# INDIANA REGIONAL CONTRASTS IN TEMPERATURE AND PRECIPITATION

## WITH SPECIAL ATTENTION TO THE LENGTH OF THE GROWING SEASON AND TO NON-AVERAGE TEMPERATURES AND RAINFALLS

STEPHEN S. VISHER, Indiana University

**Introductory.**—*The Problem:* How great are the regional contrasts in Indiana with respect to temperature and precipitation? What causes the contrasts? What significance do the contrasts have? *The Method:* The climatic data gathered during many years under the supervision of the U. S. Weather Bureau at the scores of scattered cooperative stations and the five full-time weather bureau stations in Indiana, together with data gathered at the nearby regular stations, Chicago, Cincinnati, and Louisville, supplied the data to establish the contrasts. In the following paper, 31 maps depict significant climatic contrasts. An understanding of the causes of the contrasts requires a knowledge of climatology and a consideration of the effects of Indiana's differences in latitude, altitude (Fig. 2), and relief, and relationship to Lake Michigan. The significance of the contrasts is suggested by comparisons among these 31 climatic maps (and fifteen others not published for lack of space) and numerous other maps showing distribution of crops, population, attainment, land values, etc. (At the close of the paper is a summary of the findings.)

Scores of patient volunteer observers have daily recorded the temperature, rainfall, and certain other climatic data for their localities, since 1914 under the able supervision of J. H. Armington, state director of the U. S. Weather Bureau, which maintains five full-time stations in Indiana, at Fort Wayne, Royal Center, Terre Haute, Evansville, and the state headquarters, Indianapolis. The popular interest in climatic data has been less widespread in Indiana, however, than in many other states, which fact reflects the dependability of our climate. Indiana generally receives almost enough rainfall and seldom a great excess; it generally has enough warmth and seldom a great excess; neither early nor late freezing temperatures interfere seriously with the growing of our main crops. Moreover, destructive storms are rare in Indiana. Because of this very excellence of Indiana's climate, it has been studied less fully than that of many other areas. Indeed, this paper appears to be the first on Indiana's climate which has been presented before the Academy. In less fortunate states, Iowa for example, the greater irregularity of rainfall and the greater extremes of temperature led many of even the earlier settlers to appreciate the great importance of rainfall and temperature. As a result, Iowa has many more long rainfall records than has Indiana. Our longest records are for Vevay (Switzerland County) (69 years), Richmond (65), Indianapolis (64), Evansville (58), Terre Haute (57), Lafayette (56), Logansport (56), Mauzy (Rush C.) (54), Farmland (Randolph C.) (53), Elliston (Greene C.) (53), Jeffersonville, Marengo, and Princeton (52), Bloomington and Columbus (51), and Rockville (50). There are 88 stations in the state at present, nine of which have less than ten years of records. In addition, earlier records are available for several localities not now represented.

After a sufficient number of climatic data have been gathered, they may be presented in tables and summarized on maps. Averages have commonly been considered of chief importance, and hence until recently, most published presentation of Indiana climatic data has been of averages, moreover, chiefly annual averages.[1] So far as their influence upon living things is concerned, annual averages are of little significance. The atmospheric conditions which clearly affect life are the actual ones which occur, not averages. The extremes are of particular significance as setting limits which must be withstood. Hence the conventional tables and maps of average annual rainfall and temperature should be supplemented as fully as possible by tables and maps showing extremes and the duration of specific conditions, such as freezing temperatures and periods with inadequate rainfall.

As a geographer, I am especially interested in the effects of the contrasts, but all scientists are interested in causes. The causes of observed contrasts in Indiana's climate are by no means all fully understood, and some are due to such complicated influences that it is impractical to try to present even a summary. However, a few great causes can be advantageously pointed out.[2]

## Regional Contrasts in Temperature

The northward decline in temperature shown by Figure 1, and almost all other maps of Indiana's temperatures, is due to the decreasing effectiveness of the sun's rays, resulting from the lower angle of the sun at noon.

Although the chief influence affecting average temperature is latitude, altitude plays an observable role; hence a map of elevations is illuminating. Figure 2 shows Indiana's altitudes in a generalized way, omitting the minor irregularities. It reveals that the lower Wabash and Ohio valleys are less than 500 feet above sea level, but that on the east are areas above 1,000 feet. The 800-foot contour line, through the section having an altitude of 500 to 900 feet, calls attention to the close approach of highlands to the lowlands along the Ohio River and Lake Michigan.

The influence of differences in altitude are shown on many of the following maps, and it will be worth while to compare them repeatedly with Figure 2.

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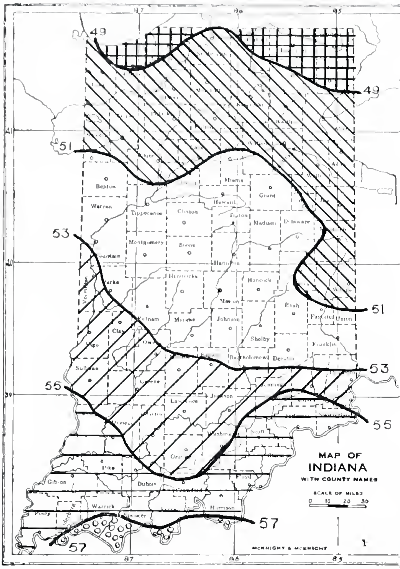
[1]The only published climatic maps of Indiana known to the writer, aside from his own, are of average annual precipitation and temperature, average length of growing season, and average dates of last and first killing frosts. These are all based on far fewer data than the maps here given. Director J. H. Armington of the Indiana section of the Weather Bureau has presented three editions of tables of averages dealing with the data accumulated up to 1915, 1922, and 1930. The last was published in 1933 and is called "Climatic Summary of the United States. Climatic Data from the Establishment of the Stations up to 1930. Section 66 Northern Indiana, Section 67, Southern Indiana." For sale for 10 cents each by the Superintendent of Documents, Washington, D. C.

The data used in making most of the following maps were obtained in this latest publication, except that the several maps of extremes and of the growing season considered also data given in the annual reports for 1931 to 1934, inclusive. Other data were obtained from recent issues of the Monthly Weather Review, the Atlas of American Agriculture, and other dependable sources.

[2]Much more extended discussions than are here appropriate may be found in the following by the author: Climatic laws, New York, 1924; Climate of Kentucky, Frankfort, 1929; Economic geography of Indiana, New York, 1923.

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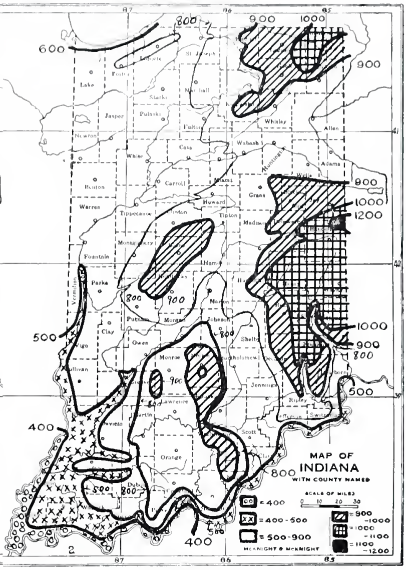


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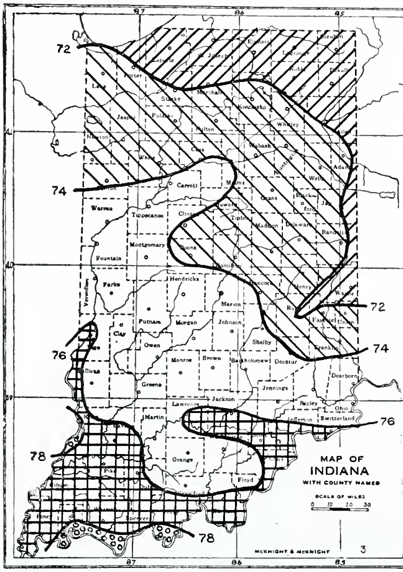
FIG. 1. Annual average temperature in degrees.
FIG. 2. Elevation in feet above sea level (generalized). Data from U. S. Geological Surv., C. A. Malott, and others.

