May 13, with the hazard only 20 percent. By consulting the variability maps for spring he may know that he is taking an 80-percent chance (4 chances in 5) that his corn will be frosted if it is up on April 25; but he knows also that corn planted on April 25 usually is up by May 13, or earlier—none too late for a good crop prospect. Or he may wish to take an 80-percent chance on one-third or one-fourth of his crop, knowing that unseasonably dry or cool weather or rains may interfere with the later planting. Thus by intelligently taking the frost hazards into consideration he may succeed in his farming operations a larger percentage of the time.

ISOCRYMAL MAPS OF GROWING SEASON

The data given by the records of the United States Weather Bureau for Manhattan, Kans., were used for the construction of the 20-, 50-, and 80-percentile maps showing the periods free from killing frosts. The percentile dates were calculated by arranging the lengths of periods for the 43 years in a numerical sequence. From this sequence it was found that Manhattan has a frost-free period of 188 days, *or more*, 20 percent of the time, 174 days, *or more*, 50 percent of the time, and 154 days, *or more*, 80 percent of the time. The data for each of the 500 stations on the Great Plains were treated in a similar manner for the construction of the three isocrymal maps that show the length of the growing season (figs. 7, 8, and 9).

The dairyman who depends on forage crops for pasturage for his cows wants to know what percentage of the year will be free from killing frosts. If he is a careful planner he may consult the maps of length of growing season for the percentage of hazard involved. He may be satisfied with an 80-percent hazard or he may not want to risk more than 20 percent.

LIMITATIONS OF THIS STUDY

The reliability of a series of maps of this kind is limited by many factors, among which the following may be noted:

1. *The short period of time during which records have been kept.*—The average length of record is about 35 years, varying from 20 to 71. The longer record, of course, is more desirable. As a rule, stations with fewer than 20 years were not used.
2. *Errors in observation* are likely to occur, especially in the spring when the response of vegetation to freezing usually is not so noticeable nor so crucial as in autumn.
3. *The relative weight to be given to short-time and long-time records* is hazardous; here interpolation and adjustment of the records were not attempted.
4. *When the recorded number of years was even, the earliest year was discarded*, in order to have the median fall in the middle of a day rather than at midnight or between two days. By so doing, any fractional part of a day was more easily disposed of when the percentile dates were being calculated.

CONCLUSIONS

The uniqueness of this variability series of maps lies not only in its portrayal of the *median dates* relative to frosts and length of growing season in all parts of the Great Plains, but also in the portrayal of the 20- and 80-percentile dates. It is not contended that they could be used to specifically forecast frost occurrences from year to year in different parts of the Plains; but there is given a summary of what the conditions in the past have been, and, to the extent that the records of the past may be used as a criterion for the future, the maps may be utilized as an indication of the general run of frost conditions that may be expected in future years in the Plains country.

The maps show that in spring there is a spread of about 30 days, in the southern part of the Great Plains, between the dates on the 20- and 80-percent maps; whereas in the northern part of the region, there is a spread of about 15 days. This indicates that while the opening of spring occurs later in the north, it advances more rapidly than in the southern part.

In the autumn, in the southern part of the Great Plains, the spread is about 20 days between the 20- and 80-percent maps, and about the same in the northern part of the region. This indicates that the season advances in autumn about as fast in the northern part of the region as in the southern.

Assuming that climatic factors are relatively constant, a farmer can, by scanning these maps, make an intelligent guess as to what he may expect in different percentages of the time with reference to the last killing frost of spring, the first killing frost of autumn, and the length of growing season.

It is the writer's opinion that percentile dates calculated from the median furnish a better criterion for practical purposes than corresponding percentile dates calculated from the mean.

INTERCORRELATIONS BETWEEN CLIMATIC VARIABLES IN THE CORN BELT [1]

By JOHN KERR ROSE

[University of Chicago, March 1936]

It is a popular belief that rain tends to reduce temperature, and that one hot day is likely to be followed by another. This study is an attempt to discover how well such assumptions apply to the succession of weather during the summer months in the Corn Belt area of the United States. Three problems are considered: (1) Are there significant correlations between precipitation and temperature factors of the same month? (2) Does the precipitation or the temperature of one month correlate well with either factor for a later month? (3) Are these correlations the same throughout the Corn Belt, or are there significant areal differences within the region?

