FREEZE PROBABILITIES IN ILLINOIS

By Lothar A. Joos

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CONTENTS

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By Lothar A. Joos[1]

The agricultural economy of Illinois is based primarily on the field crops of corn, soybeans, oats, hay, and winter wheat. Of these, only corn and soybeans are ordinarily considered as subject to freeze damage. However, the mean freeze-free season in Illinois of 160 to 190 days is usually quite adequate for these crops and serious frost losses are uncommon. Thus the traditional corn-belt type of farming has had little need for a detailed analysis of the probability of frost damage.

There is, however, a growing interest in the freeze-hazard problem, owing to the increased cultivation of vegetable crops in the northern counties and an expansion of small-fruit and tree-fruit production in southern Illinois. In both sections there is a steadily increasing pressure to cut costs through the fullest and most efficient use of harvesting, processing, and marketing facilities. The extension of a canning pack by only a few days may mean the difference between profit and loss for a season. Yet a decision to extend the season requires an accurate analysis of the risk that freezing may occur earlier or later than usual.

PURPOSE AND METHOD OF STUDY

The purpose of this bulletin is to present information on the probability of frost occurring in Illinois on dates other than the mean freeze dates and to provide supplementary material on freeze conditions in the state.[2]

Temperature records of 59 weather stations throughout Illinois (Fig. 1) for the 30-year period 1921-1950 (the base period currently used by the U. S. Weather Bureau for computing normals in temperature and precipitation) were analyzed for the last occurrence in spring and the first in fall of 32°, 28°, 24°, 20°, and 16° F. For each temperature and for each station the mean freeze date, the variance, and

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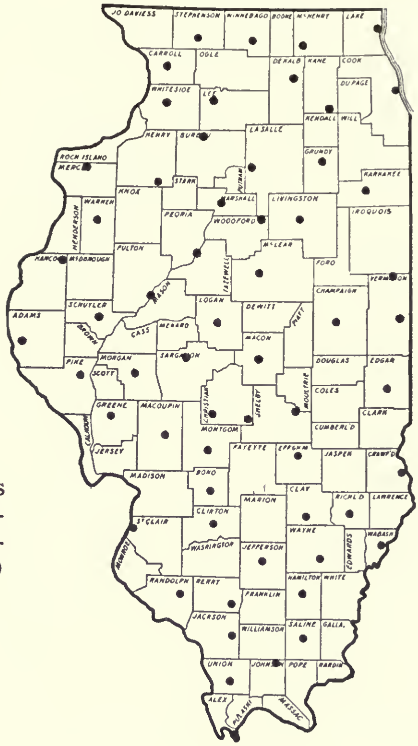
[2] Earlier publications concerning frost in Illinois include the U. S. Department of Agriculture 1941 Yearbook of Agriculture, "Climate and Man," which presents available data through 1938, and Illinois Agricultural Experiment Station Bulletin 532, "Climate of Illinois," which has data through 1946. Neither publication deals with probabilities; rather they are concerned with determining the mean dates of frost occurrence or the mean length of the freeze-free season.



Location of stations from which temperature records were obtained. (Fig. 1)

the standard deviation were computed. These computations were performed by the National Weather Records Center, U. S. Weather Bureau.

Probabilities of the selected temperatures occurring on other than the mean dates were then computed, using statistical measures described below. The final step was the preparation of freeze maps, which present in graphic form the mean freeze dates, accompanied by a conversion chart for four other levels of probability.

Computation of probabilities. The mean freeze date represents probability at the 50-percent level, that is, there is a 50-50 chance that the indicated freeze intensity will occur by the mean freeze date. For the determination of probability levels other than 50 percent, a statistical analysis was made.

It has been shown that the dates of threshold freezes (the last freeze in the spring and the first in the fall) follow the normal frequency distribution.[1] Thus it is necessary only to compute the mean freeze date and the standard deviation to describe completely the frequency distribution of threshold-freeze dates. Since the true mean and standard deviation are seldom known, the usual practice is to compute estimates of these from the available records.