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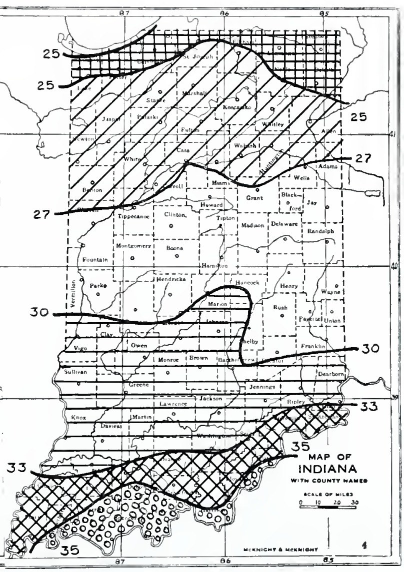


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FIG. 3. July and August average temperatures.
FIG. 4. January and February average temperatures.

Figure 3, of the average July and August temperature, reveals much less contrast with latitude than does Figure 1, but it shows at several points the influence of altitude more clearly than does Figure 1. The warmest section is along the Ohio River and lower Wabash, while the most elevated section at the northeast and east is the coolest. Most of the state has an average of 72° to 76°, which, although excellent for our chief crop, is distinctly too high for the best efficiency of man.

Figure 4 shows the average temperature for January and February. (These two months are so much alike in Indiana that it is desirable to consider them together. For similar reasons July and August are considered together.) This figure reveals that the contrast between the extreme northern and southern sections is twice as great in midwinter as in midsummer.

As the highest and lowest temperatures are of especial significance, the foregoing maps of average summer and winter temperatures should be supplemented by maps showing maximum and minimum temperatures.

**Temperature Extremes.**—Figure 5, of the average daily lowest temperatures, shows that in January the temperature falls to about 20° each night in the central part of the state but to 16° at the north and 24° at the south.

Figure 6 shows that the coolest part of the state on July afternoons is near Lake Michigan, but that nearly all of the state has a truly tropical temperature, is warmer, indeed, than most parts of the tropics, which never have long days and short nights.

Turning now to the lowest temperatures of winter, we note that nearly every winter temperatures lower than -10° are experienced

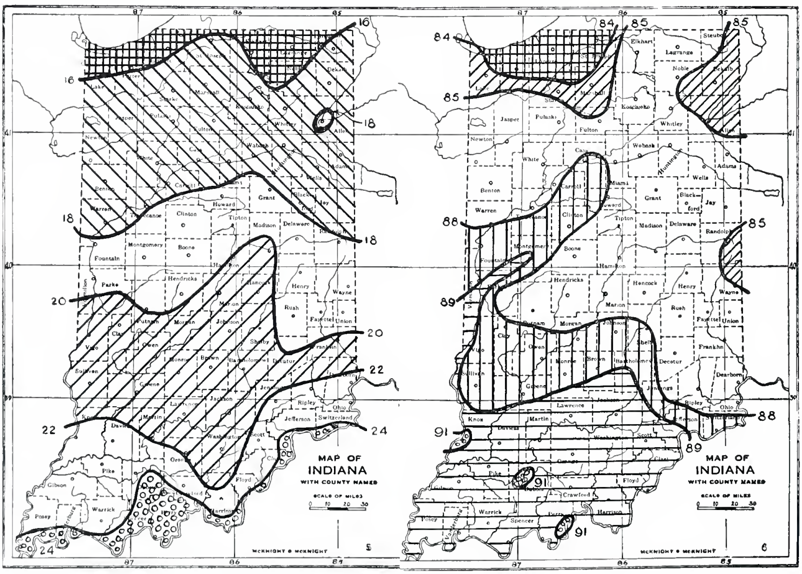


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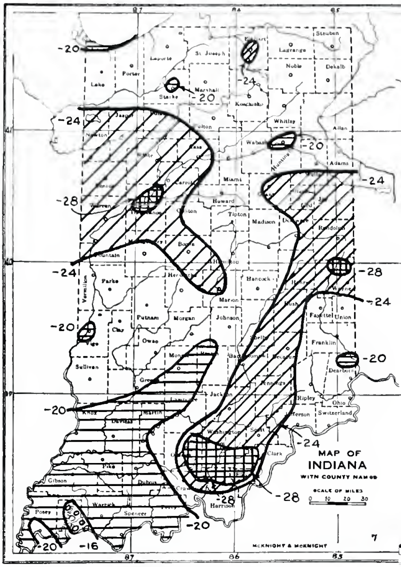
FIG. 5. Minimum temperatures, daily average for January.
FIG. 6. Maximum temperatures, daily average for July.



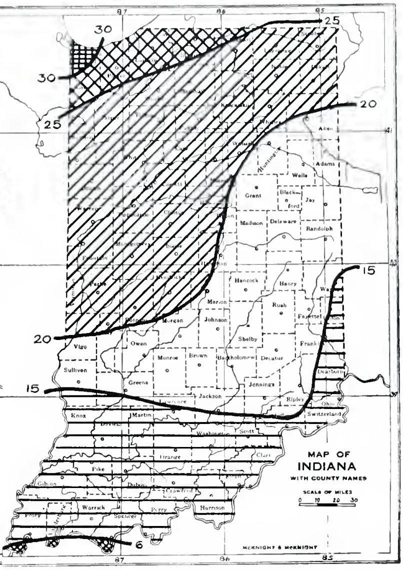




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FIG. 7. Lowest temperatures ever officially recorded (to 1935).
FIG. 8. Average frost penetration (inches).

throughout the northern half of Indiana and temperatures of -5° in the southern third. In only one-fifth of the years, indeed, is the lowest temperature at Indianapolis warmer than 12° below. The corresponding figure for Royal Center is -18°, for Chicago, -16°, and for Terre Haute and Evansville, -10°.

The lowest temperatures ever officially recorded up to 1935 at the weather stations are the basis for Figure 7. This shows that nearly all parts have had temperatures of more than 20° below zero, and the three areas which have been colder than 28 below include one on the elevated area near the southern margin of the state. The official records are -33° at Lafayette (1887) and -30° at Marengo (Dec. 1917), with nearby stations approaching those figures. The warmest spots, if -16° and -18° may be thought of as warm, are Evansville and two near Lake Michigan.

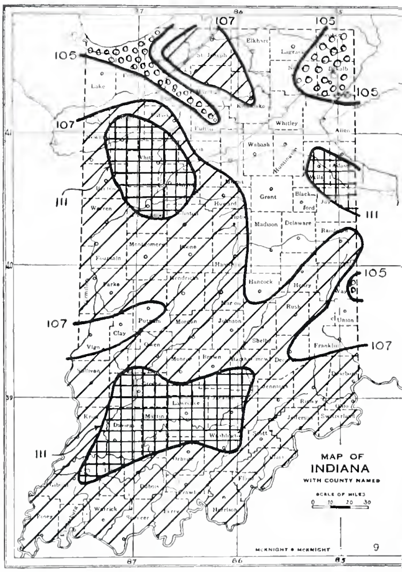
Although there is not much correlation of latitude or altitude with very low temperature records in Indiana, there is, nevertheless, considerable correlation of latitude with the frequency and duration of very cold weather. For example, subzero weather is experienced on seven days each winter, on the average, at Fort Wayne and Royal Center, four or five days at Terre Haute and Indianapolis, and only one or two days at the southern margin of the state.

A map (not published) showing the average number of days which have a minimum temperature below freezing, reveals that, in this respect, the northeast corner of the state is considerably colder than the southwest, the range being from about 75 days at Evansville to more than 120 days at the northeast. The central part of the state (Terre

Haute and Indianapolis) has frost on about 100 days, Royal Center on 128, and Fort Wayne on 121 days.