Data from 30 to 45 Corn Belt weather stations, covering a period of approximately 20 years, have been used in computing simple correlation coefficients. Monthly data for precipitation and temperature for the months of May through August were studied. The temperature data used are the number of degrees above 90° F. for each day, totaled for the month, for each station (here called the accumulated degrees above 90° F.). All data have been used without removing trends.[2]

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[1] Presented at the meeting of the American Meteorological Society, St. Louis, Mo., December 1935.

[2] It is a well known fact that if secular trends are present in correlated data, spurious correlations may result merely from the fact that paired values deviate from their respective means partly because of their positions in the time series. Small trends are present in most of the climatological data used. Investigation showed, however, that the coefficients obtained when the trends were removed differed not more than 0.05, mostly only 0.02 or 0.01, from those based on the same data without removing trends. Such differences are not significant in the present problem.

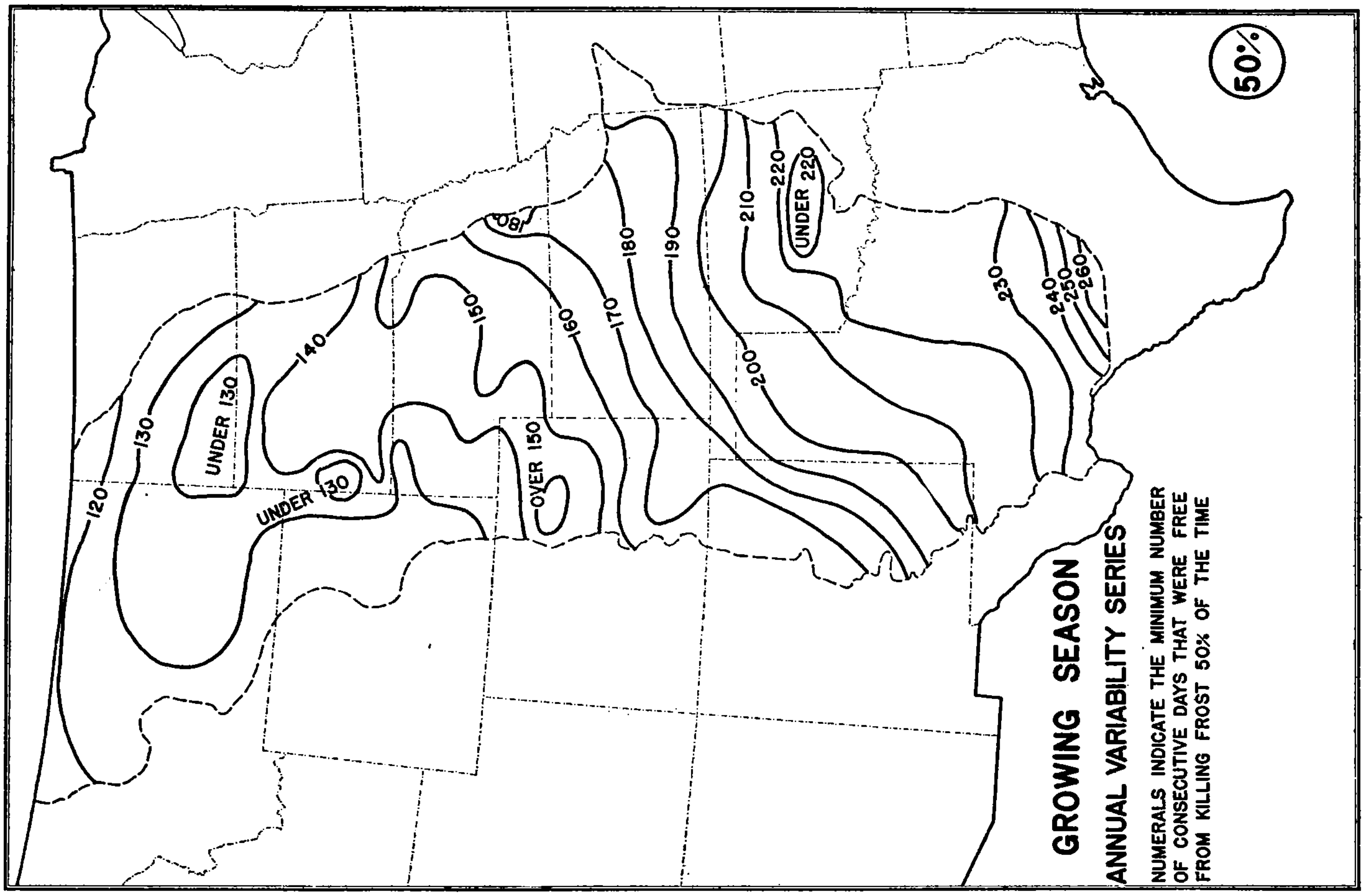

FIGURE 8.

