 27. This map shows how many times in the 20 years 1895-1914 the season without killing frost was 15 days or more shorter than the average and indicates the relative dependability of different portions of the map of the average number of days without killing frost (figure 29). The variations are wide in the western part of the country, but owing to differences in local conditions exact mapping is impracticable. The portion of the United States west of the Rocky Mountains and the Gulf and South Atlantic coasts experience the most frequent variations of two weeks or more in the length of the season without killing frost, while the Great Plains area experiences least frequently variations of this amount. The graph (figure 28) shows the actual length of the period without killing frost for each year of the record at two representative stations.

southern half of the Florida Peninsula, the immediate coast of the Gulf of Mexico, and that of southern California. Killing frost occurs in fewer than half the winters only in southern Florida and the region around San Diego, Cal. With the exception of Key West and some of the neighboring keys, frost has occurred in all parts of the United States; and over by far the greater portion of the country it is practically certain to occur every year.

In places along the northern boundary of the United States and at the higher altitudes in the western part of the country the average date of last killing frost in spring is later than June 1; this area includes about one-eighth of the whole country. A large portion of the western United States is included in this area, but in some localities within this region frost conditions are much more favorable for agricultural work.

Variations in the Dates of Spring Frost.—In order to show how far the average dates represent the frost conditions which actually occur, some statement of the variations is necessary. It is, however, not possible to state this additional information with the same degree of accuracy as that for the average dates because of the much smaller number of records of sufficient length to give significant results. Figure 16, based on about 700 records, shows the number of times in the 20 years 1895–1914, the last killing frost in spring was 10 days or more later than the average date. This map may be regarded as a measure of the variability of the dates of last killing frost; it shows for the whole country some of the information which is given by the diagrams of dispersions of frost dates (figs. 1, 5, 17, and 24). The variations are found in general to be smaller near the Atlantic Coast and in the strip of the country just east of the Rocky Mountains. The greatest variations are those in the section west of the Rocky Mountains and also in the regions where frost is less common, particularly in Florida and along the Gulf Coast. Frosts are more common in the valley bottoms than on the lower slopes, but the depths to which the valleys fill with cold air differ from time to time and from place to place, so that stations on the lower slopes are subject to widely varying frost conditions. The greater variations in the West should be taken into account in using frost maps of this portion of the country. Variations in dates of last killing frost are of little significance where frost is not of annual occurrence—that is, in Florida, along the Gulf Coast, and in portions of California and Arizona—because in these regions the type of agriculture is such that the occurrence of any frost is dangerous and proper protection of plants depends more upon timely warnings than upon general statements of the time of year in which frosts may be expected.

The security from damage by frost is indicated by figure 23, which shows the dates on which the probability of frost falls to 10 per cent. This map is similar to figure 3, except that it shows the conditions somewhat less accurately because of the smaller number of stations available (about 600 as against 4,000 for the large map). The lines showing these dates have been drawn for the same intervals as those in figure 3—that is, for the 1st, 11th, and 21st of each month east of the Rocky Mountains, and for the 1st of each month to the westward. The line showing when the chance of killing frost is 10 per cent or less on March 1 corresponds more or less with the line of annual occurrence of killing frost. In the West, in Florida, and along the Gulf Coast the chance of killing frost falls to 10 per cent about 30 days later than the average date of last killing frost in spring. In other portions of the country the difference is smaller, but is commonly not less than 10 days. The areas in which the chance of spring frost is greater than 10 per cent on June 1 include the region along the northern boundary of the United States, elevated areas in the Appalachian Mountains, and the greater part of the higher altitudes of the West.

Average Dates of First Killing Frost in Fall.—The average dates of first killing frost in fall are shown by figure 20, which is based on records for the same stations as were used in preparing figure 3. The regions which are not subject to annual frost are, of course, the same on both maps. The area for which the average dates of first killing frost are earlier than September 1 is much the same as that for which the average dates of last killing frost in spring are later than June 1, although somewhat smaller in extent. Throughout both maps the general similarity is striking, the differences being mainly those of detail.