Figure 8 shows that in northwestern Indiana the ground freezes more than six times as deeply as at the south. The maximum depth of recorded frost penetration is sixty inches in the northwestern corner of the state, 48 inches in the northeast, 48 inches at Indianapolis, and 18 inches or less at the south (only five inches at Louisville). The northwestern corner of Indiana freezes deeper than the northeastern, because of the tempering effect on the latter of northwest winds off Lake Michigan and the greater snow cover.

An unpublished map shows the average date when the mean temperature (average of night and day) rises above 35°, which is February 16 along the Ohio River, about March 8 in central Indiana, and after March 16 in northern Indiana. Another shows that the mean daily temperature rises above 55° about April 23 in central Indiana, but a week earlier along the southern margin and a week later at the north. Temperatures above 55° are significant here as corn grows slowly when the temperature is below 55°. (Careful tests at Urbana, Illinois, have shown that corn grows hardly at all when the temperature is below 49°.) During July and August, as we saw in Figure 3, the average temperatures (day and night together) are close to 74° for most of the state. The temperature reaches 90° or more on 15 to 17 days in central Indiana during the normal summer, but on 34 days at Terre Haute and on 37 days at Evansville. In four-fifths of the years it reaches 98°, 99°, or higher at least once at all the widely scattered weather stations. In the other fifth of the years the highest temperature is somewhat below 98°.

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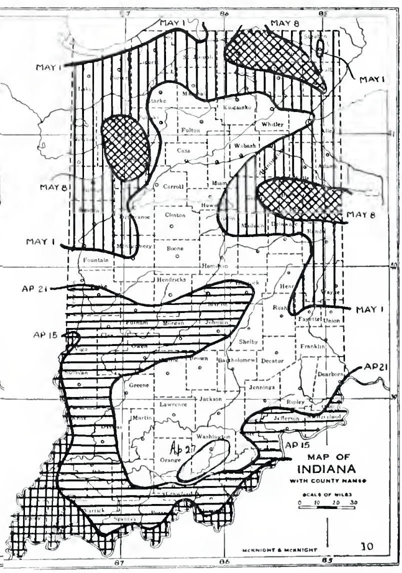


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FIG. 9. Highest temperatures ever officially recorded (to 1935).
FIG. 10. Date of average last killing frost in spring (96 stations).

Occasionally, especially during exceptionally dry periods, considerably higher temperatures are experienced. Figure 9, of the highest temperatures ever officially recorded up to 1935, shows that, except near Lake Michigan and in the elevated northeast area, temperatures of higher than 105° have been experienced. Indeed, all stations have had 105° or above except Richmond (102°), and stations near Lake Michigan (104°, 100°). The state records are 113° at Washington (1930) and at Collegeville, near Rensselaer (1934). Although there is not much regional difference in record high temperatures in Indiana, South Bend's record (109°) being higher than Evansville's (107°), nevertheless most of the northeastern third of the state has lower records than the rest. Moreover, very high temperatures are much more frequent in the south than in the north, and, until the exceptional summer of 1934 broke the heat records for most of northern Indiana, the contrast between north and south was notable. As late as 1933 several northern stations had never recorded higher than 103°, only a few had records higher than 105°, and none higher than 108°. The highest temperatures recorded at Fort Wayne during several decades was 102°, but in 1934 this record was broken by a temperature of 106°.

In the southern part of the state, almost all of the stations had temperatures of over 105° prior to 1922, and six stations had surpassed 110°. Many of the records for southern Indiana were established in 1930, but most of those for northern Indiana were established in 1934, both during exceptionally dry periods.

Although the record temperature of any summer may occur anywhere within a period of a week or two, the warmest 24 hours in most of Indiana comes on the average, on July 20, 30 days after the summer solstice. Close to Lake Michigan, however, the hottest average day is July 23 or 24, and along the Ohio River it is July 21.

Conversely, the coldest winter day in most of northern Indiana comes about 30 days after the winter solstice; near Lake Michigan it comes 32 days after, and in southern Indiana only 28 days after the solstice.

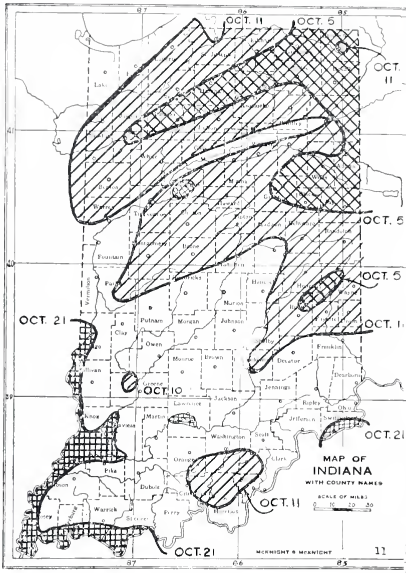
### The Frost-Free Period or Growing Season

Because of their great effect upon plant growth and animal activity, freezing temperatures are of especial significance. Hence a series of maps have been prepared to show the dates of the last killing frost in spring and the first in the autumn, not only for the average year but for exceptional years, as well as for four years out of five. These maps are based upon all available data from 96 stations up to the end of 1934.[3]

Such frost maps as these are of value to agriculturists, and the corresponding maps of the length of the growing season reveal contrasts between different sections of Indiana which help explain various observed differences in flora and fauna.

**Average conditions:** Figures 10, 11, and 12 deal with the average last killing frost in the spring, the first in the fall, and the interval

[3]These maps are far more detailed and correct than any hitherto prepared for Indiana. They are based not only on the 79 stations for which averages and extremes are given in the Summary to 1930 cited in footnote 1, p. 184, and upon the 43 stations of the 79 for which details are given therein, but upon 17 additional stations, for which the detailed data for 1901 to 1934 inclusive were compiled from the various annual reports. Data for 1931-1934 were also made use of for the other stations.



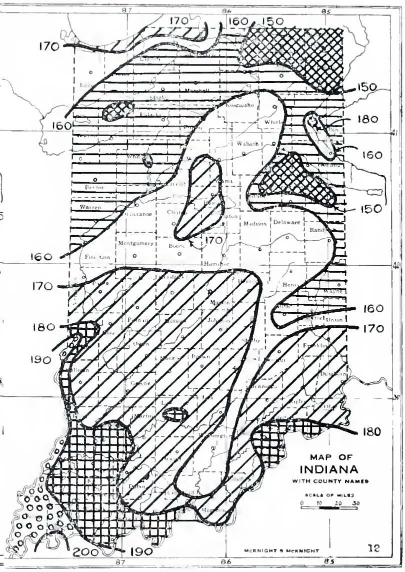




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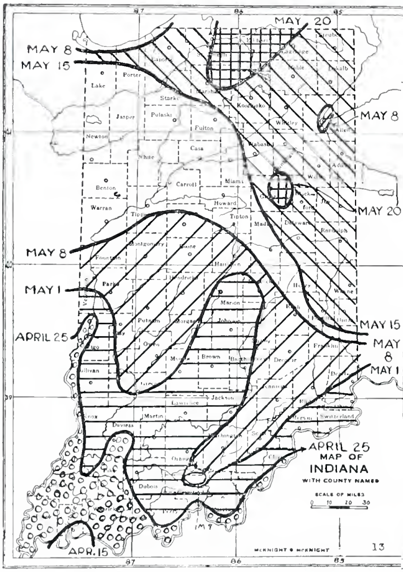
FIG. 11. Date of average first killing frost in autumn.
FIG. 12. Average length of growing season, between killing frosts.



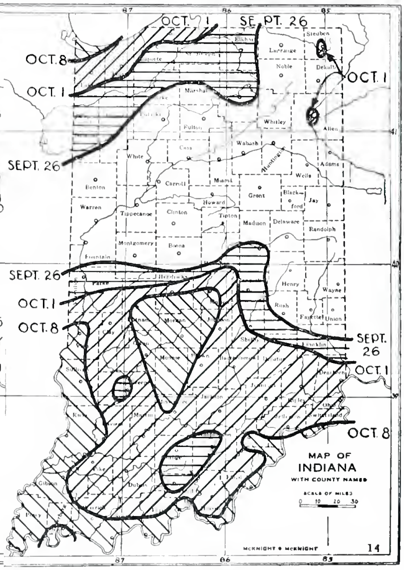




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FIG. 13. Last killing frost in spring in four out of five years. (In one-fifth of the years it is later than this.)