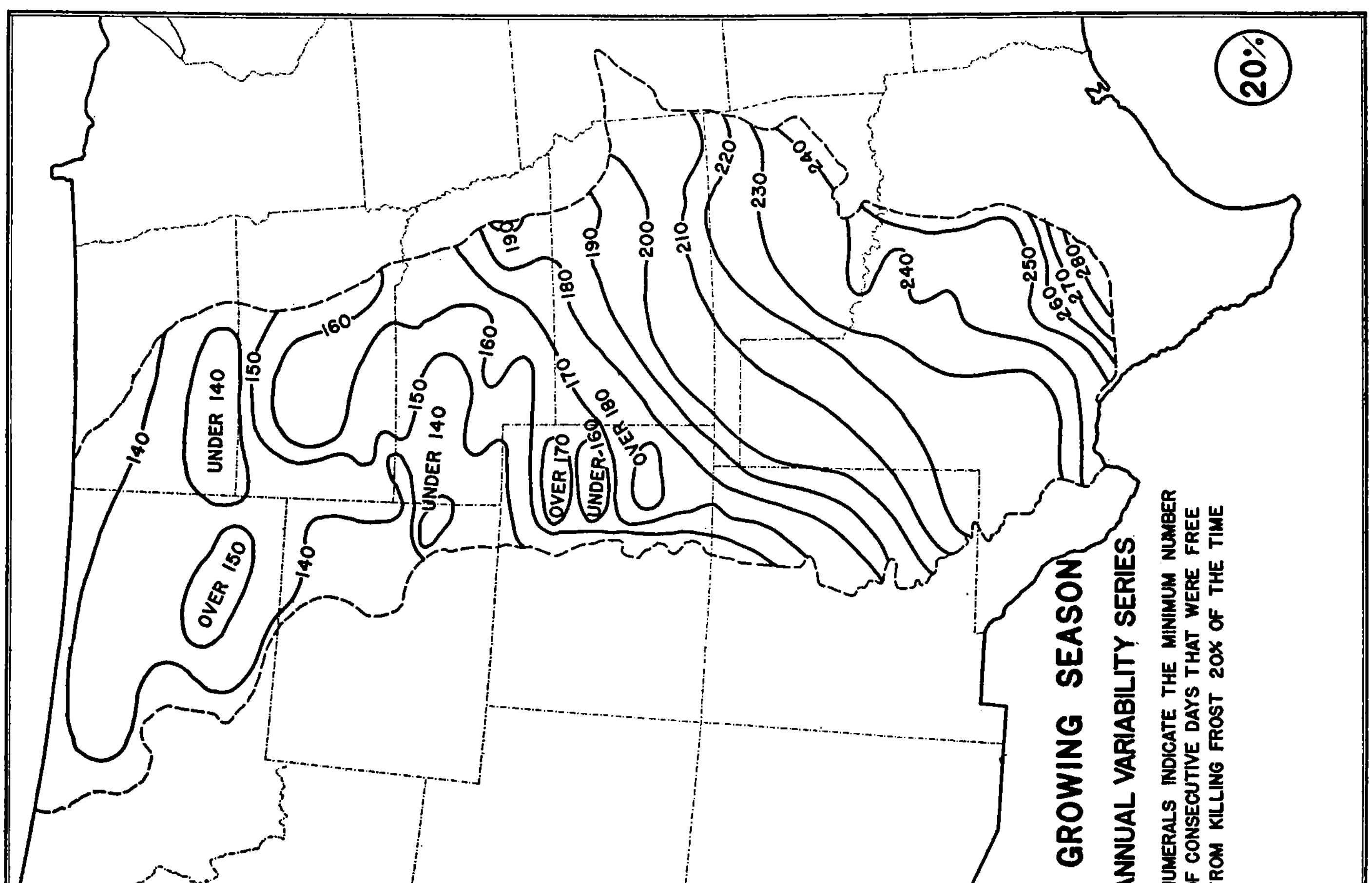

FIGURE 7.