To improve further the estimates of the variance and to simplify procedures it was decided to pool all the variances for all stations for the spring season and to do the same for the fall. The pooled variances and standard deviations were as follows:

	Spring	*Fall*
Variance	177.9	157.2
Standard deviation, days	13.3	12.5

The above values of the standard deviation were then plotted on normal-probability graph paper. The results were as follows:

	The number of days before (minus sign) or after (plus sign) the mean freeze date, at probability levels of:				
	75%	*50%*	*25%*	*10%*	*5%*
Spring	−9	0	+9	+17	+22
Fall	+9	0	−9	−16	−21

For the spring season, the probability refers to the chance that there will be another freeze after the date indicated. For example, if a mean freeze date is April 10 then there is a 25-percent chance (1 chance in 4) of a freeze after April 19 and a 10-percent chance (1 chance in 10) of a freeze after April 27.

For the fall season, the probability refers to the chance that the first freeze will occur before the date indicated. For example, if a mean freeze date is October 20 then there is only 1 chance in 10 that the first freeze will occur by October 4 but 3 chances out of 4 that it will occur by October 29.

FREEZE CONDITIONS

Threshold Occurrences

The term "threshold occurrence" refers to the last occurrence of a given freezing temperature in the spring or the first in the fall. The length of the freeze-free season is computed as the period between the spring and fall threshold occurrences. The official weather reports for Illinois list the threshold occurrences of 32°, 28°, 24°, 20°, and 16° F.

[1] H. C. S. Thom and R. H. Shaw, "Climatological Analysis of Freeze Data for Iowa," *Monthly Weather Review,* July, 1958.

These are published in the annual state summary, "Climatological Data, Illinois Section." For example, the threshold-freeze data for 1957 for Urbana are listed as follows:

	32° F.	*28° F.*	*24° F.*	*20° F.*	*16° F.*
Spring.......	Apr. 14	Apr. 14	Apr. 12	Mar. 8	Feb. 20
Fall.........	Oct. 26	Oct. 27	Nov. 9	Nov. 10	Nov. 30
Season (days)	195	196	211	247	283

Consideration of freeze intensities other than 32° enhances the usefulness of freeze data, since some crops, such as celery or pumpkin, can withstand temperatures well into the 20's. Also, in fields such as engineering and construction, data on freezing temperatures other than 32° F. are very useful.

Killing Frost

The recording of threshold occurrences has been in practice in Illinois and most other states since 1948. Previously, Weather Bureau records had listed only the "killing frost." A killing frost was recorded when tender varieties of the staple vegetation in the vicinity had been killed or when the temperature in the standard weather shelter had dropped to 32° or lower.

Difficulties arose in recording the killing frost because of the lack of a fixed criterion. For example, although the term was "killing *frost*" and frost very often did form on plants during a killing frost, the presence of frost was not essential; it was the damaging effect of the low temperature on growing plants which it was desired to record. But then, some plants might be killed on low ground or in rural areas but not on high ground or in the city. Even expert agronomists sometimes differed as to whether a general killing frost had occurred. It was thus felt that cooperative weather observers were being asked to make judgments which often could be only arbitrary decisions, and in 1948 the tabulation of killing frosts was dropped. The present listing of the threshold occurrence of 32° replaces the former killing-frost tabulation. In most areas the difference between mean dates for killing frost and for the 32° threshold freeze is only one or two days.

Effects of Freezing Temperatures

Freeze intensities can be classified for agricultural purposes as follows:

Light freeze with a minimum shelter temperature in the range of 29° to 32° will cause heavy damage to tender plants in most locations. In spring this means killing or "freezing back" the leaves of corn, soybeans, peas, tomatoes, etc. Strawberries in blossom are damaged heavily but tree fruits usually escape harm even while in blossom. Such a freeze in the fall stops the growth of corn, soybeans, pumpkins, tomatoes, and squash but ripe fruit or grain are not harmed. Vegetation on high ground may suffer little or no injury in a light freeze.

Moderate freeze with a minimum shelter temperature of 25° to 28° will cause moderate or heavy damage to tree fruits in any stage of bloom. Semi-hardy plants such as beets, carrots, lettuce, and spinach will be damaged. Tomato fruit as well as vines will be lost. Germination of hybrid corn and soybean seed may suffer unless full maturity has been reached. Tender vegetation on even the highest ground will usually be killed.

Severe freeze with a minimum temperature of 21° to 24° will damage ripe pumpkin, squash, or cabbage in the field. Even ripe potatoes near the ground surface may be frozen.

Freezing temperatures of 20° or lower are usually not dangerous to perennial plants in Illinois. However there may be damage if such temperatures occur suddenly and after a long spell of warm weather. This may occur with threshold freezes that are unusually late in the spring or early in the fall. The probability of such occurrences is an important consideration for nurserymen and orchardists.