Variations in the Dates of Fall Frost.—Figures 18 and 25 for fall frosts are similar to figures 16 and 20 for spring frosts. The differences in the variations of the dates of spring and fall frosts are small; the features shown by the maps are, therefore, much the same, although they differ in detail.

Average "Growing Season."—Figure 29 shows the length of the period between the average date of last killing frost in spring (fig. 3) and the average date of first killing frost in fall (fig. 20). The lines have been drawn for 10-day intervals in the eastern and central United States and for 30-day intervals in the West. The length of the period varies from 365 days at Key West, Fla., to considerably less than 90 days in the extreme northern portion of the country and the more elevated portions of the West. The large area in which the average length of the period without killing frost is less than 90 days is an important feature of this map and is essentially the same as that in which the average dates of last killing frost are later than June 1 and those of first killing frost earlier than September 1. The region is, for the most part, not available for general farming; where the rainfall is sufficient it is mostly forested.

Variations in Length of Growing Season.—Figure 27 shows how many times in the 20 years 1895–1914 the period without killing frost was 15 days or more shorter than the average. It was prepared from a simple count of the years in which the number of days between last killing frost in spring and first killing frost in fall was 15 days or more shorter than the average. In many years the period was less than 15 days shorter than the average, but as it began before the date of last killing frost this portion can not be considered available. The general features are similar to those shown by figures 16 and 18. It may be regarded as an indication of the variability of the season without frost in different parts of the country. It shows for the whole country information similar to that given for selected stations by figures 1, 28, 31, and 33.

Figure 32 shows the number of days available for plant growth in about four-fifths of the years. The intervals between the lines are the same as in figure 29—that is, 10 days in the East and 30 days in the West. However, the records are not of sufficient length to justify mapping on a scale as large as that of the double-page map any data for the growing season other than