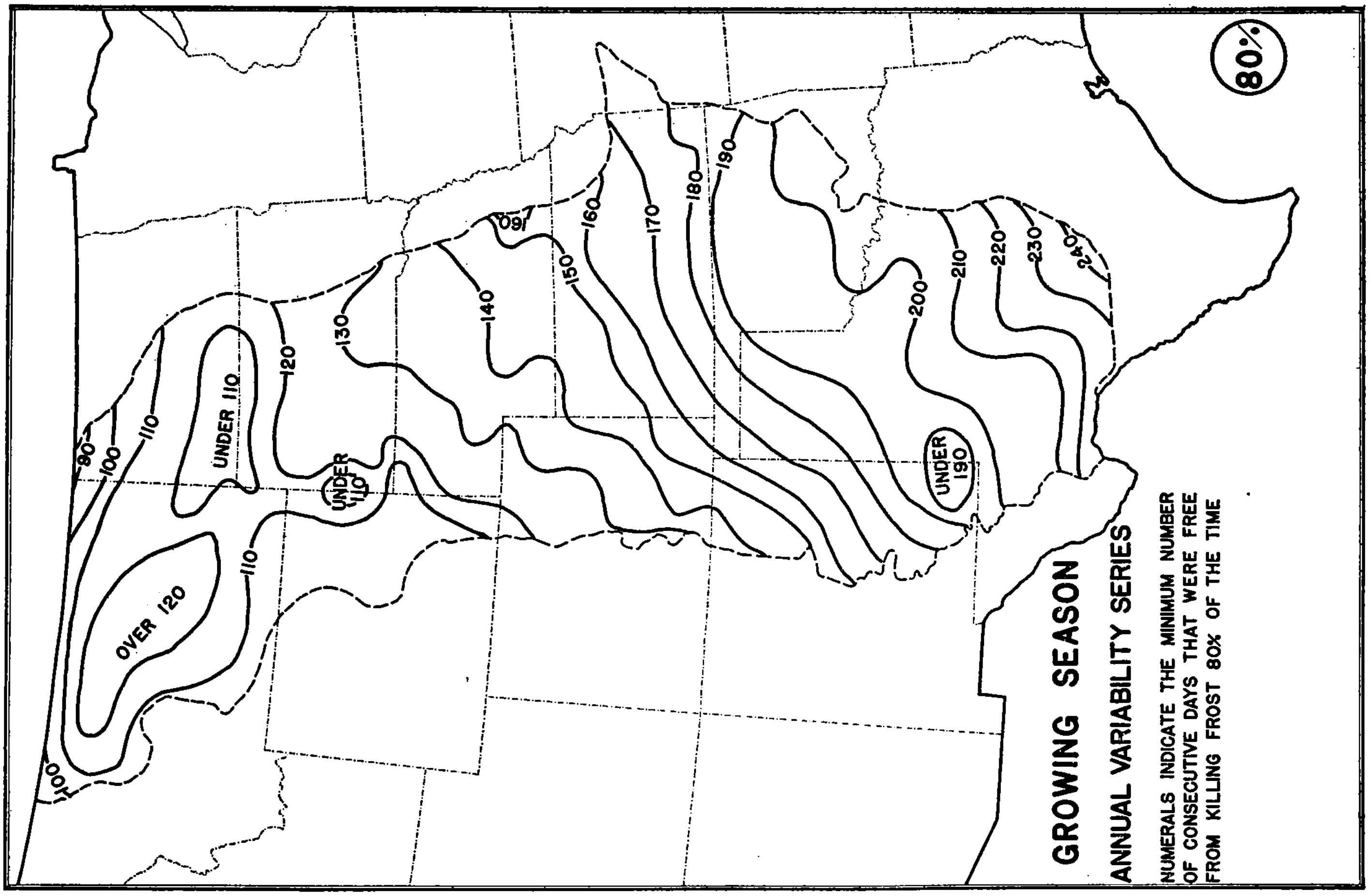

FIGURE 9.