FIG. 14. First killing frost in autumn in four out of five years. (In one-fifth of the years it is earlier than this.)

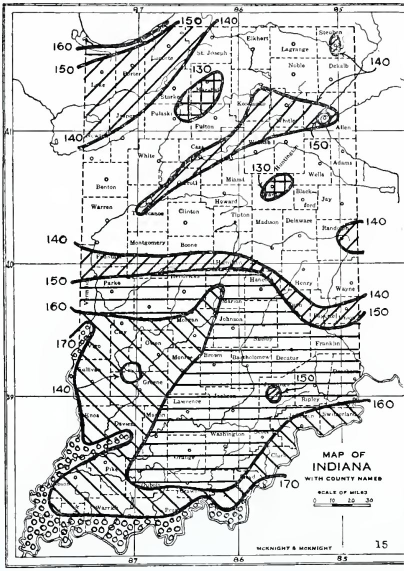
between these dates, or the average length of the growing season. In brief, in much of Indiana, killing frosts are to be expected during the last 10 days of April. The influence of elevation is strikingly illustrated by Figure 10, the elevated south central area having frost almost as late, on the average, as parts of north central Indiana. Indeed, northern Crawford County has its last frost in half of the years after April 28, while several northern stations fare distinctly better.

In the autumn the lower land along the upper Wabash River has a conspicuously later first frost than has adjacent higher land (Fig. 11), and, conversely, the high land of northern Crawford, Harrison, and Floyd counties has frost several days earlier than neighboring lower areas. For much of the state a killing frost may be expected within a few days of October 11.

Figure 12, the average length of the growing season, shows that the contrasts are far less simple than they would be if latitude alone were responsible. The effect of Lake Michigan is conspicuous because near it the frost-free season is as long as in certain areas almost bordering the Ohio River.

Figures 13, 14, and 15 deal, not with the average year (half of the years), but with killing frost data in four-fifths of the years, in other words, with what can be conservatively expected a 4 to 1 chance, in contrast with the 50-50 chance dealt with in Figures 10, 11, and 12.

Figure 13 shows that for a considerable portion of the state killing frosts after about May 8 are relatively rare.

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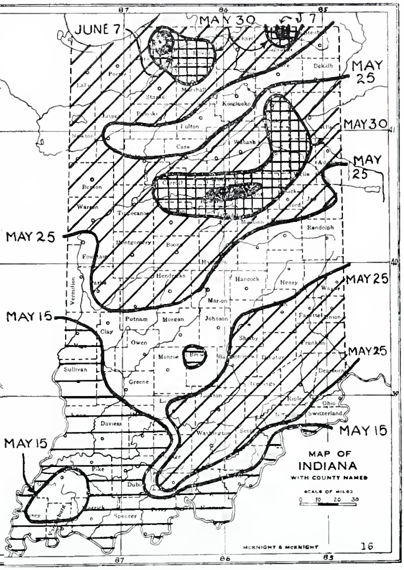


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Fig. 15. Frost free period in four out of five years. (In one-fifth of the years it is shorter than this.)

Fig. 16. Latest killing frost in the spring ever officially recorded (to 1935).

Figure 14 shows that the first killing frost of autumn comes before October 8 in only one-fifth of the years in southwestern Indiana but before September 26 in a large part of northern Indiana. The exceptions in the latter area, Angola and Fort Wayne, which are also conspicuous on other temperature maps, reflect special local conditions. Angola is near Lake James, and Fort Wayne's weather bureau thermometers are on the roof of a high building, and in calm cold weather it often happens that temperatures are abnormally high on top of high buildings.

Figure 15, for the frost-free period,[4] shows, among other things, that the strip bordering Lake Michigan has almost as long a growing season as any section.

### Record-Breaking Killing Frosts

Figures 16-19 deal with the record frosts—the latest and earliest officially recorded at about 90 stations. Killing frosts have been recorded after May 30 in considerable northern areas but not after May 15 in the south. For some reason, a sizable strip in northern Indiana never has, however, recorded frosts as late as adjacent areas. Indeed, this strip has fared better in this respect than has parts of southeastern Indiana.

Killing frosts have occurred in September in all parts of Indiana, before September in most of northern Indiana, and before September 10 in part of central Indiana. Again the effects of Lake Michigan and of the low elevations along the Ohio River are evident.

Figure 18 reveals the fact that much of southern Indiana has had years with only 130 to 141 consecutive frost-free days, while four scattered central northern areas have had less than 110 days, which period is too short for our corn.

The longest recorded growing season (Fig. 19) contrasts significantly with the shortest. All Indiana stations have had growing seasons of 177 or more days and little of the state has not had over 200 days. The southwestern counties and the Ohio River strip have had growing seasons long enough for successful cotton growing.

### Some Effects of the Temperature Contrasts

Indiana's contrasts in temperature affect appreciably several significant crops, farm practices, and biotic formations and many individual species. Their effects on man himself should not be ignored.

Because of the general suitability of Indiana's climate, the regional contrasts in temperature are less significant than are differences in relief and soil in explaining many of its contrasts in agriculture, flora, and fauna; nevertheless, a considerable number of correlations are evident. Some examples follow.

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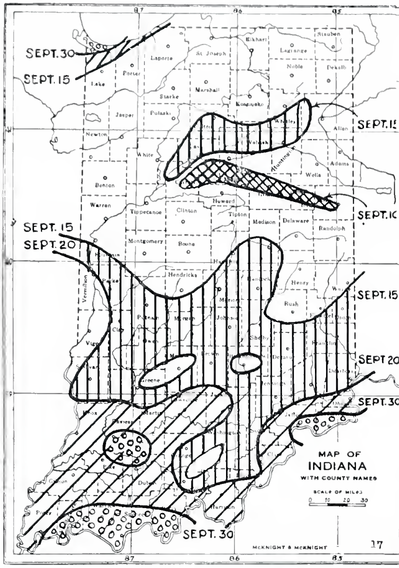
[4]Note that the length of the growing season here used is the period between the date of the last and first killing frosts in four-fifths of the years. This period is considerably shorter than the "growing season" in four years out of five as given in the tables in the climatic summaries published by the Weather Bureau in 1933. For southern Indiana many places have a conservative growing season about ten days shorter than one would expect by inspecting the lengths of the growing season of each of the years. The reason for this is that occasional years have abnormally early last frosts or late first frosts. In central and especially in northern Indiana there is, however, little discrepancy between Figure 15 and the map (not published) of the medium length of the frost-free season in four out of five of the years. This note is introduced as a warning to agriculturists to use the data of Figures 13, 14, and 15 rather than the mean of the lengths without regard to dates.



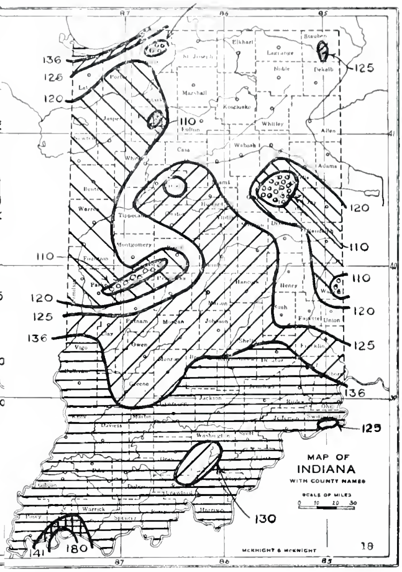




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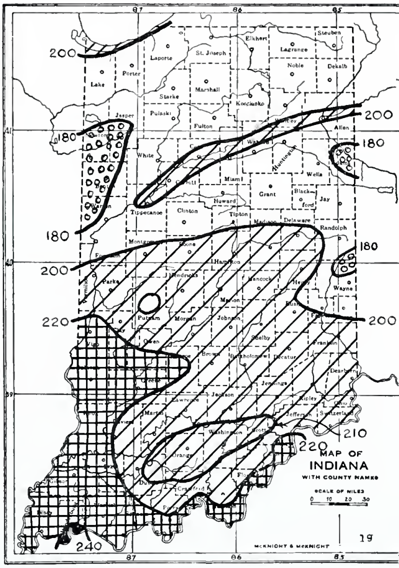
FIG. 17. Earliest killing frost in the autumn ever officially recorded (to 1935).
FIG. 18. Shortest growing season ever recorded.