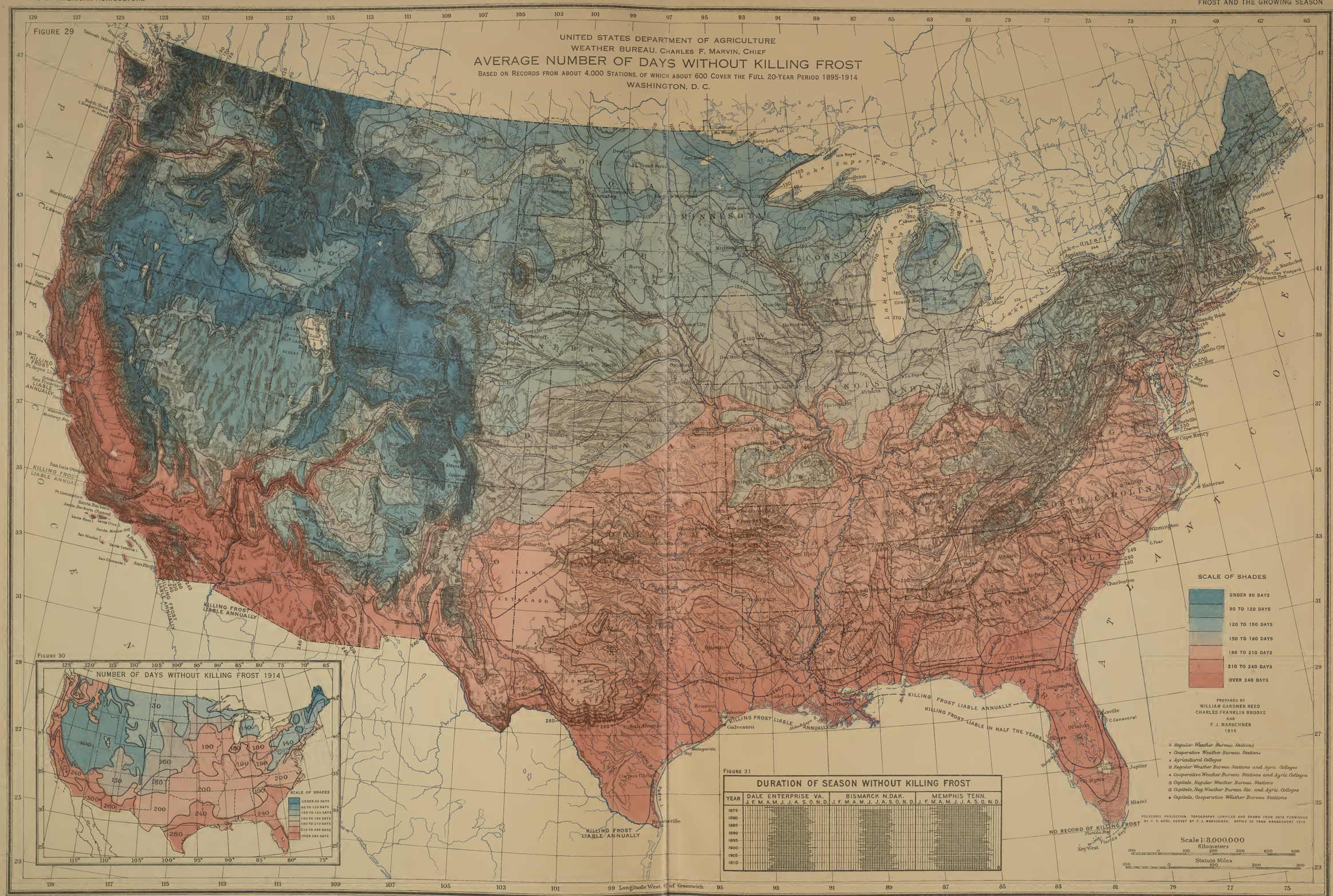



Figure 29 shows the average length of the season without killing frost for the period 1895-1914. In the East and Middle West the lines are drawn for 10-day intervals; from the Rocky Mountains westward for 30-day intervals only. At Key West, Fla., the frostless season covers the whole year. Throughout most of Florida, along the coast of the Gulf of Mexico, and in favored localities in Arizona and California, the average season without killing frost is more than 260 days. Along the northern margin of the cotton belt it is about 200 days, along the northern margin of the corn belt from 140 to 150 days, in northern Maine and northern Minnesota, where hay, potatoes, oats, and barley are the principal crops, it is about 100 days, and in the higher regions of the West it is less than 90 days. There is very little agriculture, except that based upon wild hay and grazing, where the average season between killing frost is less than 90 days. In such regions frosts are likely to occur in any of the summer months. The length of the season without killing frost varies year by year from the 20-year average indicated on the map. The insert map (figure 30) shows the length of the period without killing frost in one year—1914. These periods may be of different length and the areas of different extent in other years. The graph (figure 31) shows the length of the season at three representative stations for each year of the record.