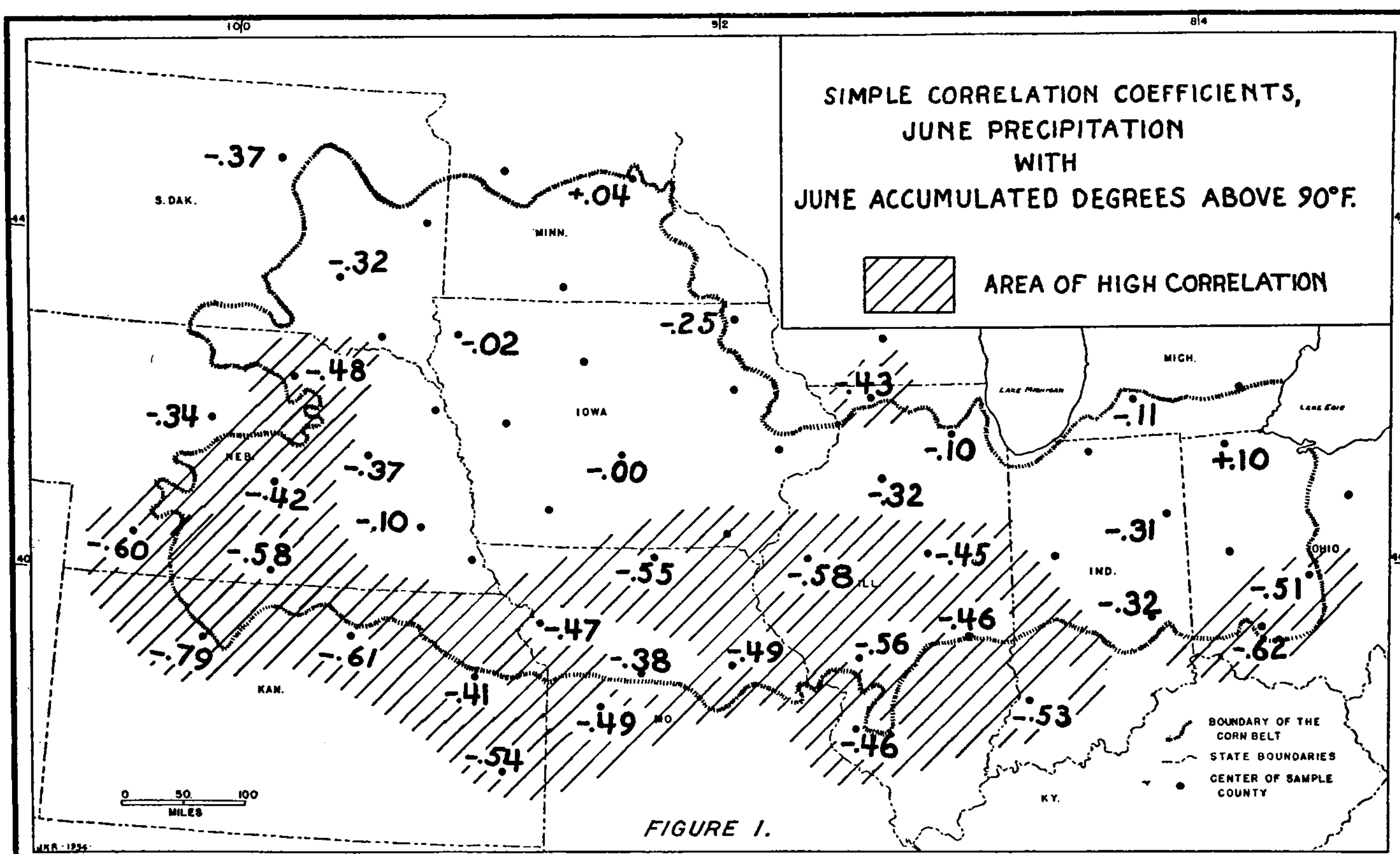

FIGURE 1.

I. CORRELATIONS BETWEEN TEMPERATURE AND RAINFALL OF THE SAME MONTHS

Figure 1 is a preliminary answer to the question: On the average, is a wet June also a hot June? The coefficients are almost all negative, showing that the greater the precipitation the fewer the accumulated degrees above 90° F., as might be expected. However, the areal distribution of these coefficients presents several interesting features. The area of relatively high coefficients (above −0.40, shaded) is an east-west strip occupying the southeastern third of the Corn Belt. In this strip, although the correlation is not perfect (perfect correlation would be ±1.00), the data indicate that a wetter than average June will also be cooler than average, and vice versa. The northern part of the region, however, with few exceptions, shows little significant correlation; and in central Iowa, none at all. In these northern and central parts of the Corn Belt, then, it does not necessarily follow that a rainy June is a cool June. Indeed, the opposite is the case in almost half the years.

The probability that so many coefficients of the considerable number computed would be above −0.40 as a result of random sampling from uncorrelated data is very small, especially when the higher coefficients are not scattered at random over the region but show areal grouping.[3]

Figure 2 shows the distribution of the correlation coefficients of the same two factors (accumulated degrees above 90° F. and rainfall) for selected stations for July. It reveals that a wet July, on the average, has a low accumulated maximum temperature throughout the Corn Belt. The southwestern part of the region has especially high correlations between wetness and relatively low temperatures.

