Probability of Killing Freezes in Missouri

Wayne L. Decker

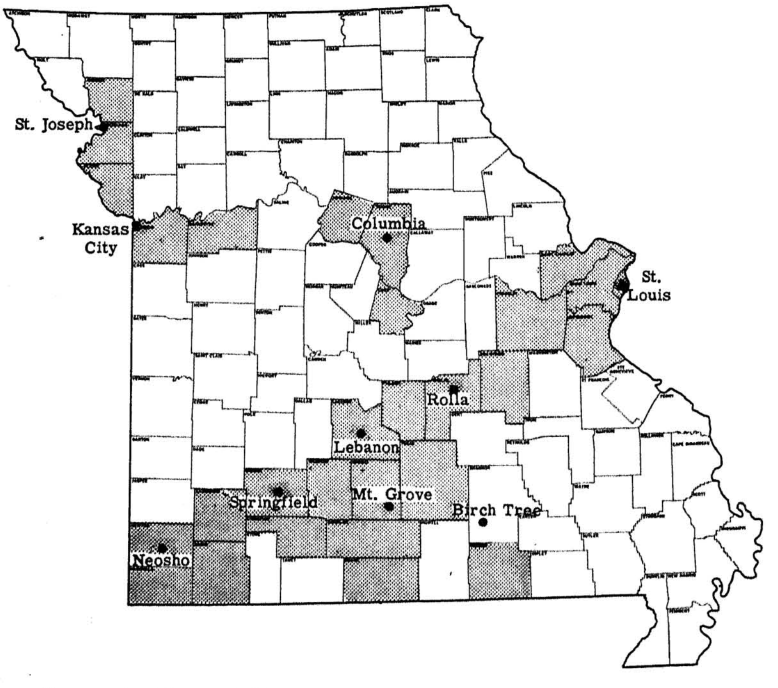

Figure 1.—Map of Missouri Showing the Areas Under Consideration and Stations Used.

UNIVERSITY OF MISSOURI COLLEGE OF AGRICULTURE

AGRICULTURAL EXPERIMENT STATION

J. H. LONGWELL, DIRECTOR

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FOREWORD

Great advances have been made in our knowledge of weather. While much of this development can be attributed to research stimulated by the demands of aviation, agriculture is sharing its benefits. Several agricultural experiment stations, including the Missouri Station, are now engaged in weather research.

This publication deals with the results of a study carried out by the Missouri Station through the use of data supplied under cooperative agreement by the United States Weather Bureau. It concerns the age-old problem of meeting the freezing hazards confronting the grower of frost sensitive crops. The study was made possible through the use of the I.B.M. system of recording and summarizing weather data for application to this problem.

It is well understood that minimum temperature readings at or near the surface of the earth may vary appreciably, even with only slight differences in elevation. They vary, too, with the exposure of the recording thermometer as determined by the proximity of trees, buildings, or other structures which influence free radiation and air movement. As a result, there may be considerable differences between the temperatures recorded at a given location and those to which the crops on neighboring farms or orchards are exposed. It it also understood that there are factors other than low temperatures which determine the freezing injury of individual crops but the nature of these has not been fully determined.

The study here reported is not sufficiently refined to take into consideration all of the factors which determine freezing injury to a crop in a given location even if these were thoroughly understood. Moreover, Missouri fruit and vegetable growers rarely attempt to influence critical freezing temperatures through the use of smudge pots or other means. They are interested primarily in avoiding serious freezing injury by adjusting their planting dates and by the selection of varieties to fit local conditions. It was to supply information for meeting these needs that this study was undertaken. Such information is presented in the body of this report. In addition to these practical implications the study indicates certain approaches to more detailed investigations in the field of critical freezing temperatures. Some such studies are underway at experiment stations in a few other states, and similar studies would be valuable under Missouri conditions.

M. F. Miller
Dean Emeritus

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ACKNOWLEDGMENT

This report is part of a cooperative investigation between the Missouri Agricultural Experiment Station, University of Missouri, and the United States Weather Bureau of the U. S. Department of Commerce. The Weather Bureau is represented on this project by Harold C. McComb, Official in Charge of the Columbia Weather Bureau Office, and W. F. Wahlgren, Director of Missouri Weather Bureau Section Center and Official in Charge of the St. Louis Weather Bureau Office. The weather records used in this study were obtained from the Weather Bureau Section Center in St. Louis. These records were then placed on I.B.M. punch cards under the direction of the Official in Charge of the Columbia Weather Bureau Office.

Acknowledgment is also made to M. F. Miller, Dean Emeritus; J. M. Poehlman, Department of Field Crops; and A. D. Hibbard, Department of Horticulture; who are representing the Experiment Station in this cooperative investigation.

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WAYNE L. DECKER

THE IMPORTANCE OF FREEZE DAMAGE

The danger of freezing temperatures has received wide attention for many years. Farmers have learned that the killing freeze, often called a killing frost, is one of the weather hazards limiting production. In the United States damage often occurs in the citrus fruit areas of Florida, California, and Texas; the deciduous fruit areas of the Pacific Northwest, Virginia, New York, and the central Great Lake states; and the cranberry marshes of Wisconsin and Massachusetts. Recently, attention has been given the problem of fall freeze damage to corn production in the northern and central corn belt.

To save a crop from impending damage, quick action is required of the producer. He must be in a position to place protective equipment in operation when freezing temperatures are expected. To aid him in knowing when the danger of a freeze is imminent, the U. S. Weather Bureau has established special frost warning advisory services in many critical areas. Through this service, which was organized about 1900, the Weather Bureau has saved the producers millions of dollars.

The frost warning service is operated by recognizing the danger of freezing temperatures and issuing frost forecasts when critically low temperatures are expected. The grower then takes quick steps to protect his crop from damage. In the case of orchard production, usually smudge pots are used to heat the orchards above the critically low temperatures. Cranberry bogs are flooded for protection, while seed corn producers pick their corn early and dry it artificially in case of impending frost.

Damage from freezing temperatures is often experienced in Missouri. Spring damage is sustained chiefly by horticultural crops. Fruit setting is impaired or prevented by occurrence of freezing temperatures during the period of tree bloom. Garden crops may be damaged by freezing temperatures occurring after the transplanting of tender and semi-hardy plants. The danger of soft corn in the fall may be great in years when the corn crop is late. Even in Missouri, where the danger of freezes is not quite so great as in some other regions of the country, farmers may suffer much damage due to the occurrence of freezing temperatures.

If a producer is to plan his spring and fall operations some time in advance he must know the most probable dates for the beginning and end of the growing season. This report will present data which can be used in evaluating the risk of freeze damage during the spring and fall. From these data the producer may be able to find more suitable planting and harvesting dates.

AREAS CONSIDERED

Tender crops are grown in widely separated areas of the State. Figure 1 shows the generalized areas by counties which were considered in this study. Types of crops grown in these areas vary quite widely. General truck gardening is carried on most extensively in the extreme east central and west central regions. In the extreme southwest, tomato production is heavy. Extensive fruit orchards are found in all of the shaded areas.

DEFINITION OF A KILLING FREEZE

Plant injury is often associated with the appearance of frost. Frost is the accumulation of very small ice crystals on the ground and plant surfaces. These ice crystals are formed by the freezing of tiny water droplets which have condensed on the cool surfaces. For this reason, frost and dew are actually the same phenomenon, except that in the case of frost the moisture is frozen by the subfreezing surface temperatures. It will be noted that dew and frost usually occur on still, clear nights. If these conditions are not present, no dew formation can be expected; and, therefore, no frost will occur, even if the temperatures are below freezing. This does not mean that subfreezing temperatures in the absence of frost will not produce plant injury. Definite plant injury may occur when temperatures are below freezing with or without frost, but a frost is reported only in cases where the ice crystals are noted on the surface.

Frosts are frequently observed which do not kill plants. Such frosts are generally considered light, and certainly are not "killing frosts". A killing frost is noted in those cases where the surrounding vegetation is damaged beyond recovery. But this means of determining the severity of the frost is not certain, since one observer may be using a tender plant while another may be using a hardy plant as an indicator.

From the above it can be seen that a frost occurrence is not a good indicator of plant injury. The appearance of frost means nothing, in-so-far as plant injury is concerned, except that it reflects the occurrence of a low temperature. It is actually the low temperature which causes the injury.

It is well known that certain plants can withstand more severe freezing than others. The temperatures at which some plants are injured have been determined, but for other plants little is known. So far as fruit blossoms are concerned, Table 1 lists the critical limits for apple and peach blossoms as compiled by Gardner, Bradford, and Hooker (1) from the results of other workers.