Kinds of Threshold Freezes

Threshold freezes are most commonly of the "radiation" type. Ideal conditions for this type of freeze include an air mass of low humidity, absence of clouds, and comparatively little wind movement. The absence of a cloud cover permits long-wave radiation from the soil and plant surfaces to escape freely into outer space whereas clouds act to absorb the radiation and return most of it to the earth. The dryness or low humidity of the air mass aids the loss of radiation since water vapor also has the power to absorb long-wave radiation and return part of it to the earth. Finally, as air near the ground becomes cooler and heavier, both vertical and horizontal wind movements are inhibited. The result is that the cool air near the ground has no opportunity to mix with the relatively warmer and lighter air aloft.

Another type of threshold freeze is the "advection" freeze. Such a freeze occurs when a uniformly cold air mass moves into the area with strong northwest or northerly winds. The winds continue through the night and there may be a persistent cloud cover. In spite of the cloud cover and the turbulent effects of the wind, surface air temperatures drop to 32° or lower. The freezing develops because of the basic coldness of the air mass. In an advection freeze there is a considerable uniformity in minimum temperatures whether the comparison is between ground and tree-top temperatures or temperatures in one county and in another. Elevation of the ground, air drainage, ground cover, etc., have little effect on such a freeze.

Thus cloudiness, wind, and water vapor generally tend to inhibit nighttime cooling and freezing while clear skies, dry air, and weak wind all favor cooling at the surface and increase the risk of freezing. The "advection" freeze is caused by an air mass so cold that freezing occurs even though cloudiness and wind persist through the night. The "radiation" freeze occurs when clear skies, light wind, and low humidity permit surface cooling to 32° or lower.

An "advection-radiation" freeze is a freeze that occurs when the cold air mass moves in strongly during the day or evening and is followed by clearing skies and reduction of wind during the night. This combination often produces the most severe freezing.

Effects of Elevation

During radiation freezes (the most common type of threshold freeze) differences in elevation of even 5 feet can result in different temperatures. The temperature at a leaf surface may be 28° or 30° while the thermometer in the Weather Bureau instrument shelter, which is generally 5 feet above the ground, may register 34° or 35°. Where there is some slope to the land, there will also be a difference between official observing stations that are located on high ground and those that are on low ground. For example, Morrison in northwestern Illinois is 603 feet above sea level while nearby Mt. Carroll is 817 feet high. Radiation freezes generally occur with greater ease (later in the spring and earlier in the fall) at Morrison than at Mt. Carroll.

The same tendency can be noted when analyzing the freeze hazard at a particular farm or orchard. If the land is lower than the surrounding area or lower than the official observing station, the freeze hazard is somewhat increased, while an increase in elevation means a reduction in the freeze hazard.

The reason for these temperature differences is that cold air collecting near the ground is heavy and tends to drain into low places. This produces the well-known "frost hollow" effect. This temperature difference due to elevation may be considerable in hilly areas, such as the extreme northwestern parts of Illinois or in the Illinois Ozarks in the south.

It should be noted that differences in elevation of 2,000 feet or more give an opposite effect. At such higher elevations the climate is cooler and the freeze hazard is thus increased. However, in Illinois differences in elevation are much smaller than 2,000 feet and any climatic cooling due to elevation is more than overcome by the increased freeze hazard at lower elevations due to air drainage.

THE FREEZE MAPS

Preparation of Maps

After the mean freeze dates for all stations were computed, they were plotted on maps of Illinois. These maps were then analyzed and isolines (lines joining points having the same mean freeze dates) were drawn to provide an area representation of the freeze hazard. Variations affecting freeze, such as elevation, rooftop exposures, and presence of large bodies of water were considered and adjustments in the isolines were made accordingly. Variations due to sampling error were reduced by smoothing out minor irregularities on the analyzed maps.

Elevation. Varying elevations were a principal cause of irregularity. Some Illinois observing stations are located in the valleys of the Mississippi, Illinois, Ohio, and Wabash rivers while others are on higher ground. One step in the analysis was the consideration of the elevation of each station in relation to the surrounding area; if there was a significant difference, adjustments were made so that a more logical pattern of the freeze hazard would be shown.

Rooftop exposures. Another source of irregularity was the rooftop exposure of thermometers at some urban stations. Since rooftop temperatures are usually warmer during freeze situations than at ground level, considerable adjustments were necessary in order to represent more accurately the areas in question.