The same two factors correlated for August show significant coefficients only in the Kansas-Nebraska part of the Corn Belt, where the month is likely to be either cool and rainy or hot and dry.

II. CORRELATIONS BETWEEN ACCUMULATED TEMPERATURES OF SUCCESSIVE MONTHS

Figure 3 shows the correlations between accumulated degrees above 90° F. for June with the same factor for July. The results are consistently positive—that is, a warm June is followed by a warm July all over the Corn Belt. However, only in the northwest and the southeast are the coefficients high enough to have considerable value in prediction.

The chances that a warm June will be followed by a warm August vary in different parts of the region, as shown by figure 4. In a broad strip across the southwest, the chances are great, with coefficients as high as +0.65 and +0.70. Over the rest of the Corn Belt, however, the coefficients are too low to indicate any considerable relation. In a few areas, there are slight indications (negative coefficients) that a cool August follows a warm June.

Correlation between accumulated degrees above 90° F. for July and the same factor for August (figure 5) shows that over most of the Corn Belt a warm July is likely to be followed by a warm August. Only in Kansas-Nebraska and a few small areas on the edges of the region are the coefficients indecisive.

III. CORRELATIONS BETWEEN MONTHLY RAINFALL AND THE TEMPERATURE OF THE FOLLOWING MONTH

Correlation of May rainfall with accumulated degrees above 90° F. for June (figure 6) reveals few significant coefficients. Only 8 of the 32 stations studied had coefficients as high as −0.40. In south-central Illinois and southwestern Indiana, however, the coefficients are high enough to be significant, so that one may conclude that a wet May tends to be followed by a cool June (with small totals of accumulated degrees above 90° F.). In the rest of the Corn Belt the correlations are mixed and largely indecisive.

A rainy July, on the other hand, is likely to be followed by a cool August, as indicated by the negative coefficients on figure 7. The relationship is consistent over the whole area, since the coefficients are all of the same sign; but a cool August can be most confidently expected after a rainy July in the central and southern part of the Corn Belt east of the Missouri River—including eastern Kansas and excluding all of Iowa except the southeastern corner.

SUMMARY

There is as yet no satisfactory explanation of these correlations. The concept of "temperature persistence" is helpful so long as we consider only the areas with high coefficients; but why is such tendency for continuation of drought, excess precipitation, subnormal and supernormal temperatures not evidenced in all parts of the Corn Belt instead of in only parts of it? It has been suggested[4] that data (for the period studied) on the percentage of time during which the different parts of the Corn Belt were under the influence of air masses of various origins might afford the solution, but such data are not available.

In spite of the fact that no satisfactory explanation is available, the enormous statistical improbability that the correlations are accidental, plus the fact that so many of the coefficients fall into a more or less regular areal grouping, or pattern, makes it practically certain that the correlations discovered are valid. Some of them have considerable predictive value. As to possible predictive utility, McEwen, writing on methods of seasonal weather forecasting, may be quoted: "It [correlation] is the method by which our trial forecasts were begun and continues to receive our main attention."[5]

In conclusion, the foregoing study reveals that rainfall and accumulated temperatures, of the same month and of successive months, correlate to significant extents in parts of the American Corn Belt; and moreover, that the distribution of the areas of significant correlation reveals problems which invite further research that may yield highly important results.

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[3] The standard error (and hence the probable error, derived therefrom) has been shown by R. A. Fisher, "Statistical Methods for Research Workers," Fifth edition, to be notoriously unreliable for samples of less than 25 cases; hence such criteria of the significance of the coefficients are not used in this study. Instead, Fisher's tables (*ibid.*) have been used to ascertain (by considering the numerical value of the coefficient, and the number of paired values used in its computation) the chance that the coefficient could have resulted by accident of random sampling in an uncorrelated universe. Thus the selection of the value ±0.40, above which coefficients are considered as definitely significant (shaded areas on the maps), is based on the fact that there is only one chance in ten that a coefficient of ±0.40 could arise by accident of random sampling if correlation were not truly present.

The same tables show that if the coefficient is as high as ±0.45, the chance of its being accidental is only one in twenty; if as high as ±0.53, only one chance in fifty; and if as high as ±0.57, only one in a hundred. Thus an approximate evaluation of the coefficients on any of the maps is possible by applying the above tests and the theorem of compound probability for independent events. The probability that all of a set of independent events will occur on a given occasion when all of them are in question is the product of their separate probabilities.