From Table 1, it can be seen that there is no complete agreement between authorities as to the temperature at which damage will be sustained. This is not surprising, since the extent of damage would also depend on other factors such as the length of time the temperature was at the lowest point, and the stage

Table 1.—Temperatures at Which Damage Was Noted in Apple and Peach Blossoms

Fruit	Danger Points	Authority
Apple	27°-30°	Wilson
Apple	27°-30°	O'Gara
Apple	25°-28°	Chandler
Peach	22°-28°	Paddock and Whipple
Peach	25°-27°	Chandler
Peach	25°-28°	Garcia and Rigney

of flower development. Taking the two fruits (apples and peaches) together, it might be safe to say that little damage can be expected so long as the temperature remains above 30°; and that heavy damage will occur when the temperature falls to 25°. Moderate damage might be expected in the intermediate values, say 26° to 28°.

In the case of truck-garden crops, almost no information is available on the danger points of the various plants. In general, truck crops are classified under one of three categories: tender, semi-hardy, or hardy. Tender plants are those which will be injured by any temperature below freezing. Temperatures slightly below freezing are required to produce injury in semi-hardy plants, while hardy plants will withstand a fairly hard freeze. The hardy group includes such plants as spinach, turnips, onions, and peas. The semi-hardy group is characterized by beets, carrots, parsnips, and lettuce. Included in the tender group are such plants as beans, sweetcorn, melons and tomatoes.

Wallace and Bressman (5) report that soft corn will result if the temperature drops in the fall to 24° while the corn kernels still have a water content greater than 15%.

From the above, certain arbitrary critical temperature limits are postulated. Perhaps, these limits should be made for each plant under consideration, but this is beyond the scope of this report. These temperature limits are not meant to be inclusive, but are arbitrary and general limits which should give a generalized solution to the problems involved. These temperature limits are:

Light Freeze	28°-32°	Little or no damage to most plants. Heavy damage to tender plants, and to semi-hardy plants in low lands.
Moderate Freeze	24°-28°	Some damage to all plants. Heavy damage to fruit blossoms, tender and semi-hardy plants, particularly if situated in low lands.
Severe Freeze	Less than 24°	Heavy damage to all plants.

WEATHER STATIONS STUDIED

In order to understand the nature of the risk of freezing temperatures, it is necessary to study the occurrences of these phenomena at weather stations in the areas concerned. Fortunately, there are a number of weather stations located within the areas of the state which grow tender crops. Ten such stations have been selected for use in this study. These stations are shown in Figure 1. At each station the lowest temperatures recorded during each night was used to determine the freeze occurrences.

There are usually variations in temperature within the region surrounding a weather station. Temperatures are normally warmer within sheltered towns and cities than in the open country; and cold air often drains into valleys producing lower valley temperatures than those reported along the hillsides. Some consideration should be given to the location of each weather station in relation to the surrounding territory. In this way it will be possible to determine whether the weather station is representative of its area. Below are listed data regarding the locations of each of the ten weather stations used in this study.

St. Louis.—The weather station has always been located in the downtown area. Comparison of the minimum temperatures at the Weather Bureau City Office with those recorded at St. Louis University, Washington University, St. Louis Airport, St. Charles, Crystal City, and Union, show that, on the average, the minimum temperatures at the city offices are about 2° higher than those recorded in the open country.

Columbia.—The weather station has always been within the city. It was found that the minimum temperature at the city office averaged 1° higher than the Columbia airport and 2° higher than the Midway Horticulture Experiment Farm.

St. Joseph.—Present location is at Rosecrans Field, northwest of the city. It is located in the Missouri River bottom some distance from the river bluffs. Prior to 1947 it was located in the downtown area, so that most of the weather records are from this sheltered city position. There are no other weather stations with which to compare the records.

Kansas City.—Present location is at the Municipal Airport, located in the Missouri River bottom just north of downtown Kansas City. It was moved from the downtown area to this location in 1934. It was impossible to obtain an estimate of how these temperatures differ from those of the open country.

Rolla.—This weather station is located at the Missouri School of Mines and nearly approximates open country conditions.

Lebanon.—At present, this location is in the open country. Prior to 1937, the station was located within the town, but had an open exposure.

Mountain Grove.—This station has always been located at the Missouri State Fruit Experiment Station. This location is most favorable from an agricultural point of view.

Birch Tree.—The size of the town is too small to cause a great deal of difficulty.

Springfield.—The weather station is now located at the Municipal Airport. It was moved to this location from the downtown area in 1940. The portion of the record taken at the downtown area does not represent open country conditions, but there are no weather stations in the area with which to compare these temperature observations.

Neosho.—This station is located at the U. S. Fish Hatchery. The location is not ideal since it is located in a valley. Undoubtedly, cold air settles into this valley on many occasions.

In order to estimate the likelihood of a damaging freeze at these locations, it is necessary to study the temperature occurrences for a number of years. The length of record used varies slightly at the different stations. For Kansas City, St. Louis, and Springfield, a 40-year record, 1908 through 1947, was used. In the case of St. Joseph, the length of record was 38 years, 1910 through 1947; while Columbia's weather record was for 50 years, 1898 through 1947. For the remainder of the stations, a 30-year record was used beginning in 1918 and extending through 1947.

It has been noted that when the weather stations are located in sheltered cities, appreciably warmer minimum temperatures are recorded than in the open country. In the case of St. Louis and Columbia, this difference averaged about two degrees. For this reason, the critical limits for a light, moderate, and severe freeze were adjusted by two degrees when the weather records were taken within a city. These new limits, which are listed below, were used in the cases of St. Louis, Columbia, St. Joseph, Kansas City, and Springfield.

Light Freeze	30°-34°
Moderate Freeze	26°-30°
Severe Freeze	Less than 26°

AVERAGE DATES OF KILLING FREEZE

In the past, a great deal of attention has been given to the average date of the last killing freeze in the spring and the first killing freeze in the fall. This has been used by many as an indication of the progress of the spring and fall seasons. From an operational point of view, little knowledge is gained by this figure, since it represents only the half-way point. There remains a 50-50 chance of a frost occurring after the average date in the spring or before the average date in the fall. This certainly is a greater risk than most farmers can afford to take.

Nevertheless, the average dates for the last freeze in the spring and the first in the fall are included in Table 2. It must be borne in mind that these dates do not represent a date that is relatively safe from frost. In the spring, a freeze will occur after the average dates 50 per cent of the time. Similarly,

Table 2.—Average Dates of the Last Freeze in the Spring and the First Freeze in the Fall

	Last in Spring			First in Fall		
Station	Light Freeze	Moderate Freeze	Severe Freeze	Light Freeze	Moderate Freeze	Severe Freeze
St. Joseph	Apr. 17	Apr. 3	Mar. 26	Oct. 17	Oct. 27	Nov. 7
Kansas City	Apr. 12	Apr. 2	Mar. 22	Oct. 26	Nov. 3	Nov. 14
Columbia	Apr. 19	Apr. 7	Mar. 25	Oct. 14	Oct. 25	Nov. 7
St. Louis	Apr. 8	Mar. 29	Mar. 17	Nov. 1	Nov. 11	Nov. 21
Rolla	Apr. 16	Apr. 3	Mar. 22	Oct. 23	Nov. 4	Nov. 16
Lebanon	Apr. 23	Apr. 8	Mar. 26	Oct. 16	Oct. 28	Nov. 8
Mountain Grove	Apr. 18	Apr. 3	Mar. 23	Oct. 20	Nov. 2	Nov. 13
Birch Tree	Apr. 14	Apr. 3	Mar. 25	Oct. 22	Nov. 1	Nov. 11
Springfield	Apr. 17	Apr. 3	Mar. 24	Oct. 23	Nov. 2	Nov. 12
Neosho	Apr. 18	Apr. 4	Mar. 27	Oct. 18	Oct. 30	Nov. 7

a freeze will occur before the average fall date 50 per cent of the time.

From Table 2, it can be seen that there is a wide variation between the average dates of the various locations. The surprising thing in these figures is that the average dates of the last freeze in spring are often latest in the Ozark area.

LIKELIHOOD OF A FREEZE

So far as this report is concerned, we are interested in estimating the likelihood of freezing temperatures occurring either after an arbitrary date in the spring or before some date in the fall. These likelihoods may be expressed either as percentages or as ratios. The likelihood of a freeze occurring after the average date for the last freeze in the spring is 50%, or it will occur, on the average, one year out of two. If the likelihood is 10%, the freeze can be expected to occur one year out of ten; a likelihood of 20% is actually two years out of ten, etc.

In 1916 Reed and Tolley (3) and Reed (2) first described the nature of frost distribution curves. Although they did not attempt to expand their results into estimates of the likelihood of freezing temperatures, they showed that the dates of the last killing frost in the spring and the first in the fall followed an independent normal distribution. Thirty years later Thom (4) verified these results and described a method for evaluation of the likelihood of late spring and early fall freezing temperatures. The method described by Thom has been followed in this work with only slight modification.[1] The actual method of computation will not be presented here, but charts showing the results will be given later in this report.