Lake Michigan area. Adjustments for the Lake Michigan area were more difficult to make than those for elevation differences and for differences in thermometer exposure. Since the lake is always warmer than the land during threshold-freeze situations, the presence of the lake may considerably reduce the freeze hazard. This warming influence may extend 20 miles or more inland when the wind is easterly but less than 5 miles when winds are toward the lake. It would have required many more observing stations than available to evaluate properly the freeze hazard near the lake. Thus the maps as drawn reflect a fairly subjective analysis for the Lake Michigan area. The general pattern is correct but the values for individual locations near Lake Michigan may not be very accurate.

Patterns of Freeze Hazard

As can be seen from the freeze maps (Figs. 2-11) the warmest areas in Illinois (earlier spring and later fall freeze dates) are in the south and at slightly higher elevations between the Mississippi and Illinois rivers in the west. The Lake Michigan area also has a reduced freeze hazard because of the warming influence of the lake. Cooler areas (later spring and earlier fall freeze dates) are found in the north and at lower elevations near the rivers. These patterns of freeze hazard are similar for both spring and fall seasons and for the different freeze intensities.

The difference in freeze hazard between the north and south is somewhat greater in spring than in fall. During spring there is a difference of about 30 days between mean freeze dates in the extreme north and the extreme south. Spring seems to arrive about a month later at Freeport than at Vienna or Anna. During the fall the difference in freeze hazard between the extreme north and extreme south is only about three weeks.

How to Use the Maps

To determine the likelihood of a freeze of a given intensity in a particular area, first locate the area on the appropriate freeze map. The lines on the map indicate the mean date for the freeze; if the area in question is between lines, it is possible to interpolate with an accuracy of one or two days.

The mean date is the 50-percent probability date. This date is convenient for reference and for comparing one area with another. Although the mean dates of freezing are used most often, frequently it is important to know probabilities other than 50 percent. For example, if a farmer plans to transplant tomatoes on the mean freeze date he is taking a 50-percent chance that there will be no freeze after that date. Generally 50 percent is too great a risk but if he waits until all danger of a freeze is past, the planting date may be too late for best results. In most situations, the acceptable level of risk is somewhere between 50 percent and 5 percent.

To find the dates for other probability levels, refer to the map legend and apply the proper correction. On the maps showing spring threshold occurrences (Figs. 2 through 6) the probability levels given in the legend refer to the chance that a freeze will occur after the date indicated. The freeze maps giving fall threshold occurrences (Figs. 7 through 11) give the probabilities of a freeze occurring before the date indicated.

Here are two examples of how the freeze maps may be used to help solve agricultural problems:

1. It is assumed that cabbage transplants can withstand a 32° freeze but not a 28° freeze. In planting for the early market, what is the earliest that farmers in the Joliet area, in Will county, should transplant cabbage? Growers are willing to take a 25-percent chance of freeze damage.

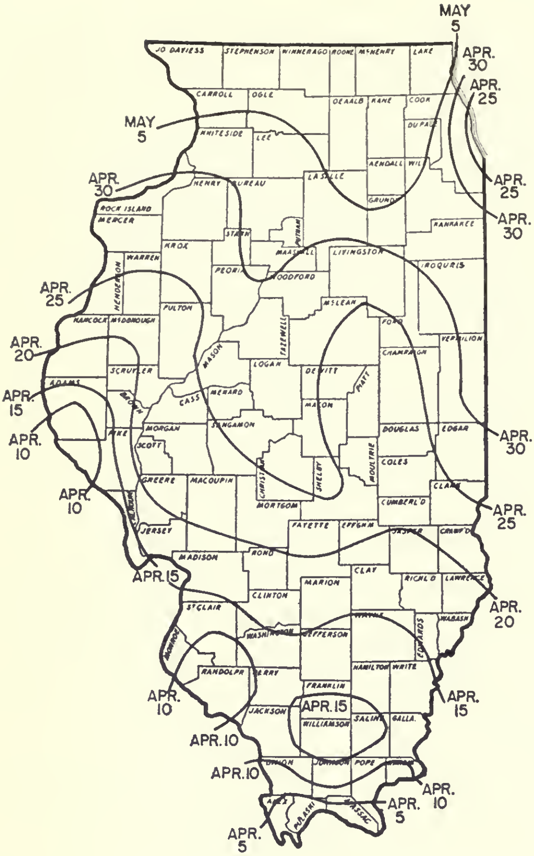
Answer: Fig. 3 shows that the mean date for the last 28° freeze at Joliet is April 20. The legend shows that there is a 25-percent chance that a 28° freeze will occur after April 29 (nine days later than the mean freeze date). Therefore April 29 is the earliest date on which farmers in the Joliet area should transplant cabbage.