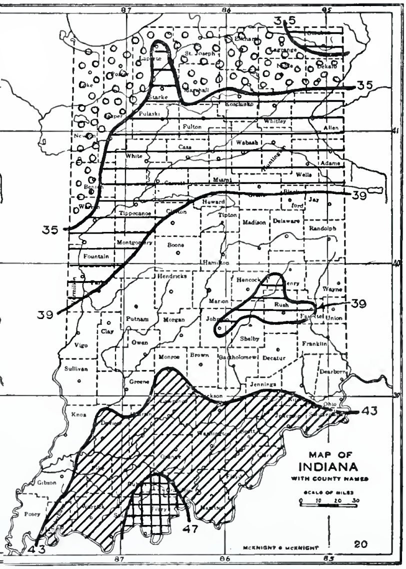




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FIG. 19. Longest growing season ever recorded.
FIG. 20. Annual precipitation in inches, average of all years to 1931.

1. Differences in length of growing season and duration of high temperature clearly affect the relative importance of corn as a crop. For most of the state temperature conditions are normally nearly ideal for corn, and this helps to explain the high rank that Indiana holds in corn production. Along the northern border, however, the period of high temperatures is often too short, with the result that corn is relatively less important there, and much of it is cut for fodder. Consequently the Corn Belt proper does not extend into the coolest part of the state, and is so delimited on recent maps issued by the U. S. Department of Agriculture.

2. Wheat, our crop next in importance, is likewise grown in all parts of the state because of the general excellence of the climatic conditions. But almost no spring wheat is grown, because the interval between sufficient drying out of the ground in spring and the coming of hot weather, which checks vegetative growth of wheat, is too short to permit a good yield. Winter wheat is harmed by heaving, during the frequent freezings of the top soil, but such damage is oftener overcome in southern Indiana than in northern because the period warm enough for wheat to grow but not hot enough to check growth is fully a month longer in southern than in northern Indiana. (As noted above the average daily temperature rises above 35° on February 16 along the southern margin of the state but not until a month later at the north; yet both north and south become too hot for wheat to grow vegetatively at almost the same date in June.) Partly as a result of this condition, wheat, which 50 years ago was most extensively grown along the northern border of the state, is now most extensively grown in southern Indiana, especially in the extreme southwestern part, the area with mildest winters.

3. Oats are grown widely also but most extensively in the northern part of the state, except the northern tier of counties. Oats are especially important in the western section which is slightly drier in winter and spring making it possible for the ground to be worked earlier and permitting a little longer vegetative growth before hot weather comes.

4. Fruits are cultivated in all parts of the state, but there is a conspicuous concentration of grapes near Lake Michigan with its notable effect in delaying autumn frosts. Strawberries are notably concentrated elsewhere in the northern section. Peaches, and to a lesser extent apples, are relatively abundant in the hilly southern section where slopes afford air drainage, which reduces damage from late spring frosts, and where subzero temperatures come less early in the winter and are less likely to damage buds.

5. Although watermelons and cantaloupes are grown locally in considerable amounts on sandy soils even in northern Indiana, the main concentrations of these crops are in almost the warmest part of the state, in the lower Wabash valley. There the last killing frost in spring comes earliest, as does hot weather. Hence the crop ripens some days earlier than elsewhere in Indiana or in higher latitudes or altitudes in other nearby states, and the crop brings a higher price.

6. The "southern" temperature conditions prevailing much of the year in the lowland of the southwest are more favorable for mules than for horses and help explain their relative abundance there.

7. Sheep are very much more plentiful in the northeastern coolest corner of the state than elsewhere, except in the relatively elevated, eastern counties south to Randolph. The only other county having half as many sheep per square mile as the five northeastern counties is Boone County, much of which is above 900 feet in elevation and has often a shorter growing season than surrounding counties.

8. The native flora and fauna are distributed in many instances in such a way as to indicate significant correlations with contrasts in temperature. There is time now for only a few examples. (The writer will appreciate being informed of additional correlations with the climatic maps.)

The cypress-tupelo-red gum forest extends northward into the lowest, warmest section in the southwestern corner of the state. The chestnut-chestnut oak-tulip forest extends northward into southern Indiana, and the line between it and the oak-hickory forest is at many points near various temperature lines shown on the above maps.

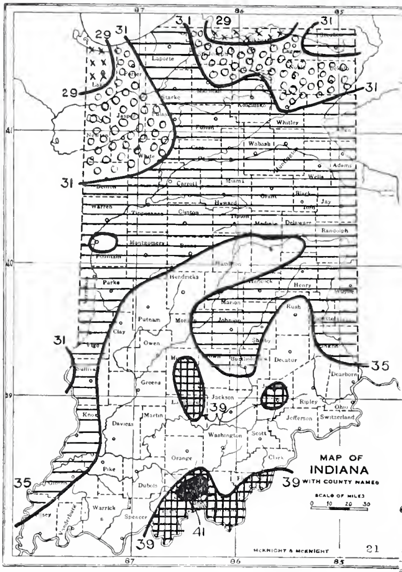
Many species characteristic of cooler regions reach their southern limit in northern Indiana, some of which like the badger, extend southward along the elevated, cooler eastern margin of the state to Randolph County. The Jack pine of the sand dunes, the tamarack, alder, and several other bogs species, the white cedar, paper birch, pin cherry, and balsam poplar are trees limited to the northern, cooler counties. Some trees limited as natives to the warmer southwestern part of the state are the pecan, overcup oak, catalpa, and persimmon.

9. Man himself also apparently reflects to some degree the contrasts in temperature conditions. The frequently observed greater energy and progressiveness in northern Indiana, as compared with southern Indiana, are presumably partly due to the fact that southern Indiana is much too hot for a distinctly longer period than is northern Indiana. Moreover, the summer heat is much more often broken by cooler periods in northern than in southern Indiana. This is because many of the highs and lows, which cause our change of weather, pass north of Indiana in summer, and their effects often scarcely reach southern Indiana. Although northern Indiana is more often too cold, mankind has been more successful in counteracting the effects of too low temperatures than in compensating for too high temperatures. Unquestionably northern Indiana's temperatures more closely approach, than do southern Indiana's, the optimum for civilized mankind, which is not over 65° F.

10. The striking regional contrasts on the death rates, discussed in the Proceedings for last year, also strongly suggest that regional contrasts in climate have a significant influence on disease and health in Indiana.

## Precipitation

**Annual precipitation:** The average rainfall of Indiana (Fig. 20) decreases from the south northward in much the same way as the average temperature, but the explanation is very different. It is due to increased distance from the one important source of Indiana's rainfall, the Gulf of Mexico. The small influence of Lake Michigan upon Indiana rainfall is shown by the fact that the driest section of the state borders the lake and extends eastward therefrom. Most of the state normally receives

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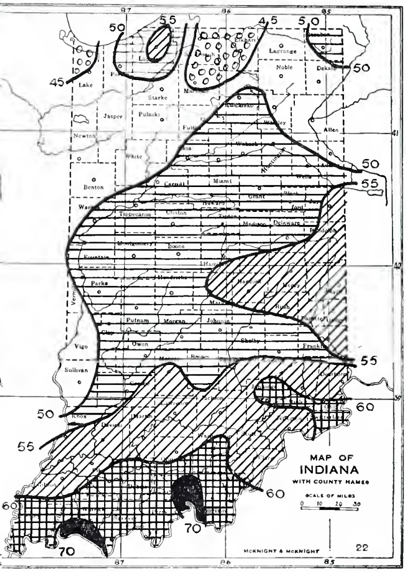
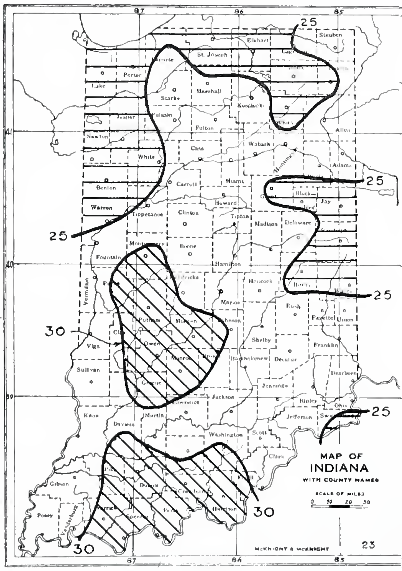



22

FIG. 21. Annual precipitation in four years out of five. (In one-fifth of the years it is less, in the other four it is this great or greater.)