[1]Decker, Wayne L., Unpublished Data, University of Missouri, Columbia, Mo., 1950.

LIKELIHOOD OF A KILLING FREEZE AFTER A GIVEN DATE IN SPRING

Through use of the records from the ten weather stations, it is possible to estimate the chances of experiencing a killing freeze after any date in the spring. The chances will be expressed in percentages, and called a "Freeze Likelihood". For example, a freeze likelihood of 10% indicates that damage will be expected one year out of ten.

Freeze likelihoods have been computed for each of the ten weather stations within the critical areas. At each station a separate likelihood has been prepared for a light, moderate, and severe freeze. The likelihood for a light freeze would be useful for indicating the risk in the case of very tender plants. The likelihood for a moderate freeze indicates the risk in the case of semi-hardy plants and orchard blooms. The likelihood of a severe freeze would be used as an indication of the danger for the remaining hardy plants.

We know intuitively how the nature of these freeze likelihoods should run. Early in the spring, say about March 1, there is a very good chance of receiving at least one more damaging freeze, so that the likelihood of freeze would be large. Late in the season, say about May 1, the chances are very good that no more freezing temperatures will be encountered, so the likelihood of freeze for these dates would be low.

It is possible to design a chart for presenting the likelihoods. For the purpose of this study, likelihoods from 1 to 99 per cent will be used. The 99% likelihood will occur early in the spring and will indicate the date after which a killing freeze can be expected ninety-nine years out of a hundred. The 1% likelihood will occur late in the spring and give the date after which a killing freeze can be expected only one year out of a hundred. Such charts are shown for the ten stations used in this study in Figures 2 through 11.

It will be noted that there are three lines in each of these figures. These lines are marked light, moderate, or severe. They correspond to a light, moderate, or severe freeze.

Let us suppose that we are interested in knowing the chances of receiving freezing temperatures after April 1 at St. Joseph, Missouri. This can be determined quite easily from Figure 2. Find the point along the left hand side of the chart corresponding to April 1, and move across horizontally until the freeze likelihood lines are intersected. The likelihood of a freeze after April 1 can then be read off the scale in the lower portion of the chart. This process is demonstrated for St. Joseph by the lines drawn on Figure 2. It can be seen that the likelihood of receiving a killing freeze of severe intensity at St. Joseph after April 1 is 30%; of a moderate freeze, 59%; and of a light freeze, 93%. In other words, one can expect a severe freeze after April 1 three out of ten years, a moderate freeze six out of ten years, and a light freeze about nineteen out of twenty years.

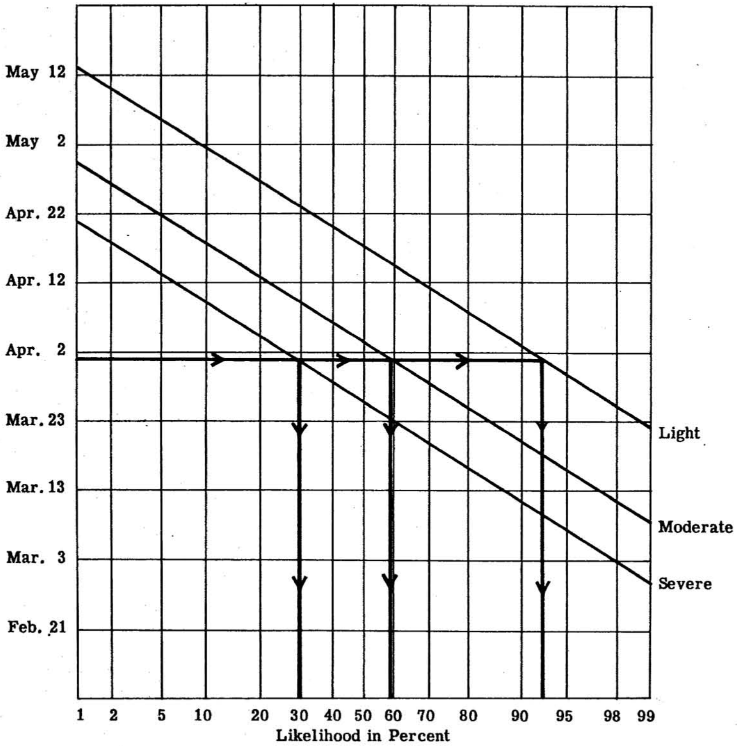

Figure 2.—Likelihood of a Killing Freeze After Any Date in Spring at St. Joseph, Missouri.

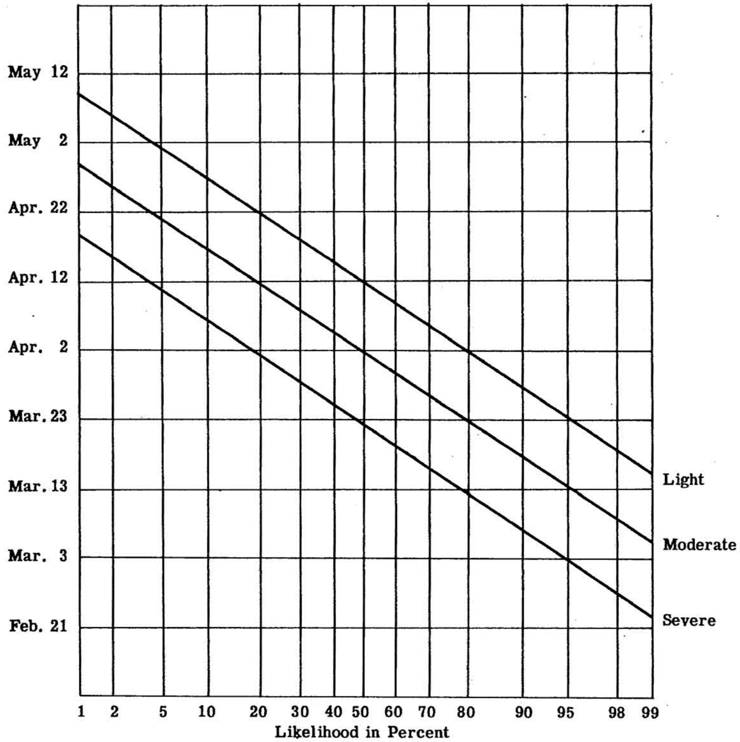

Figure 3.—Likelihood of a Killing Freeze After Any Date in Spring at Kansas City, Missouri.

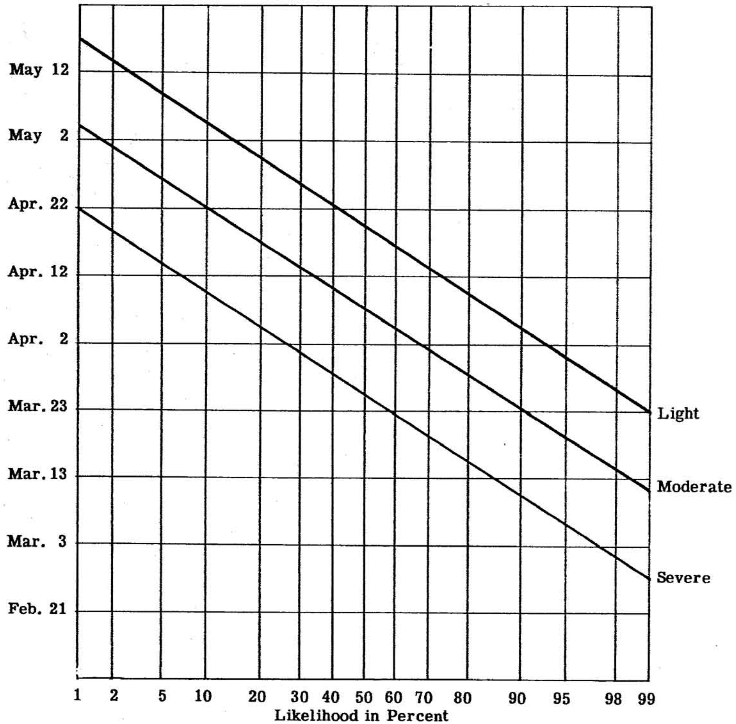

Figure 4.—Likelihood of a Killing Freeze After Any Date in Spring at Columbia, Missouri.