2. During the pumpkin harvest at Eureka, 16 miles east of Peoria, in Woodford county, ripe pumpkins left in the field can withstand 25° without damage. If wet weather should delay completion of the harvest beyond October 31, what is the risk of freeze damage by that date?

Answer: Fig. 9 shows the mean dates for the first 24° freeze in the fall. On the map Eureka is located between the isolines indicating mean freeze dates of October 31 and November 5, but is closer to the November 5 isoline; hence the mean freeze date for Eureka can be estimated as November 4. In other words, there is a 50-percent chance of a 24° freeze occurring at Eureka by November 4. The legend shows that there is a 25-percent chance that the first 24° freeze will occur nine days earlier, or October 26 at Eureka. Thus the risk of 24° occurring at Eureka by October 31 is between 25 percent and 50 percent, probably around 40 percent.

CONCLUDING REMARKS

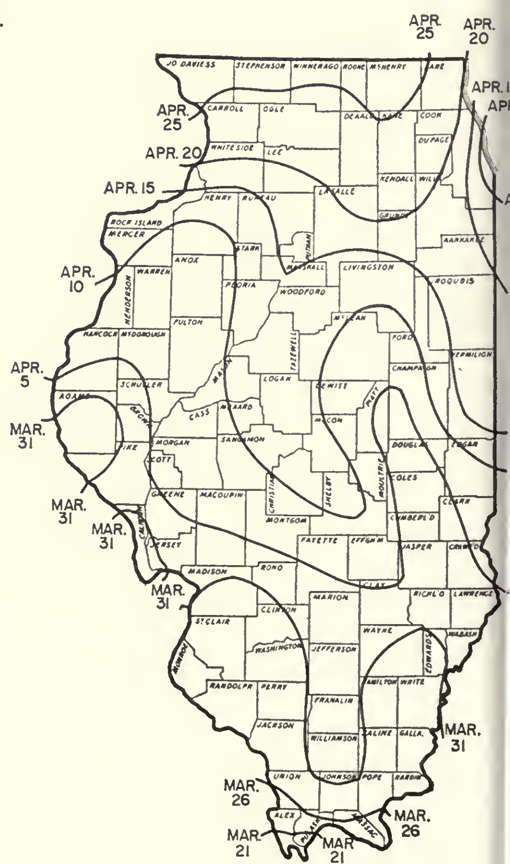
The usefulness of the probability statements given in this bulletin is limited to long-range planning, when no other type of forecast or outlook is available. During a particular season and as the 30-day outlook, the 5-day forecast, and the 2-day forecast become available, the climatic risk "forecast" should retire from consideration.



Mean dates of last 32° freeze in spring. (Fig.

PROBABILITY OF A FREEZE AFTER:

9 days earlier than mean date	75 %
the mean date	50 %
9 days later than mean date	25 %
17 days later than mean date	10 %
22 days later than mean date	5 %



Mean dates of last 28° freeze in the spring. (Fig. 3)

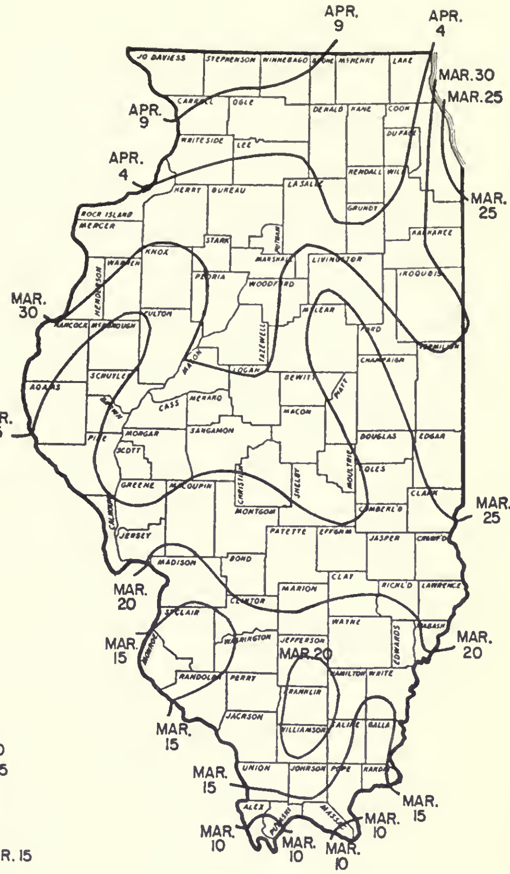
PROBABILITY OF A FREEZE AFTER:

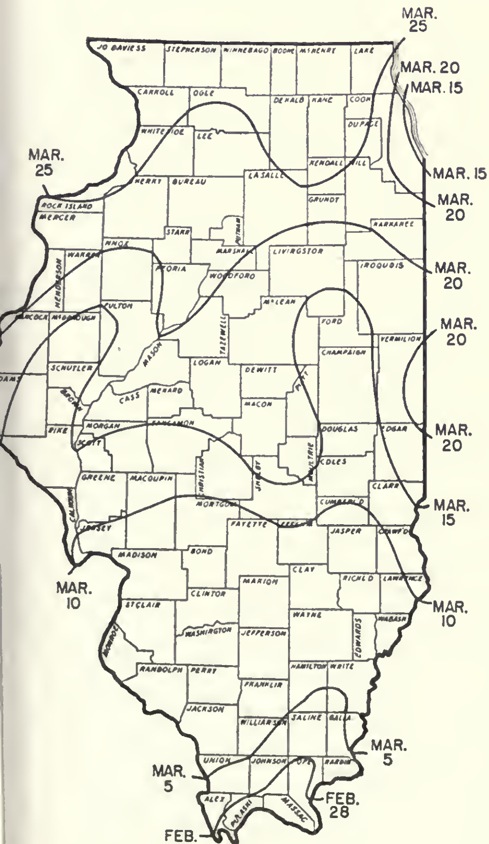
9 days earlier than mean date	75 %
the mean date	50 %
9 days later than mean date	25 %
17 days later than mean date	10 %
22 days later than mean date	5 %

n dates of last 24° freeze in the
ng. (Fig. 4)

PROBABILITY OF A FREEZE AFTER:

days earlier than mean date....	75%
e mean date.................	50%
days later than mean date......	25%
7 days later than mean date.....	10%
2 days later than mean date.....	5%

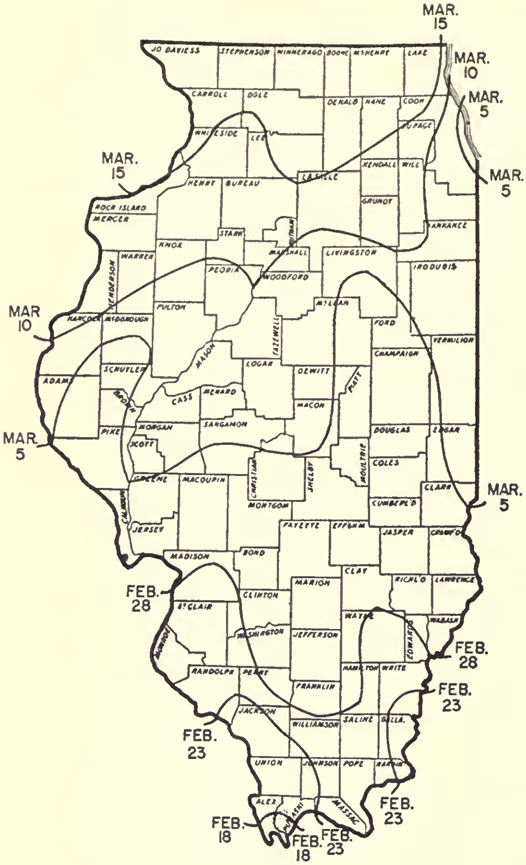




Mean dates of last 20° freeze in the spring. (Fig. 5)