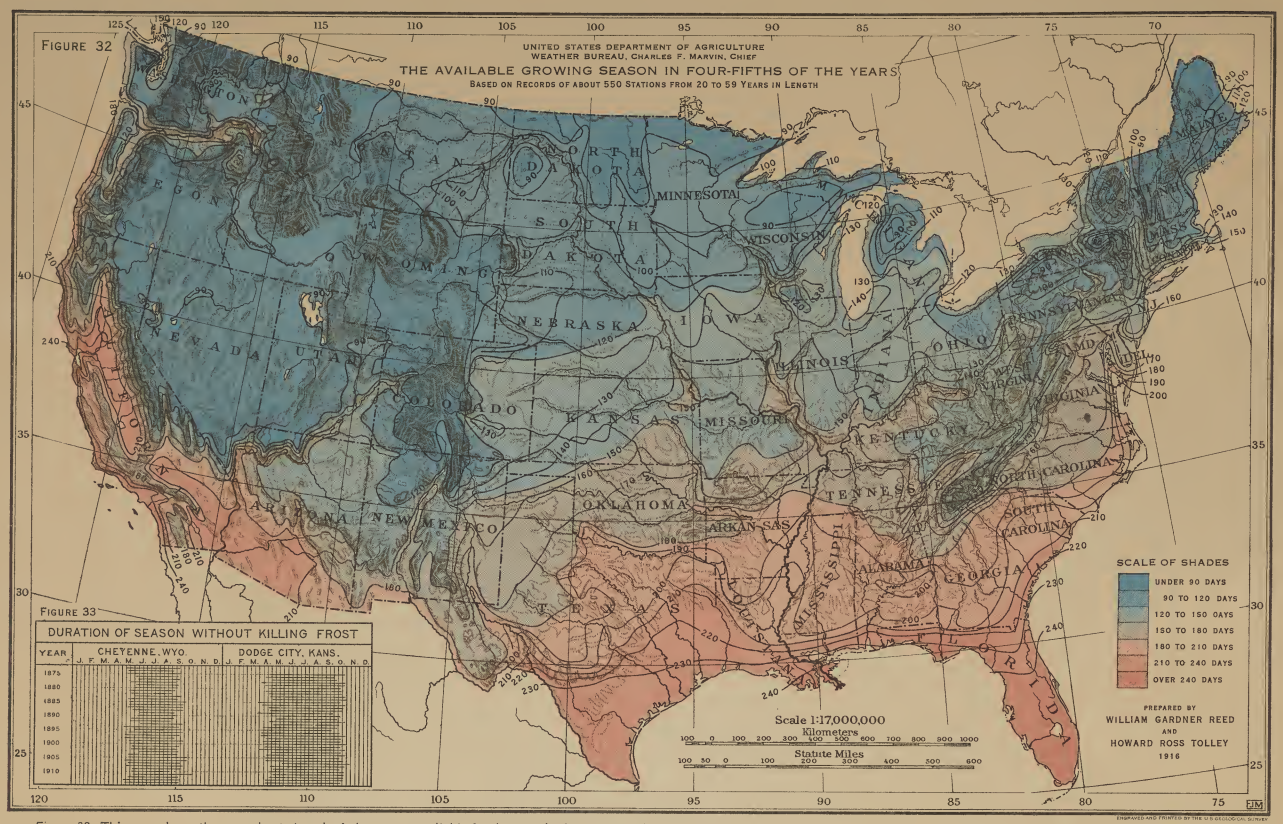



Figure 32. This map shows the approximate length of the season available for the growth of many crops in about four-fifths of the years. This period is measured by the number of days between the date on which the chance of spring frost falls to 10 per cent and that on which the chance of fall frost rises to 10 per cent. Lines have been drawn for 10-day intervals in the East and Middle West and for 30-day intervals from the Rocky Mountains westward. In the southern part of Florida and of Louisiana and in parts of California this available growing season is 240 days or more; in northern Maine, northern Minnesota, and North Dakota, and in the more elevated regions, especially in the West, it is less than 90 days. The graph (figure 33) shows for two representative stations the actual length of the period without killing frost for each year of the record.

the average length of the period without killing frost. The length of the season shown by figure 32 varies from 15 days shorter than the average period without killing frost in some localities to 50 days shorter in others. The differences between the two maps are greatest in those regions where departures of 15 days or more (see fig. 27) are most numerous. In the regions having 90 days or less without frost in four years out of five general farming is limited largely to small grains, grasses, and potatoes, and in general the area is much the same as that in which the average period without killing frost is less than 90 days, although of course somewhat greater in extent. The longest safe growing season is found in the states bordering the Gulf of Mexico, in southern Arizona, and portions of California. The safe growing season in the eastern United States varies from about 240 days along the Gulf of Mexico to 100 days or less in Minnesota and the Dakotas, and 90 days or less in parts of the Appalachian Mountains and the higher altitudes in New York and New England. In the more elevated regions of the West the safe season is less than 90 days. This map represents in general the number of days expected to be available for the growth of crops in a sufficiently large proportion of the years to enable the organization of farm enterprises on that basis with a reasonable chance of success.