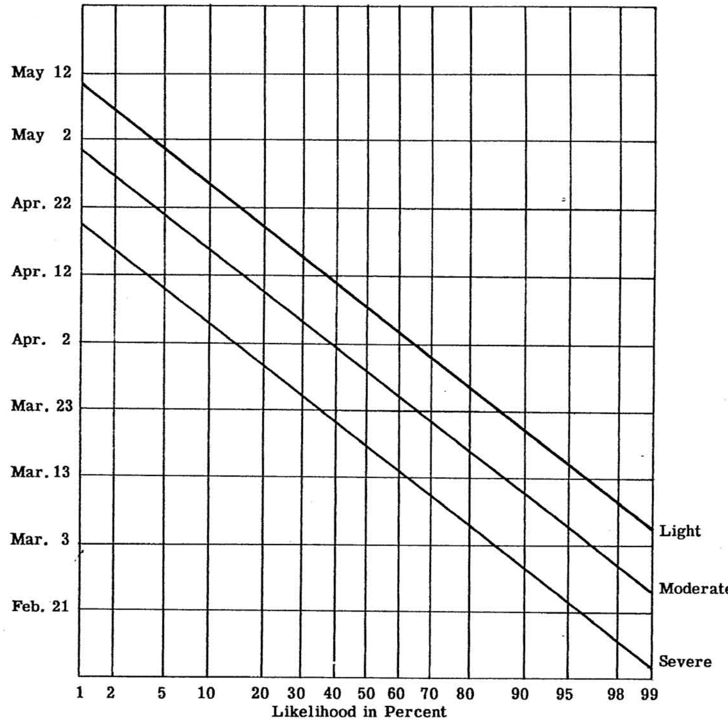

Figure 5.—Likelihood of a Killing Freeze After Any Date in Spring at St. Louis, Missouri.

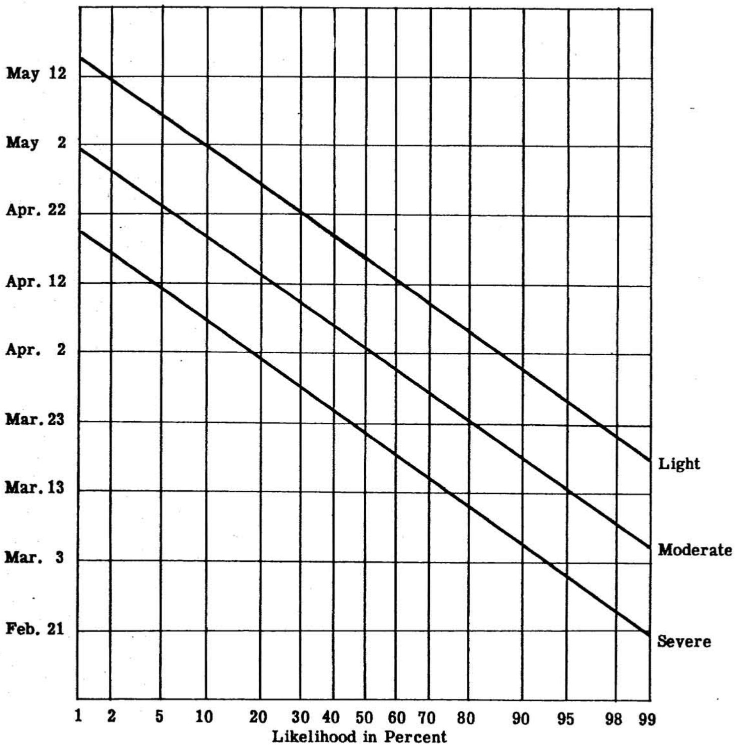

Figure 6.—Likelihood of a Killing Freeze After Any Date in Spring at Rolla, Missouri.

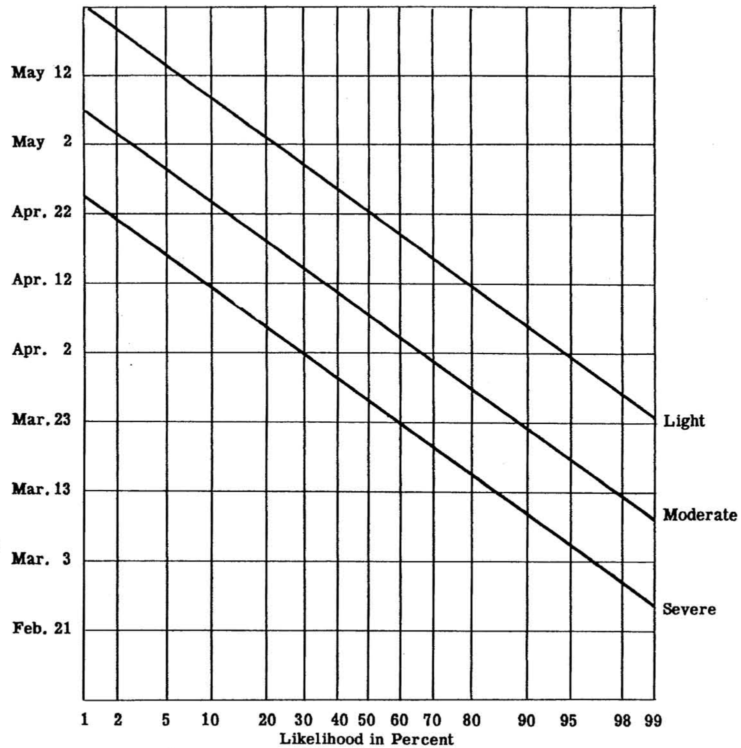

Figure 7.—Likelihood of a Killing Freeze After Any Date in Spring at Lebanon, Missouri.

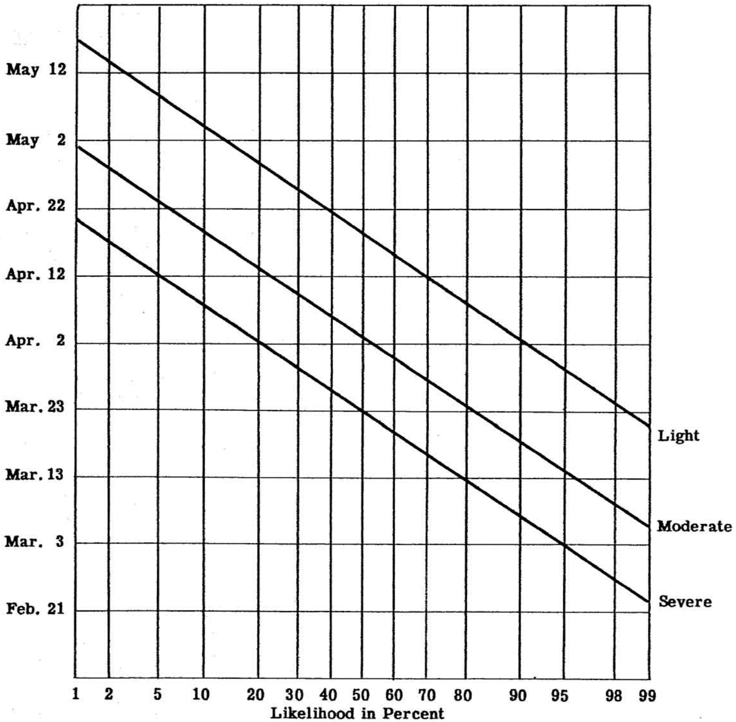

Figure 8.—Likelihood of a Killing Freeze After Any Date in Spring at Mountain Grove, Missouri.

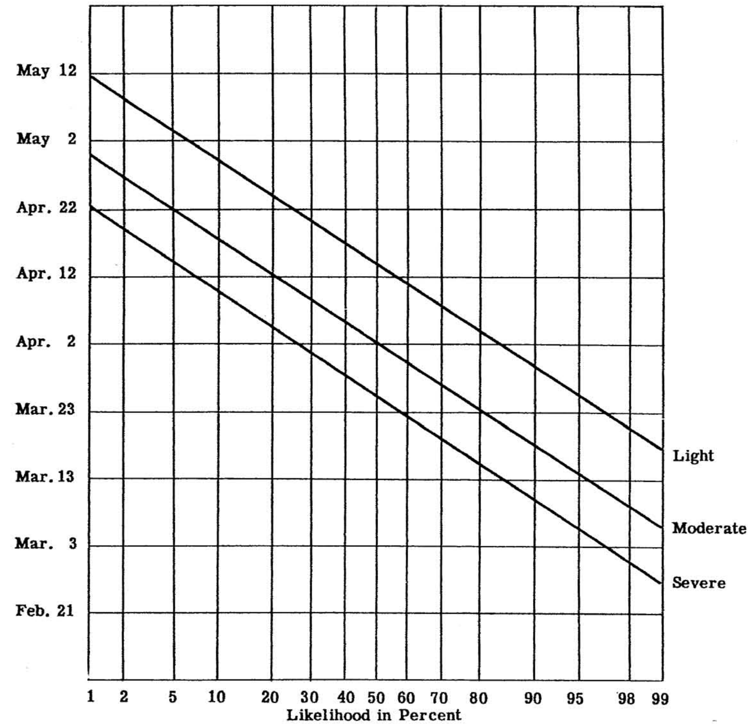

Figure 9.—Likelihood of a Killing Freeze After Any Date in Spring at Birch Tree, Missouri.