FIG. 22. Heaviest precipitation ever officially recorded (to 1935 different years for different stations).

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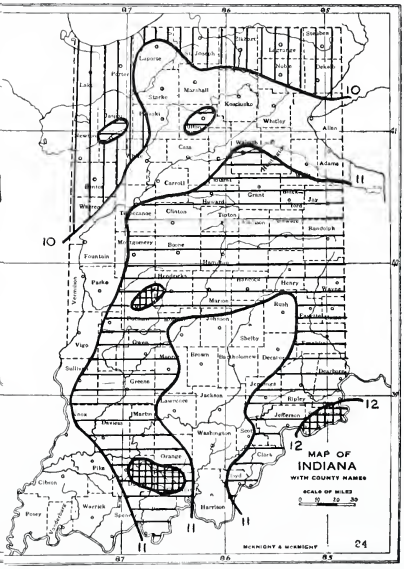



24

FIG. 23. Lowest precipitation, in inches. Record dry year for each station (different years for different stations).

FIG. 24. Average summer rainfall (total inches for June, July, and August).

within four inches of 39 inches of rainfall. The eastern half of the state receives more than the western half because the winds which bring the moisture from the Gulf spiral into the lows counter-clockwise, entering from the east, Moreover the lows move eastward rather rapidly, carrying with them some of the moist air.

Figure 21 is much more significant than Figure 20. It reveals that much of the state receives about 35 inches in four out of five years. Many stations of southern Indiana which receive over 43 inches in the average year (Fig. 20) receive less than 36 inches in four years out of five, or only six-sevenths as much, a much greater decline than is found in northern Indiana.

Figure 22 shows the greatest precipitation received in any year up to 1935 (different years for different stations). The state record (one of the highest reported by any station east of the Pacific coast) is 97 inches at Marengo, in 1890.

Figure 23 shows the precipitation totals for the driest year of record. Only eight out of 96 stations have received in their driest year more than 30 inches. Most of these eight received only 31 or 32 inches; indeed, no station with a long record has received over 33 in its driest year; nor has any received less than 22 inches except Valparaiso (18). Although nearly one-half of northern Indiana has received an inch or two less than 25 inches, much of the southern part has received only an inch or two more than 25 inches, a difference by no means sufficient to offset the greater evaporation due to the higher temperature of the south. In other words, much of southern Indiana during dry years is physiologically drier than northern Indiana. Excepting Valparaiso, the driest record for any station is Vevay on the Ohio River (22.5 inches in 1934).

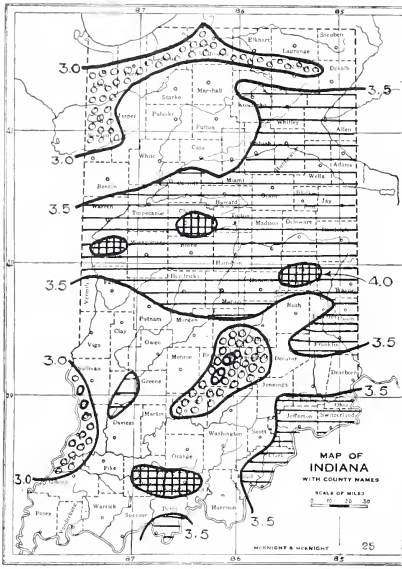
## Seasonal Rainfall

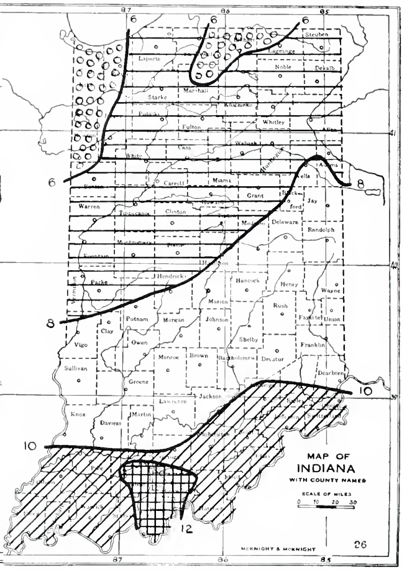
Now let us turn to the rainfall of the warmer season, the rainfall that is especially important for plant growth.

Figure 24 reveals that in summer (June, July, and August) most of the state receives approximately 11 inches of rain, and there is little difference between the northern and southern sections. Indeed, the area in south-central and southwestern Indiana which receives less than 11 inches is almost as large as the drier part of northern Indiana, and part of this southern area is distinctly drier than much of central Indiana. In other words, the higher average annual rainfall of the southern part of the state (Fig. 20) is not received in summer.

Maps of the average rainfall for each of the months April to August, inclusive, have been made, but only that for July is published here. The others, however, may advantageously be summarized. In April most of the state receives approximately 3.6 inches of rain; the northern third mostly receives a little less than 3.4 and the southern half mostly about 3.7. The rainiest extreme south-central section receives an average of 4.4 inches, but nearby southern stations receive as little as 3.6.

In May there is more rain on the average, much of the state receiving close to 4.1 inches. Of special interest is the fact that in May the

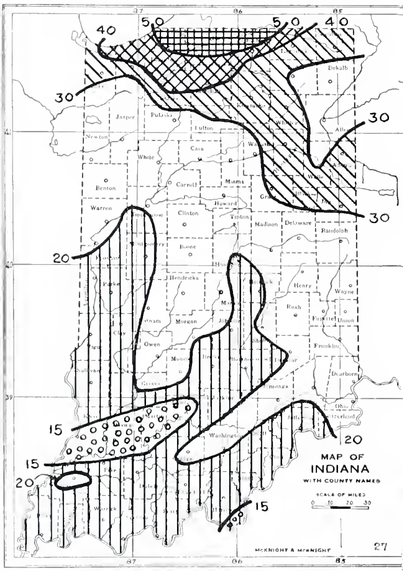


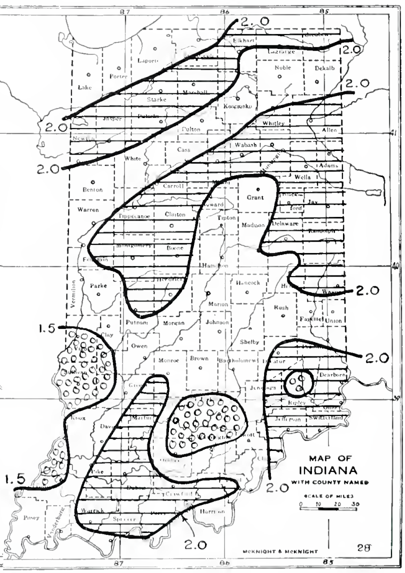




25 26

FIG. 25. Average July rainfall, in inches.

FIG. 26. Average winter precipitation (total inches for December, January, and February).




27 28

FIG. 27. Snowfall, annual average depth in inches.

FIG. 28. July rainfall in four out of five years. (In one-fifth the years less than this is received, in the other four, this much or more.)

west-central third normally receives most rain. Two of the three rainiest areas, receiving more than 4.7 inches, are in the northwest quarter.