Suitable Planting Dates.—It is essential that crops be planted late enough to be safe from too great risk of spring frost and at the same time early enough to permit maturity before the risk from fall frost becomes too great. When the selection of planting dates is made, the chance of damage by spring frost, the advantages of maturity for early markets, and the length of the growing period of the crop must all be considered. In the intelligent selection of planting dates the additional profits from early maturity must be weighed against the possibilities of loss from spring frost, and in regions where the growing period of the crop is such that fall frost may result in damage before maturity, planting dates should be selected which will give a reasonable chance of safety in the spring and also in the fall. Greater risks can also be taken at least on a part of the crop where the cost of replanting is comparatively small and the profits from early marketing are considerable.

The risk of frost may be determined mathematically if the record is of sufficient length. From a study of the long records in the United States it appears that any record of more than 20 years may be used as a basis for such computation. There are in the United States records of about 600 stations, which are suitable for this purpose. A study of general farming conditions has led to the conclusion that, for many crops, profit in the long run will result if crops are lost by spring frost in not more than 10 per cent of the years. In other words, the date when the frost risk falls to 10 per cent appears a reasonable time for planting certain crops, especially those sensitive to frost. Figure 23 shows the dates upon which the frost risk falls to 10 per cent. A crop which is not in a condition to be damaged by killing frost before the dates shown by figure 23 (for example, at Peoria, April 29) will be safe 9 years in 10 on the average. This means that only 10 years in a century will have killing frost after that date and not that one year in each decade is subject to killing frost after April 29. On this scale only the general conditions over wide areas can be shown, and the records must be consulted for information in regard to particular places. In general, the date upon which the chance of loss becomes small enough to justify the risk of planting is in different sections of the country from 10 to 30 days later than the average date of last killing frost.

Suitable Harvest Dates.—The amount of risk which can be assumed in fall does not differ greatly from that which can be assumed in spring, and the risk may be computed in the same manner. Figure 25 shows the dates upon which the chance of killing frost in fall rises to 10 per cent, which for Peoria is October 6. After this date there are fewer than nine chances of safety in ten. These dates are from 10 to 30 days earlier than the average date, the difference between the two dates for any station being about the same as the difference between the similar dates in spring.

The Season Available for Plant Growth.—The number of days available for plant growth is an important factor in determining the availability of any region for a particular crop. The length of this growing season is conveniently stated in the number of days free from killing frost, although the length of the day, the amount of sunshine, and probably other factors tend to modify the period required. Even when the length of the growing season and the total amount of heat received are sufficient, it does not necessarily follow that crops will mature, as favorable temperatures during critical periods of growth are necessary for normal plant development. The three factors—length of growing season, total heat, and temperatures reached—operate on plant development more or less independently. As in the case of frost dates, some method of summarizing the period without killing frost must be adopted when more than a very small number of places are considered at one time. Figure 29 is a map of the average number of days without killing frost for the United States. Crops in a condition to be damaged on the average date of last killing frost in spring will be lost in half the years, but half of those surviving spring frost, and not harvested until the average date of first killing frost in fall, will be lost by fall frost. Therefore, for crops requiring the full length of the season to mature, the average period without killing frost is available to the farmer in only about one-fourth the years.

If a region is to be regarded as available for a particular crop, loss from spring and fall frosts must not occur frequently enough to consume the profits of the years without such losses. The results of the studies of the chance of killing frost in spring and fall provide a method of determining the chance of a growing season of any given length. For example, if the chance of safety from frost after a certain date in spring is 90 per cent, and if the chance of safety from frost before another certain date in fall is also 90 per cent, then the chance that the period between these two dates will be free from killing frost in any given year is 81 per cent. This means that, in the long run, frost damage would not occur in this period four years in five. This may be regarded as the season safely available for the growth of many planted crops; it is shown by figure 32. The number of days indicated by the map is the period after the dates shown by figure 23 which will be free from killing frost in about four-fifths of the years. In general the length of period in which the chance of killing frost is small enough to permit profitable agriculture is, depending on the locality, between 15 and 50 days less than the average number of days without killing frost.

William Gardner Reed.

| Folio 1 Ag864A | U.S. At |
|---|---|
| Regular cop. Adv.sheet 2. | |
| NOV 20 | C.H. 60 |

GPO 8—2432