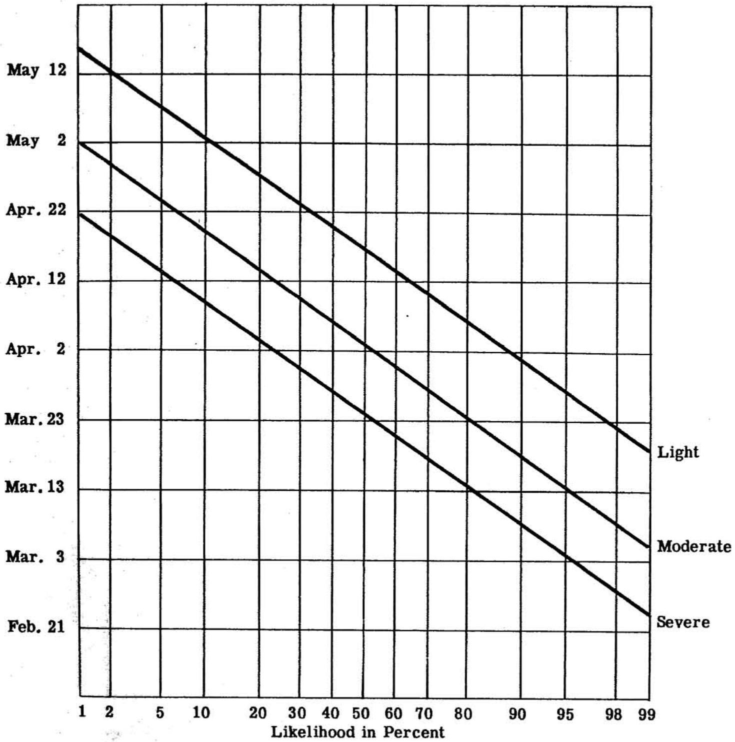

Figure 10.—Likelihood of a Killing Freeze After Any Date in Spring at Springfield, Missouri.

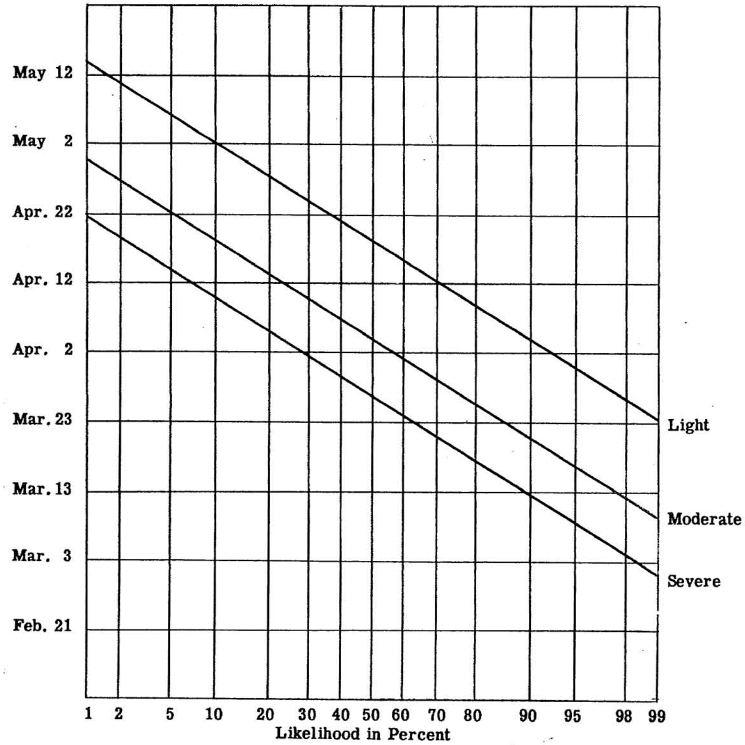

Figure 11.—Likelihood of a Killing Freeze After Any Date in Spring at Neosho, Missouri.

SPRING DATES FOR DIFFERENT FREEZE LIKELIHOODS

It might be of interest to study the dates after which there is a given likelihood that freezing temperatures will occur. The producer could decide beforehand the risk he is willing to take, and use this risk to determine when he should begin his spring operations. If he feels that he can afford to take a 20% chance of a freeze occurring, he would not plan to begin his operations until after the date where there was a 20% likelihood.

In Table 3 are listed the dates for different light freeze likelihoods at each station. The dates are given for likelihoods of 40%, 30%, 20%, 10%, and 5%. In other words, these are the dates after which a light freeze will be expected on four out of ten years, three out of ten years, two out of ten years, one out of ten years, and one out of twenty years, respectively. To be as safe as possible, the producer would wait until after the 5% date has passed. By using this date, he would expect damage only one out of twenty years. If it is felt that a likelihood of a light freeze of 10%, i. e., one out of ten years would not be too great, then the date corresponding to 10% would be used. The 40% date indicates that a freeze will occur four years out of ten, so would not be used for tender plants unless there was a tremendous advantage in supplying an early market. By way of example, let us suppose that a certain plant would be damaged by a light freeze, and that the producer does not want to take more than a 10% chance of experiencing damage by such a freeze. From Table 3, he would discover that he should not plant such a crop before May 1 in the St. Joseph area, May 4 near Columbia, etc.

In Table 4 are shown the dates after which the likelihood of a moderate freeze is 40, 30, 20, 10, and 5 per cent. Similarly, the dates for a severe freeze are shown in Table 5.

Table 3.—Dates After Which There Is the Given Likelihood of a Light Freeze Occurring

Station	Likelihoods				
	40%	30%	20%	10%	5%
St. Joseph	Apr. 20	Apr. 23	Apr. 26	May 1	May 5
Kansas City	Apr. 15	Apr. 18	Apr. 22	Apr. 27	May 1
Columbia	Apr. 22	Apr. 25	Apr. 29	May 4	May 9
St. Louis	Apr. 11	Apr. 15	Apr. 19	Apr. 26	May 1
Rolla	Apr. 19	Apr. 22	Apr. 26	May 2	May 6
Lebanon	Apr. 26	Apr. 29	May 3	May 9	May 14
Mountain Grove	Apr. 21	Apr. 25	Apr. 29	May 4	May 8
Birch Tree	Apr. 17	Apr. 20	Apr. 24	Apr. 29	May 4
Springfield	Apr. 20	Apr. 23	Apr. 27	May 3	May 7
Neosho	Apr. 21	Apr. 24	Apr. 27	May 2	May 6

Table 4.—Dates After Which There Is the Given Likelihood of a Moderate Freeze Occurring

Station	Likelihoods				
	40%	30%	20%	10%	5%
St. Joseph	Apr. 6	Apr. 9	Apr. 13	Apr. 18	Apr. 22
Kansas City	Apr. 5	Apr. 8	Apr. 12	Apr. 17	Apr. 21
Columbia	Apr. 10	Apr. 13	Apr. 17	Apr. 22	Apr. 26
St. Louis	Apr. 1	Apr. 5	Apr. 10	Apr. 16	Apr. 21
Rolla	Apr. 6	Apr. 9	Apr. 13	Apr. 19	Apr. 23
Lebanon	Apr. 11	Apr. 14	Apr. 18	Apr. 24	Apr. 29
Mountain Grove	Apr. 6	Apr. 10	Apr. 13	Apr. 19	Apr. 23
Birch Tree	Apr. 6	Apr. 9	Apr. 2	Apr. 18	Apr. 22
Springfield	Apr. 6	Apr. 10	Apr. 14	Apr. 19	Apr. 24
Neosho	Apr. 7	Apr. 10	Apr. 13	Apr. 18	Apr. 22

Table 5.—Dates After Which There Is the Given Likelihood of a Severe Freeze Occurring

Station	Likelihoods				
	40%	30%	20%	10%	5%
St. Joseph	Mar. 29	Apr. 1	Apr. 4	Apr. 9	Apr. 13
Kansas City	Mar. 25	Mar. 29	Apr. 1	Apr. 6	Apr. 11
Columbia	Mar. 28	Apr. 1	Apr. 4	Apr. 9	Apr. 14
St. Louis	Mar. 21	Mar. 25	Mar. 29	Apr. 5	Apr. 10
Rolla	Mar. 25	Mar. 28	Apr. 1	Apr. 7	Apr. 11
Lebanon	Mar. 30	Apr. 2	Apr. 6	Apr. 12	Apr. 16
Mountain Grove	Mar. 26	Mar. 30	Apr. 3	Apr. 8	Apr. 12
Birch Tree	Mar. 29	Apr. 1	Apr. 5	Apr. 10	Apr. 14
Springfield	Mar. 27	Mar. 31	Apr. 4	Apr. 9	Apr. 13
Neosho	Mar. 30	Apr. 2	Apr. 5	Apr. 10	Apr. 14

The most significant fact found in the above tables is that spring freezes occur later in several of the southern Ozark areas than in some of the more northern areas considered. This is contrary to the general concept that the growing season lengthens as one moves southward. It is not easy to explain these apparent discrepancies, but it seems rather certain that there is a significant difference. One possible explanation lies in the general altitude of the terrain in southern Missouri. It is possible that the increase in elevation is sufficient to cause the cooler spring condition. This does not completely explain the differences, and further study will be necessary to isolate the actual cause or causes.