In June most of the state receives about 3.8 inches, but three northern areas (at the northwest and northeast) receive slightly under 3.5, and three central and one large southern area receive between 4 and 4.7 inches. Two southern areas, however, receive less than 4.0 inches (in the south-central and southwestern sections).

July, perhaps the most critical month as far as rainfall is concerned, is especially interesting, and its average rainfall is depicted in Figure 25. The striking condition shown by this map is that most of southern Indiana receives one-fifth less rainfall in July than does central Indiana, and much of it receives less than northern Indiana. The amount received is, moreover, distinctly less than that of April, May, or June. As July is the hottest month, this lighter rainfall is unfortunate, and the southern section is especially handicapped.

In August all parts of the state share more equally, most stations receiving about 3.5 inches. Four small areas, two on the Ohio River and two on the northern boundary, receive less than three inches, and two small areas, one in the southwest and the other in the northwest, receive slightly over four.

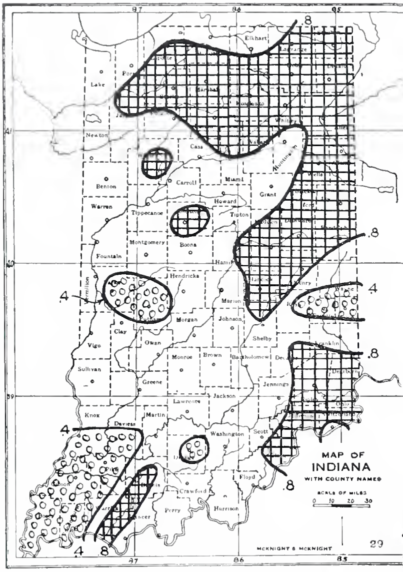
During the three autumn months most of Indiana receives between eight and ten inches, but a large southwestern area and a smaller southeastern one receive somewhat more than ten inches, while areas at the northwest and northeast receive somewhat less than eight inches.

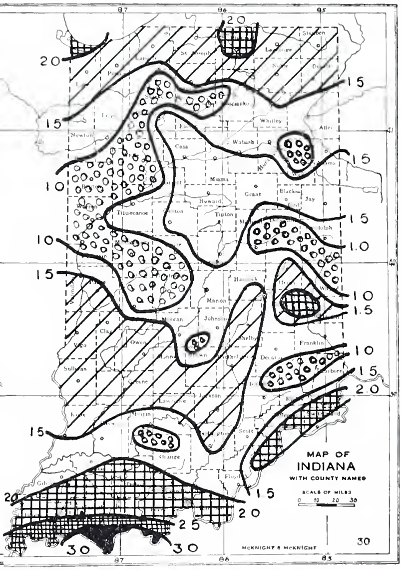
During the winter months (December, January, and February—Fig. 26) south-central Indiana, with over 12 inches, receives twice as much precipitation as the northwestern corner and an area surrounding Elkhart.

Figure 27 reveals that much of the state receives in an average year 20 to 30 inches of snowfall with an increase from southwest to northeast. The small area east of Lake Michigan receiving more than 50 inches indicates that, although the lake does not appreciably affect the rainfall, it does increase the snowfall. Winds which have blown across the lake in winter are chilled by the land, which is often then cooler than the lake, and sometimes are forced to yield snow. The Valparaiso moraine, just south of the end of Lake Michigan, also often receives several inches more snowfall than adjacent areas. The difference in duration of snow-cover corresponds roughly with the amount of snowfall, southern Indiana generally being snow-covered 10 to 20 days and northern Indiana 50 to 60 days.

Thus far we have considered under seasonal precipitation only the average conditions. Next it is desirable to consider the departures from normal. Figure 28 shows the July rainfall in four-fifths of the years. During one-fifth of the Julys less than those amounts are received and in the other four-fifths this amount or more. It shows that the driest one-fifth of the Julys receive less than two inches of rain in much of the state, and that southern Indiana fares worst.

Figure 29, the rainfall during the two driest Julys of record at each of the 70 stations, is highly significant. It reveals that at each station having records longer than ten years there have been two or more Julys when very small amounts were received. Since the mean length of the

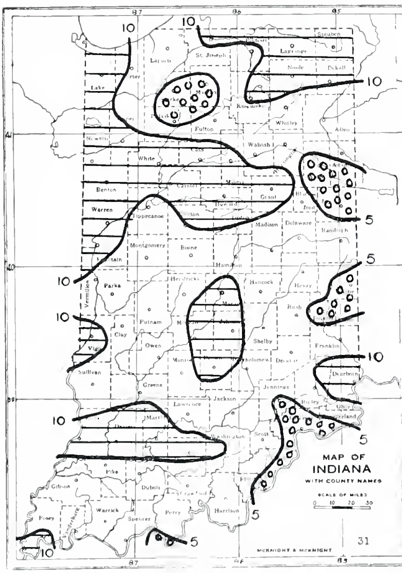


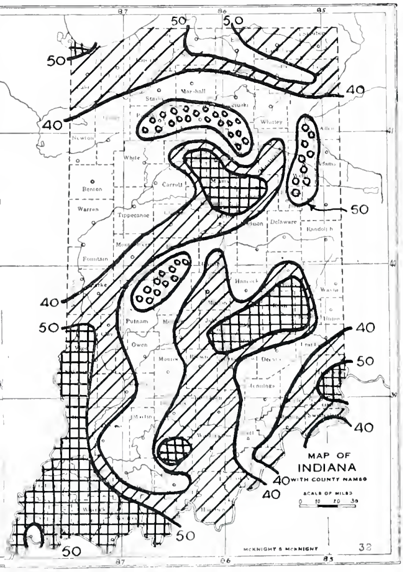




29 30

FIG. 29. July rainfall in the two driest Julys of record (median of the two), in tenths of an inch.

FIG. 30. Dry Augusts—percentage of the Augusts which have received less than 1.56 inches of rainfall.




31 32

FIG. 31. Dry Junes—percentage of the Junes which have received less than 1.56 inches of rainfall.

FIG. 32. Dry summer months—the sum of the percentages of Junes, Julys, and Augusts which have received less than 1.56 inches of rainfall (Figs. 30, 31, and an unpublished map).

records for these 70 stations is only about 25 years, this map indicates that one July in twelve or so is about this dry, much too dry for the best crop yields. These rainfall data indicate clearly that even in favored Indiana July is often too dry, and that the southern part of the state suffers more seriously from July drouth than do the central and northern parts of the state.

Next let us consider rainfall deficiencies in August. Instead of taking the two driest months of record, as was done for July, Figure 30 shows the percentage of the years when the August rainfall is less than 1.56 inches, or somewhat less than two-fifths of the normal. In as hot a month as August is in Indiana, 1.5 inches of rainfall means a serious drouth, with corn and other crops suffering seriously except where the soil is very retentive of moisture and has been well supplied with moisture late in July, or when the August rainfall happens to come almost ideally (as in three half-inch moderate rains on August 7, 15, and 23).

Figure 30 shows that a large share of west-central Indiana and a part of southeastern central Indiana do not have one August in an average decade that receives less than 1.5 inches of rain, but instead has one in from 11 to 15 years. Only three small areas in southern Indiana are that fortunate. Indeed, two considerable areas bordering the Ohio River receive less than 1.5 inches in more than one-fifth of their Augusts and one area has three Augusts out of ten which receive less than this amount. In the northern two-thirds of the state, however, only two stations, Hammond and Goshen, have had more than one-fifth of their Augusts this dry; they had one-fourth. Their temperatures in August average, however, 6° less than those along the Ohio River, which means that the average rate of evaporation is decidedly less. (The capacity of air for moisture doubles with a rise of 20° F., and, since 6° is nearly a third of 20°, nearly one-third more moisture is required normally to saturate the air in August near the Ohio River than at Goshen or Hammond.)