Thus there is only approximately one chance in fifty raised to the twenty-sixth power (50^{26}) of securing, by accident of random sampling of uncorrelated data, the coefficients in the shaded areas of figure 1 from the number of trials shown on that map. For fig. 2 this chance is one in 100^{80}; for fig. 3, one in 100^{15}; for fig. 4, one in 100^{11}; for fig. 5, one in 100^{50}; for fig. 6, one in 10^{60}; and for fig. 7, one in 50^{20}. Even these high probabilities that the correlations are not accidental do not take account of the fact that the higher coefficients are not arranged at random over the map but show a striking tendency toward areal grouping.

[4] H. Landsberg, in discussion of paper at joint session of A. A. G. and A. M. S., St. Louis.

[5] George F. McEwen: "Methods of Seasonal Weather Forecasting at the Scripps Institution of Oceanography." Bull. Am. Met. Soc., vol. 15, no. 11, p. 251. Nov. 1934.

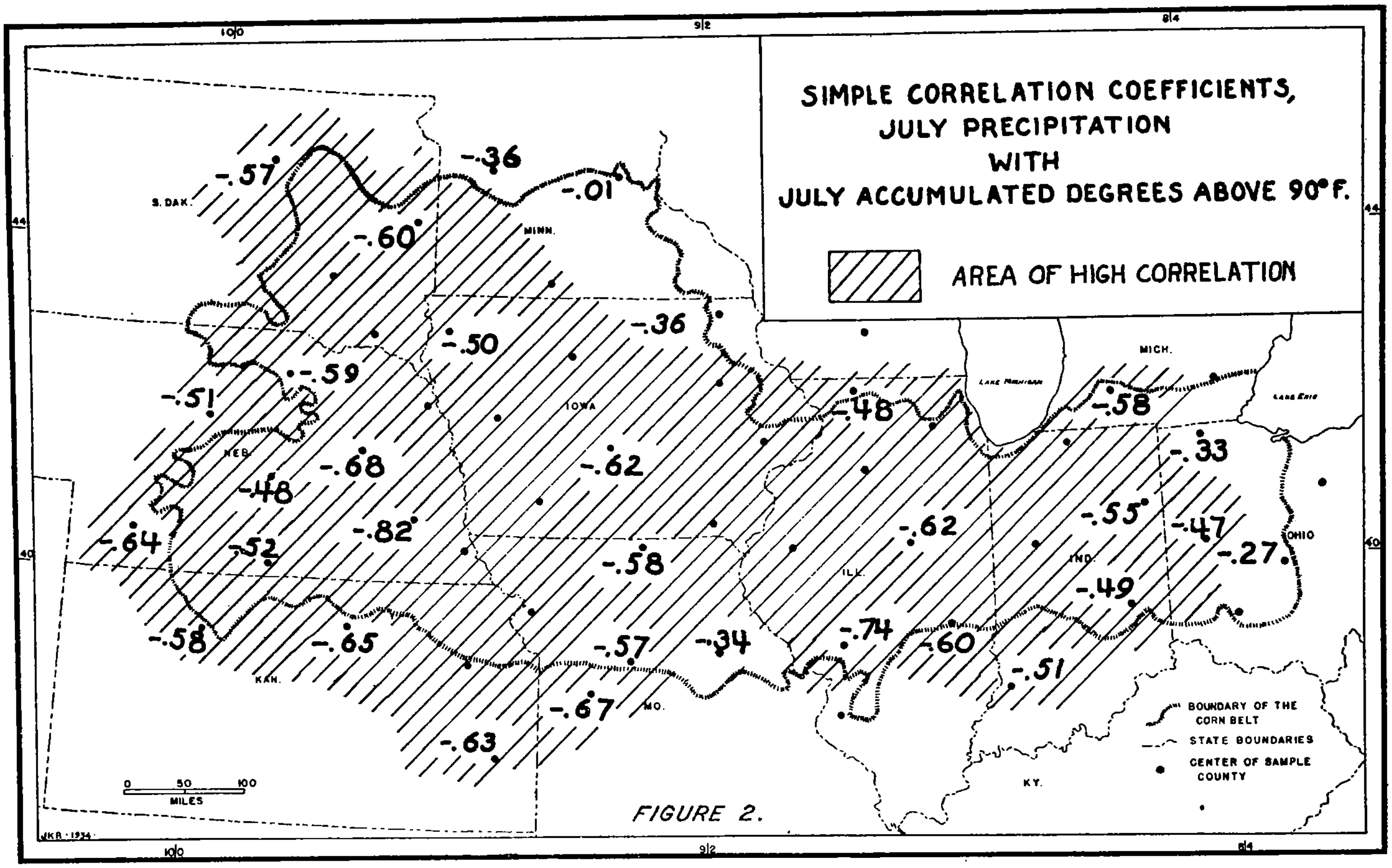

FIGURE 2.