LIKELIHOOD OF A FREEZE BEFORE A GIVEN DATE IN THE FALL

The first killing freeze in the fall terminates the season's growth for many economic plants. Some plants can withstand appreciably lower temperatures than others; but once a temperature low enough to produce injury for a particular plant is reached, growth for that season is terminated.

It should be valuable to have estimates of the risks involved in encountering freezing temperatures in the fall. The producer can prolong the season by taking protective measures, or plan his activities in such a way as to minimize the risk. By the same method used in calculating the likelihood of freezing temperatures after a given date in the spring, likelihoods of experiencing a killing freeze before a given date in the fall have been determined. These likelihoods are expressed in the same terms as before, i. e., as a percentage.

The likelihoods of a light, moderate, or severe freeze before any date in the fall for the ten stations are shown in Figures 12 through 21. The interpretations of these figures are the same as discussed in the case of the spring freezes. For example, from Figure 12 it can be seen that the likelihood of a severe freeze at St. Joseph, Missouri, before November 10, is 62%, the likelihood of receiving a moderate freeze before that date is 88%, and the likelihood of a light freeze is 97%. This means that the chances of receiving a light freeze before November 10 are great, (19 out of 20); while a severe freeze can be expected before this date on six out of ten years.

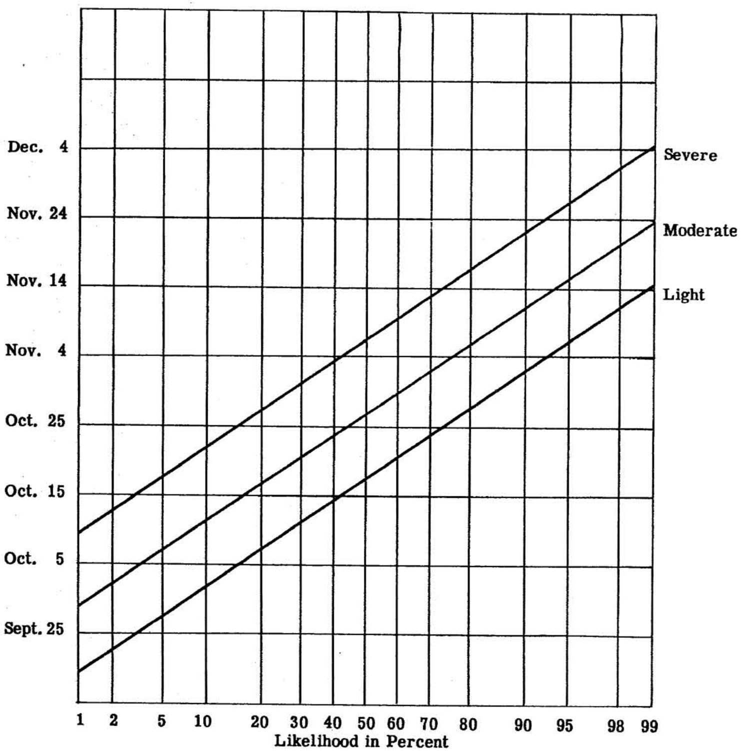

Figure 12.—Likelihood of a Killing Freeze Before Any Date in Fall at St. Joseph, Missouri.

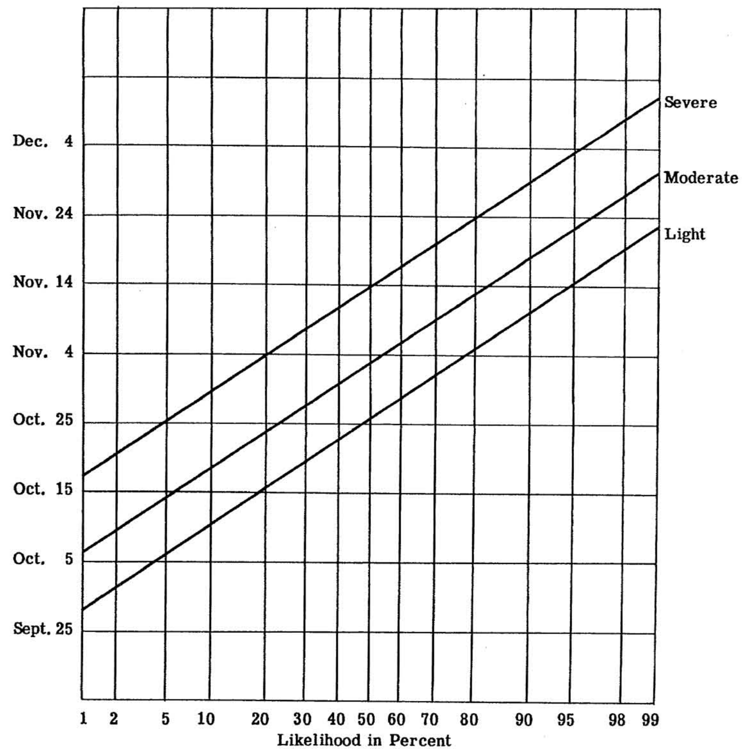

Figure 13.—Likelihood of a Killing Freeze Before Any Date in Fall at Kansas City, Missouri.

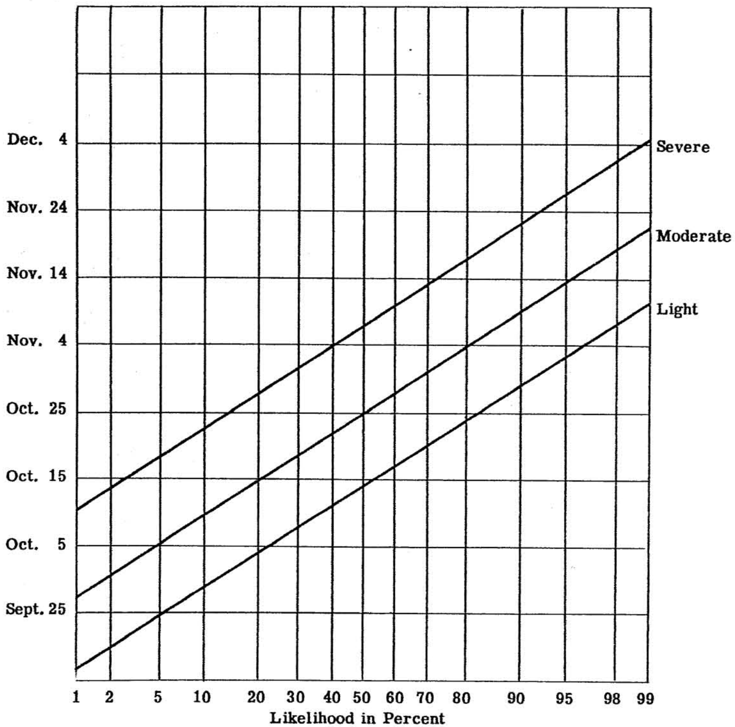

Figure 14.—Likelihood of a Killing Freeze Before Any Date in Fall at Columbia, Missouri.

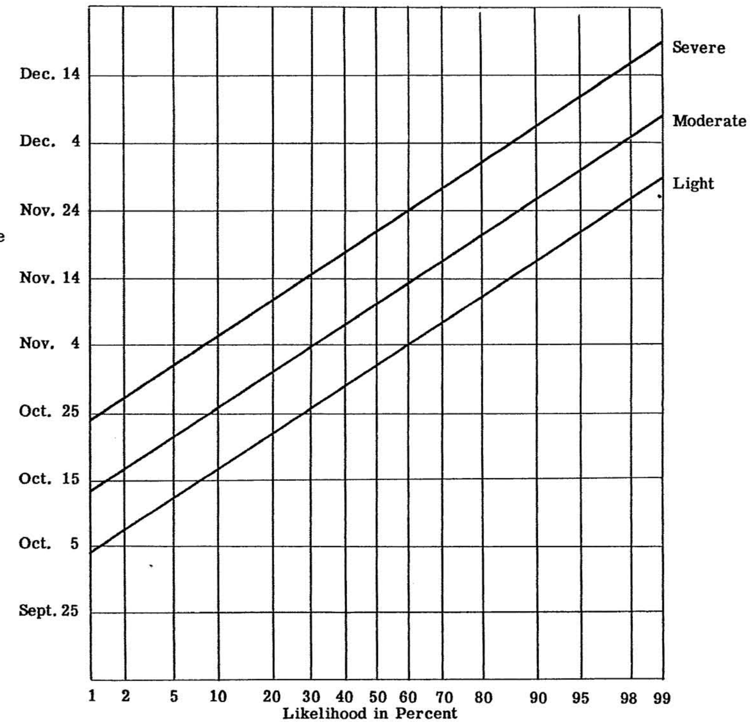

Figure 15.—Likelihood of a Killing Freeze Before Any Date in Fall at St. Louis, Missouri.