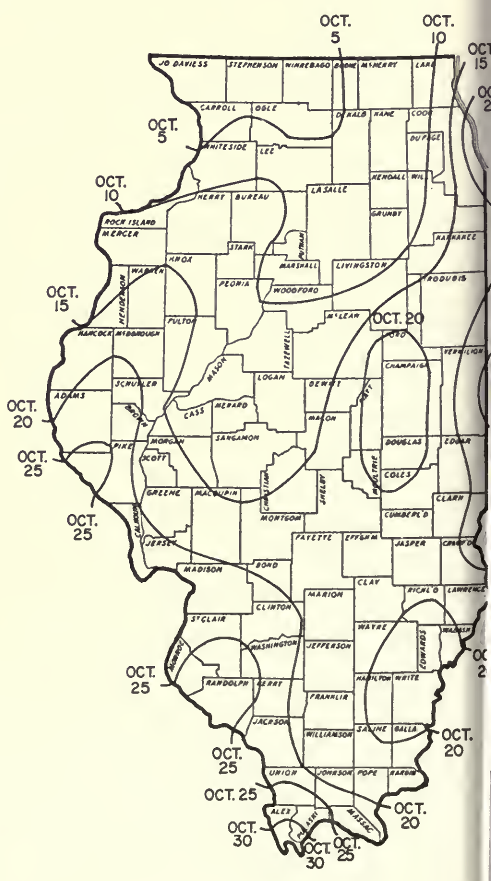
PROBABILITY OF A FREEZE AFTER:

9 days earlier than mean date....	75%
the mean date.................	50%
9 days later than mean date......	25%
17 days later than mean date.....	10%
22 days later than mean date.....	5%



Mean dates of last 16° freeze in spring. (Fi

PROBABILITY OF A FREEZE AFTER:	
9 days earlier than mean date....	75
the mean date.................	50
9 days later than mean date......	25
17 days later than mean date.....	10
22 days later than mean date.....	5

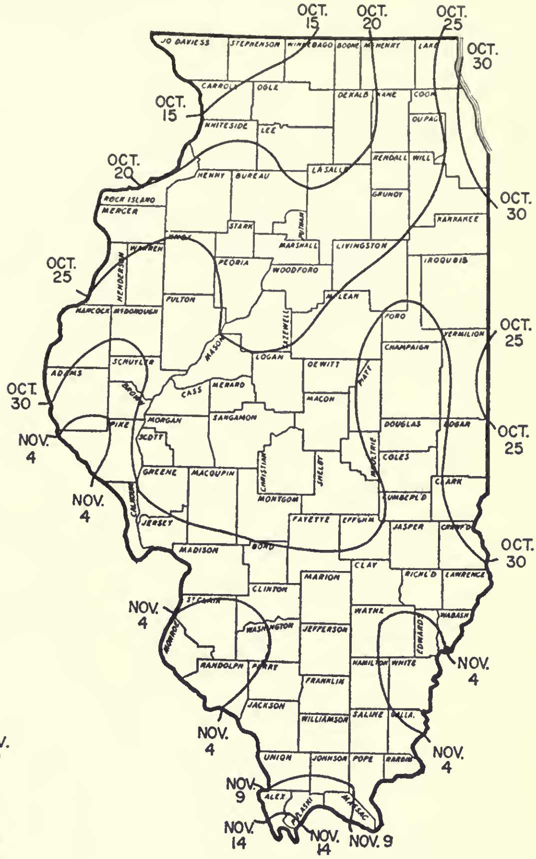


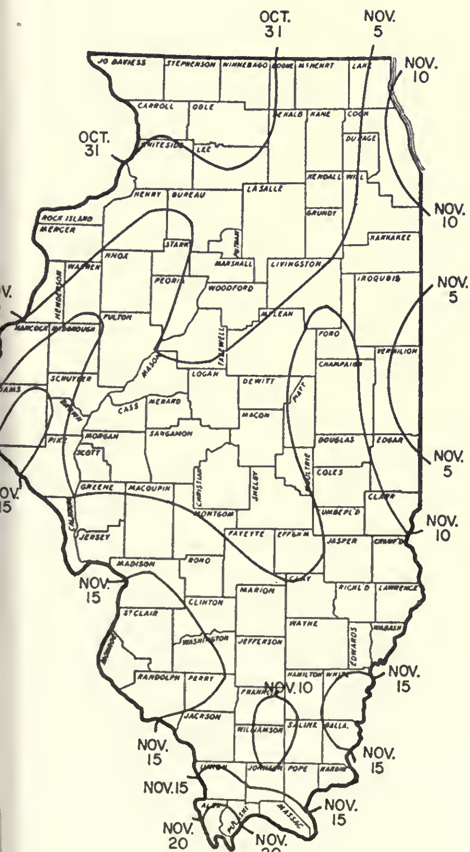
Mean dates of first 32° freeze in the fall. (Fig. 7)