Maps corresponding to Figure 30 have been made for June and July. The one for July is not published here, because three maps of July rainfall are included (Figs. 25, 28, and 29). July is, however, such a critical month for our chief crop that the map showing the percentages of very dry Julys will be described. It shows that nearly all of the southwestern quarter of the state receives in July less than 1.56 inches of rainfall in one year out of five, on the average, and some parts of this quarter have had from 25% to 33% of their Julys this dry. On the other hand, only about one-tenth of the northern half of Indiana has had 20% of their Julys this dry. A large area in north-central and east-central Indiana has had fewer than ten percent of its Julys so dry that less than 1.56 inches of rain fell. Only one station (Bloomington) in the southern third of the state has been this fortunate.

June is sufficiently important for several crops that at least one map of its rainfall should be published. Figure 31 shows the percentage of Junes which have received less than 1.56 inches of rainfall. It is based on the 83 localities with a record of 14 years or more, 29 of which have records of 40 years or longer.

In June the average rainfall is, as already noted, greater than in July or August. Partly because of this, a smaller percentage of the

Junes have received less than 1.56 inches of rain. Few stations have had more than one-eighth of their Junes this dry, and for most of the state only five to ten percent are this dry.

The final map of this series (Fig. 32) considers June, July, and August and shows the sum of the percentages of these months which are very dry (receiving less than 1.56 inches of rain). Again the central part of the state with an average of 38 is seen to be distinctly more fortunate than the southern with an average of about 48. The southwestern section and most of the unglaciated, south-central region fare relatively poorly. No southern section is in the most fortunate division (less than 30%).

### Causes of Rainfall Contrasts

Despite the northward decline in average annual rainfall, this study establishes that during dry years, during the average July, and during dry Junes, Julys, and Augusts, less rainfall is received in southern than in central Indiana. This northward increase is, of course, contrary to what has been assumed, on the basis of the annual averages.

It is due chiefly to the cooperation of two influences. The first is that a greater number of cyclonic disturbances or lows affect northern Indiana in summer. As already noted, the centers of many of the lows of summer pass to the north of Indiana, scarcely affecting southern Indiana. The lows cause much of our rainfall, partly by inducing convectional overturning or thunderstorms. Although, for the year as a whole, thunderstorms are more frequent in southern than northern Indiana, nevertheless in June, July, and August they are more frequent in the north than at the south. The regular weather bureau stations record, as accurately as they can, thunderstorm numbers, and that during each of the three summer months Royal Center has most thunderstorms and that in July Fort Wayne has as many as any other station, or more.

The second important cause of the frequently lower rainfall in summer in southern than in central Indiana lies in the fact that occasionally the high barometric pressures characteristic of a shifting belt often known as the High Pressure Calm Belt (which lies some 20 degrees on each side of the heat equator) reaches southern Indiana. This belt lies in summer across northern Africa in latitudes corresponding to southern Indiana. Wherever it is present, on sea or on land, drouths prevail and are broken only when some cyclonic disturbance temporarily overcomes the calm. This belt of calms very seldom extends north of latitude 40°, or central Indiana.

The local contrasts in rainfall revealed by many of the foregoing maps are due to two sorts of conditions, one more or less accidental and the other based on local differences in elevation, relief, and character of the surface as to moisture, vegetation, and soil. The more accidental influence is associated with irregularities in the course of cyclonic disturbances (lows) and their associated rains. In so far as these irregularities are accidental they tend to be equalized in time and hence disappear when a long enough record is available. Indeed, a number of striking irregularities shown by the average rainfall map of Indiana, issued in 1926 by the Weather Bureau, largely disappear when the fuller data now available are used, as has been done here.

The paths followed by thunderstorms are, however, frequently influenced by local surface conditions, and presumably some of the irregularities evident in the maps are related to elevation, relief, soil, etc. It is hoped that these maps will encourage studies of possible influences. (The author will appreciate evidence on these matters.)

**Some Effects of Precipitation Contrasts**

The precipitation contrasts in Indiana are of significance in more ways than can be pointed out here. A few, however, will be mentioned.

1. The heavy winter rains in the southern part of the state are important factors in causing extensive soil leaching and erosion there. Indeed, the ruggedness of much of southern Indiana is intimately associated with the heavy winter rainfall which much more often occurs in southern Indiana than elsewhere in the state.

2. The lower average crop yields (except on fertile almost flat river bottoms) in the south as compared with central Indiana are due, not only to differences in the soil and the people, but also partly to the more frequent deficiencies in rainfall in relation to temperature. Furthermore, because of greater ruggedness at the south, the runoff is greater than in central Indiana. In other words, more of the rainfall runs away without benefitting the crops, than does in central Indiana. Consequently the conspicuous contrasts in land values between southern and central Indiana are only partly the direct results of glaciation. The increased soil erosion is a factor, as are lower crop yields, associated partly with the frequently lower precipitation during the summer months, especially July.

3. Southern Indiana is not in the Corn Belt proper, as delimited in recent maps by the U. S. Department of Agriculture. Climatic basis for this is clearly evident in the low summer rainfall (Figs. 25, 28-32). Careful studies at the Experiment Station at the University of Illinois have established that corn should receive at least 2½ inches of rain a month during the three months of its chief growth. When more rain than this falls at the right time, the yield is much increased. For example, in eight years when a total of less than seven inches fell during the three months, June, July, and August, the average yield was 25.3 bushels per acre in an experimental plot. In the nine years when between 7 and 10 inches was received during three months, the average yield was 32.4 bushels per acre. In the eleven years when more than 10 inches fell, the average was more than 40 bushels. A yield of 100 bushels of corn per acre requires about 16 inches of rain, and, of course, rich soil, excellent seed, and good care.

The fact that in southern Indiana a large share of the Julys and Augusts receive less than 1.56 inches explains, therefore, the smaller average corn yields there.

4. The main area which was not forested was chiefly in the northwestern part of the state, in the section receiving less than 31 inches of precipitation in one-fifth of the years (Fig. 21). The northeastern dry area was forested, possibly partly because that area has much more snowfall. Small "prairies" along the western margin of southern Indiana, near Vincennes for example, were in the part of the state having

almost the least snowfall (Fig. 27) and also having more severe drouths than nearby forested areas. (Figs. 25, 28).

5. Rainfall is important not only for plants and animals but also for city water supply and factories. The relatively greater irregularity of rainfall in southern Indiana combines with higher temperatures and various other conditions to interfere with urban development. Except on large rivers, expensive reservoirs would be required to permit large cities to grow up there, and, because of greater erosion, such reservoirs would be filled with sediment relatively rapidly.

(It is my intention to present to the Academy next year additional regional contrasts, some local contrasts between nearby stations, and something as to variations from year to year, including possible secular changes. Suggestions will be appreciated.)

## Conclusion

Despite Indiana's relatively small size and slight relief, there are significant contrasts in temperature and precipitation, and they have appreciable effects. The temperature contrasts are chiefly related to latitude, the southern part of the state normally being several degrees warmer than the northern part, especially in winter. Elevation also is significant, the most elevated sections of the state, at the east and northeast, usually being distinctly cooler than adjacent lower sections, and having a distinctly shorter frost-free season. The section of the state with highest average temperatures and longest growing season is the least elevated southwestern corner. Higher land east of there generally has a distinctly shorter growing season. At the extreme north, cooler temperatures interfere sufficiently with corn-growing so that northernmost Indiana is beyond the Corn Belt. Northern Indiana has, however, temperatures that are nearer the optimum for man than is true of southern Indiana, which is distinctly too warm during the summer. The influence of Lake Michigan in lessening severe cold and in prolonging the growing season is made strikingly evident by the temperature maps.

Annual average rainfall likewise decreases northward but as a result of increased distance from the one important source, the Gulf of Mexico. The northward average decrease is due, however, to the sharp decline in winter. During the summer, southern Indiana frequently receives somewhat less rainfall than central and northern Indiana. Moreover, the variations from year to year are greater at the south than farther north, and summer drouths are more frequent and serious there.

Regional contrasts in temperature affect the distribution of various crops, native trees, and animals, and also apparently affect human efficiency and progressiveness. Precipitation contrasts are clearly of significance with respect to the distribution of "prairies," corn yields, soil erosion, the value of agricultural land, and regional contrasts in suitability for urban development.