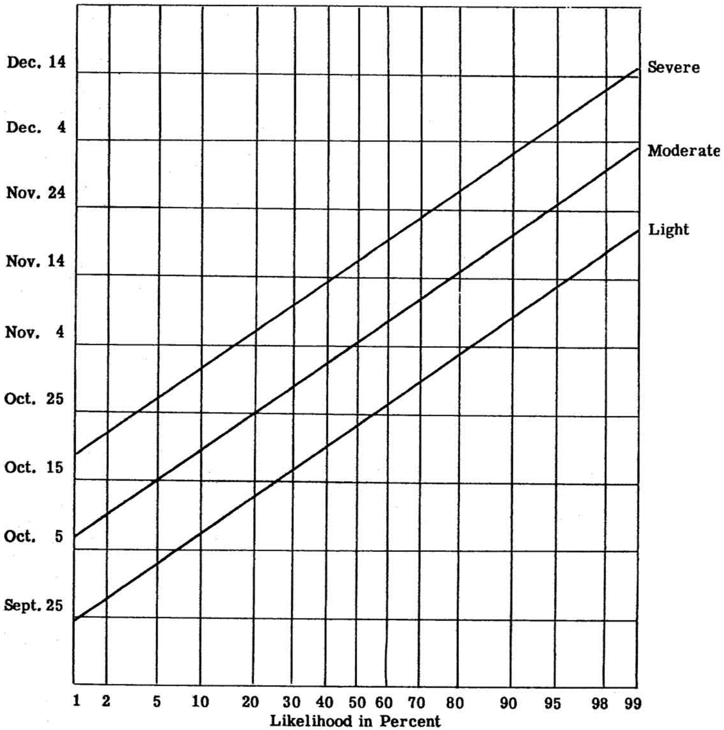

Figure 16.—Likelihood of a Killing Freeze Before Any Date in Fall at Rolla, Missouri.

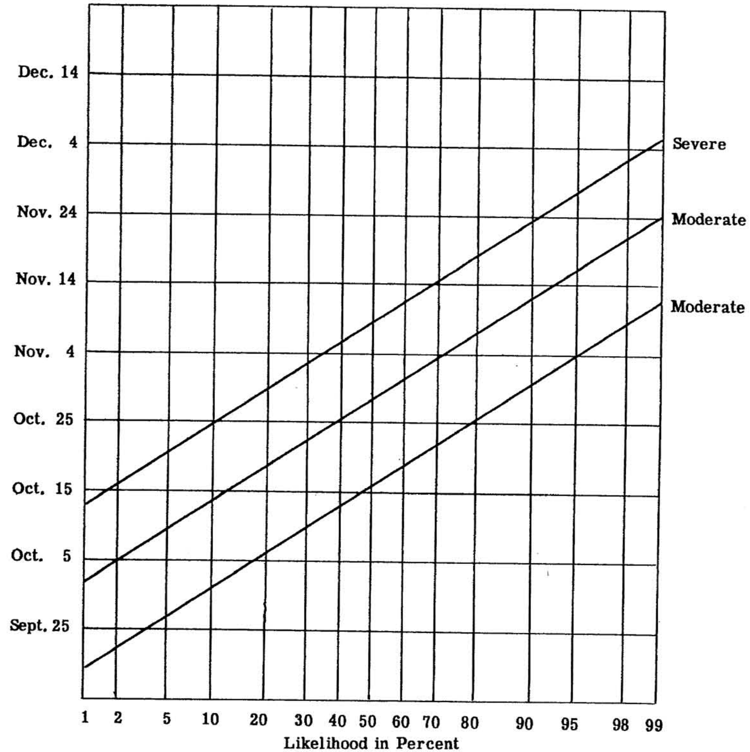

Figure 17.—Likelihood of a Killing Freeze Before Any Date in Fall at Lebanon, Missouri.

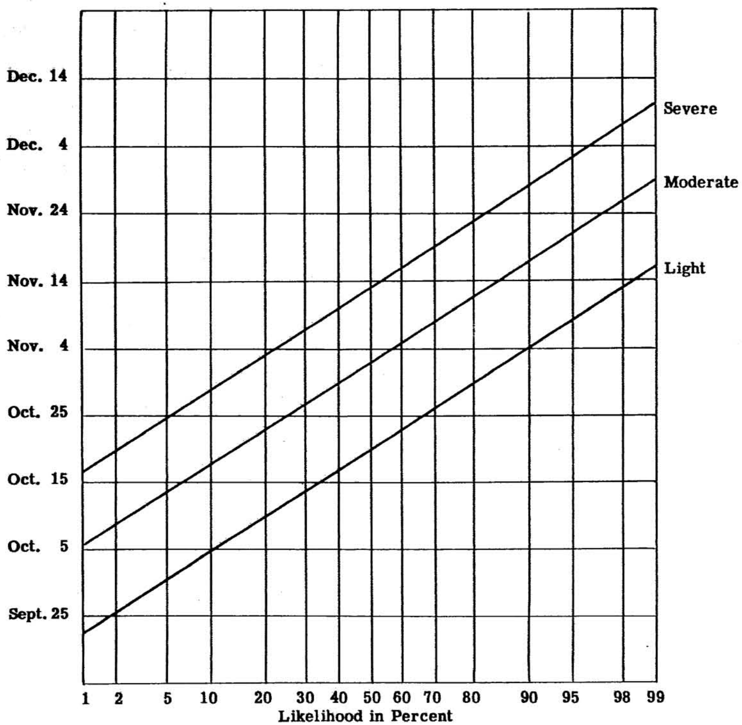

Figure 18.—Likelihood of a Killing Freeze Before Any Date in Fall at Mountain Grove, Missouri.

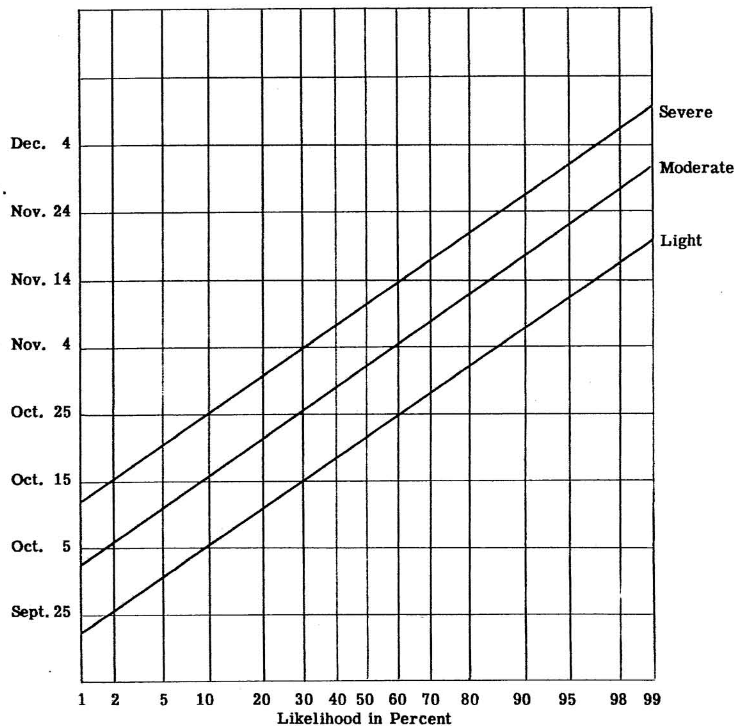

Figure 19.—Likelihood of a Killing Freeze Before Any Date in Fall at Birch Tree, Missouri.