PROBABILITY OF A FREEZE BEFORE:	
9 days later than mean date......	75%
the mean date.................	50%
9 days earlier than mean date....	25%
16 days earlier than mean date...	10%
21 days earlier than mean date...	5%

n dates of first 28° freeze in the
(Fig. 8)

PROBABILITY OF A FREEZE BEFORE:	
days later than mean date......	75%
mean date..................	50%
days earlier than mean date....	25%
days earlier than mean date...	10%
days earlier than mean date...	5%





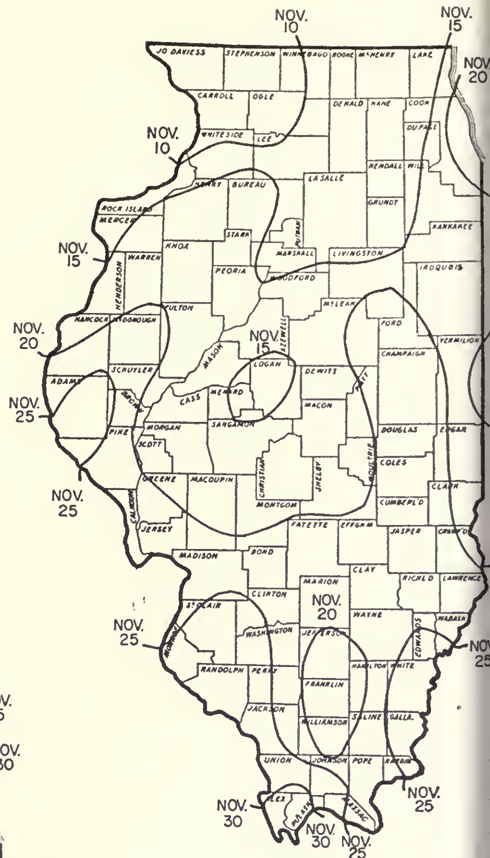
Mean dates of first 24° freeze in the fall. (Fig. 9)

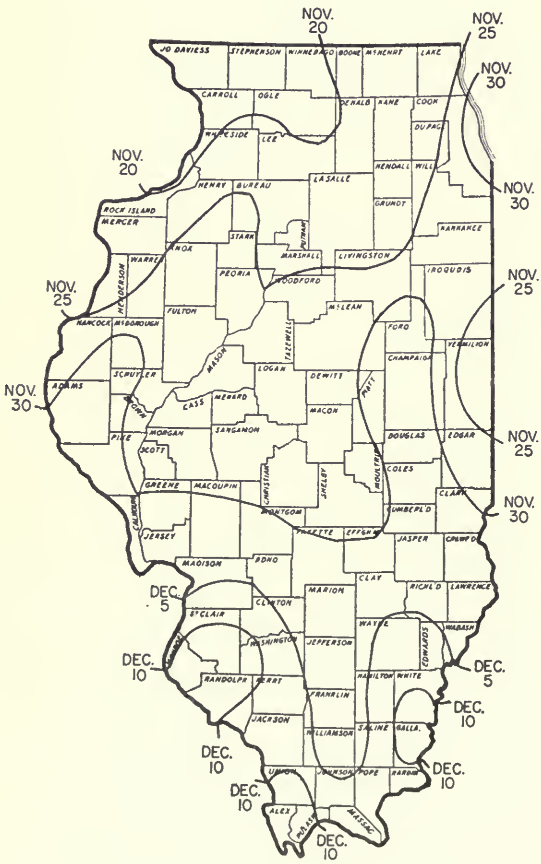
PROBABILITY OF A FREEZE BEFORE:	
9 days later than mean date......	75%
the mean date..................	50%
9 days earlier than mean date....	25%
16 days earlier than mean date...	10%
21 days earlier than mean date...	5%

Mean dates of first 20° freeze in the fall. (Fig. 10)

PROBABILITY OF A FREEZE BEFORE:

9 days later than mean date	75 %
the mean date	50 %
9 days earlier than mean date	25 %
16 days earlier than mean date	10 %
21 days earlier than mean date	5 %





Mean dates of first 16° freeze in fall. (Fig.

PROBABILITY OF A FREEZE BEFORE:

9 days later than mean date	75
the mean date	50
9 days earlier than mean date	25
16 days earlier than mean date	10
21 days earlier than mean date	5