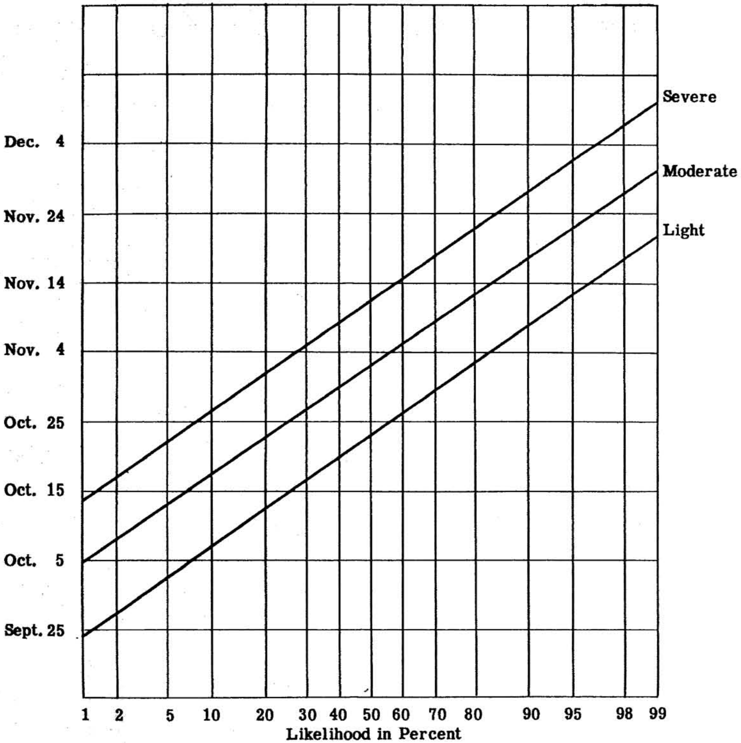

Figure 20.—Likelihood of a Killing Freeze Before Any Date in Fall at Springfield, Missouri.

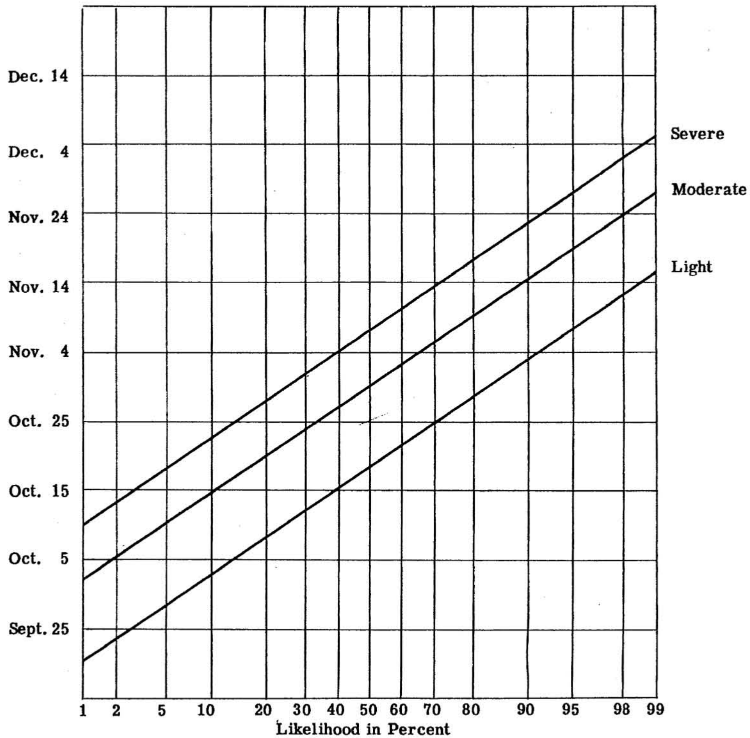

Figure 21.—Likelihood of a Killing Freeze Before Any Date in Fall at Neosho, Missouri.

FALL DATES FOR DIFFERENT FREEZE LIKELIHOODS

In Tables 6, 7, and 8 are shown the dates of specific likelihoods of a light, moderate, and severe freeze, respectively. The likelihoods express the chances of a freeze occurring before the dates given in the body of the table. The specific likelihoods used are 40, 30, 20, 10, and 5 per cent. As in the case of the spring freeze, these likelihoods really express the chances of occurrence as

Table 6.—Dates Before Which There Is the Given Likelihood of a Light Freeze Occurring

Station	Likelihoods				
	40%	30%	20%	10%	5%
St. Joseph	Oct. 15	Oct. 11	Oct. 7	Oct. 2	Sept. 28
Kansas City	Oct. 23	Oct. 19	Oct. 16	Oct. 10	Oct. 6
Columbia	Oct. 11	Oct. 8	Oct. 4	Sept. 29	Sept. 25
St. Louis	Oct. 29	Oct. 26	Oct. 22	Oct. 17	Oct. 12
Rolla	Oct. 19	Oct. 16	Oct. 12	Oct. 7	Oct. 2
Lebanon	Oct. 13	Oct. 10	Oct. 6	Oct. 1	Sept. 27
Mountain Grove	Oct. 17	Oct. 14	Oct. 10	Oct. 5	Oct. 1
Birch Tree	Oct. 18	Oct. 15	Oct. 11	Oct. 5	Oct. 1
Springfield	Oct. 20	Oct. 17	Oct. 13	Oct. 7	Oct. 3
Neosho	Oct. 15	Oct. 12	Oct. 8	Oct. 3	Sept. 28

Table 7.—Dates Before Which There Is the Given Likelihood of a Moderate Freeze Occurring

Station	Likelihoods				
	40%	30%	20%	10%	5%
St. Joseph	Oct. 24	Oct. 21	Oct. 17	Oct. 12	Oct. 7
Kansas City	Oct. 31	Oct. 28	Oct. 24	Oct. 19	Oct. 14
Columbia	Oct. 22	Oct. 19	Oct. 15	Oct. 10	Oct. 5
St. Louis	Nov. 7	Nov. 4	Oct. 31	Oct. 26	Oct. 22
Rolla	Oct. 31	Oct. 28	Oct. 24	Oct. 19	Oct. 14
Lebanon	Oct. 25	Oct. 22	Oct. 19	Oct. 14	Oct. 10
Mountain Grove	Oct. 30	Oct. 27	Oct. 23	Oct. 18	Oct. 14
Birch Tree	Oct. 29	Oct. 25	Oct. 21	Oct. 16	Oct. 11
Springfield	Oct. 30	Oct. 27	Oct. 23	Oct. 18	Oct. 13
Neosho	Oct. 27	Oct. 24	Oct. 20	Oct. 15	Oct. 10

Table 8.—Dates Before Which There Is the Given Likelihood of a Severe Freeze Occurring

Station	Likelihoods 40%	30%	20%	10%	5%
St. Joseph	Nov. 3	Oct. 31	Oct. 27	Oct. 22	Oct. 18
Kansas City	Nov. 11	Nov. 8	Nov. 4	Oct. 30	Oct. 26
Columbia	Nov. 4	Nov. 1	Oct. 28	Oct. 23	Oct. 19
St. Louis	Nov. 18	Nov. 15	Nov. 11	Nov. 6	Nov. 1
Rolla	Nov. 12	Nov. 9	Nov. 5	Oct. 31	Oct. 26
Lebanon	Nov. 6	Nov. 2	Oct. 30	Oct. 25	Oct. 21
Mountain Grove	Nov. 10	Nov. 7	Nov. 3	Oct. 29	Oct. 25
Birch Tree	Nov. 7	Nov. 4	Oct. 31	Oct. 25	Oct. 21
Springfield	Nov. 8	Nov. 5	Nov. 1	Oct. 27	Oct. 22
Neosho	Nov. 4	Oct. 31	Oct. 27	Oct. 22	Oct. 18

follows: a likelihood of 40% means that a freeze can be expected on four out of ten years, 30% a freeze three out of ten years, 20% a freeze two out of ten years, 10% a freeze one out of ten years, and 5% a freeze one out of twenty years. To be entirely safe, the producer should attempt to cease ooperations before the 5% date, but in a good many cases it might be well to take some chance, and these tables should aid in determining the amount of risk involved.

SUMMARY

1.—Three types of freeze have been defined. The light freeze was considered as causing injury only to extremely sensitive plants. The moderate freeze was defined to be a freeze which would also injure semi-hardy garden plants and orchard blooms, while the severe freeze would damage all tender vegetation.

2.—The danger of spring and fall freezing temperatures is expressed as freeze likelihoods. These freeze likelihoods are given in percentage for a particular date and indicate the chances of sustaining freeze damage. If, for example, it is said that the freeze likelihood of a light freeze after May 4 is 10% at Columbia, Missouri, it would mean that a light freeze in the spring would be expected at Columbia after May 4 on one out of ten years. Similarly, the freeze likelihood of a light freeze of 10% before September 29 at Columbia, Missouri, indicates that a light freeze in the fall can be expected before September 29 on one out of ten years.

3.—The likelihood of freeze damage in the spring at the ten Missouri locations considered in this report can be found in Figures 2 through 11 and Tables 3 through 5. If these data are examined it will be noted, for example, that the last freeze in spring normally occurs earlier in the St. Louis area than in the other regions of the state considered in this report. Likewise, Lebanon can expect freezing temperatures later in the spring than the other locations.

4.—In the case of the fall season the freeze likelihoods can be found in

Figures 12 through 21 and Tables 6 through 8. From these data it can be seen that the first fall freeze can be expected in the St. Louis area later than in the other regions of the state considered.

5.—By following the freeze likelihoods found in the body of this report the farmer should obtain a means of determining the best dates for planting and harvesting many tender crops. He will be able to minimize his risk while making a maximum use of the growing season.

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