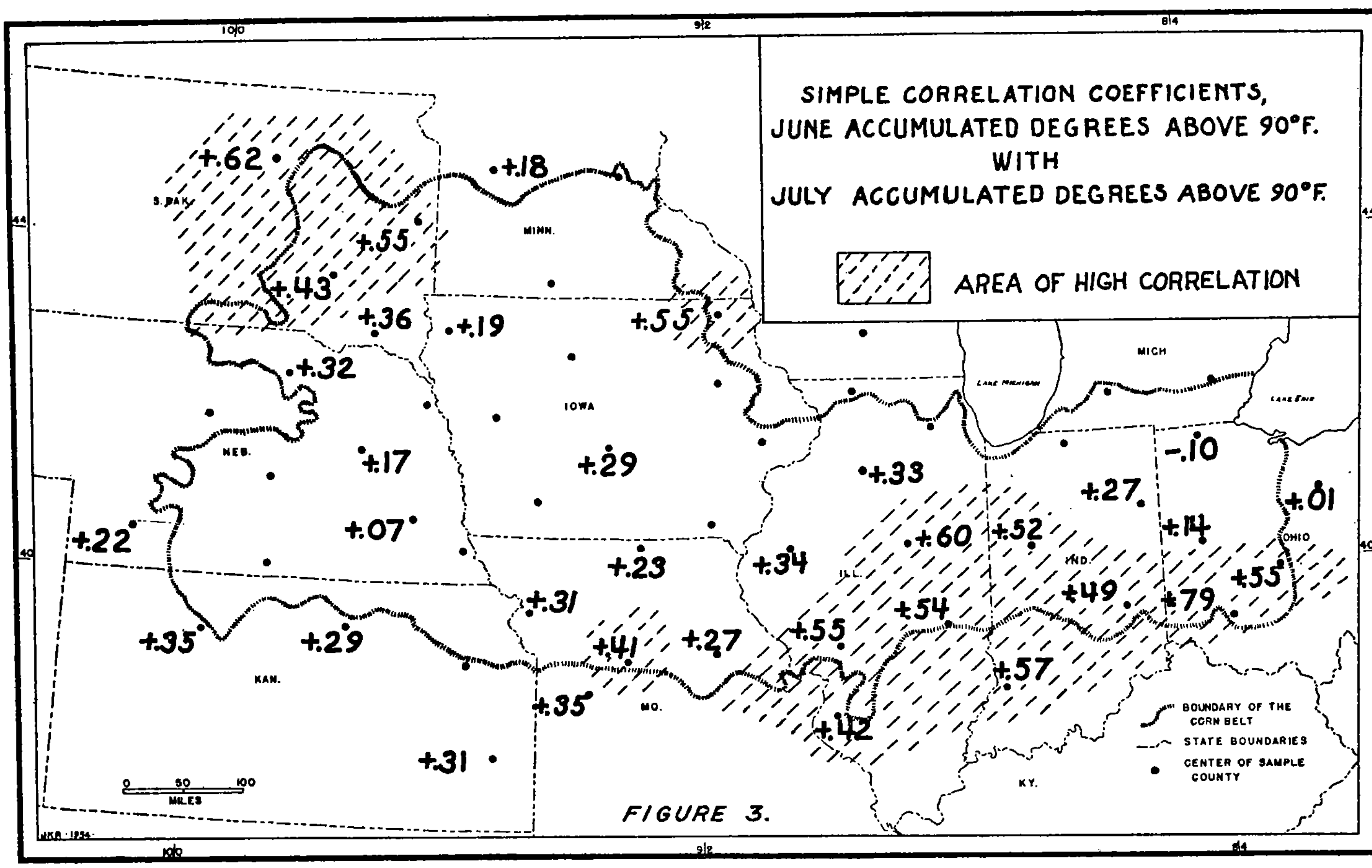

FIGURE 3.

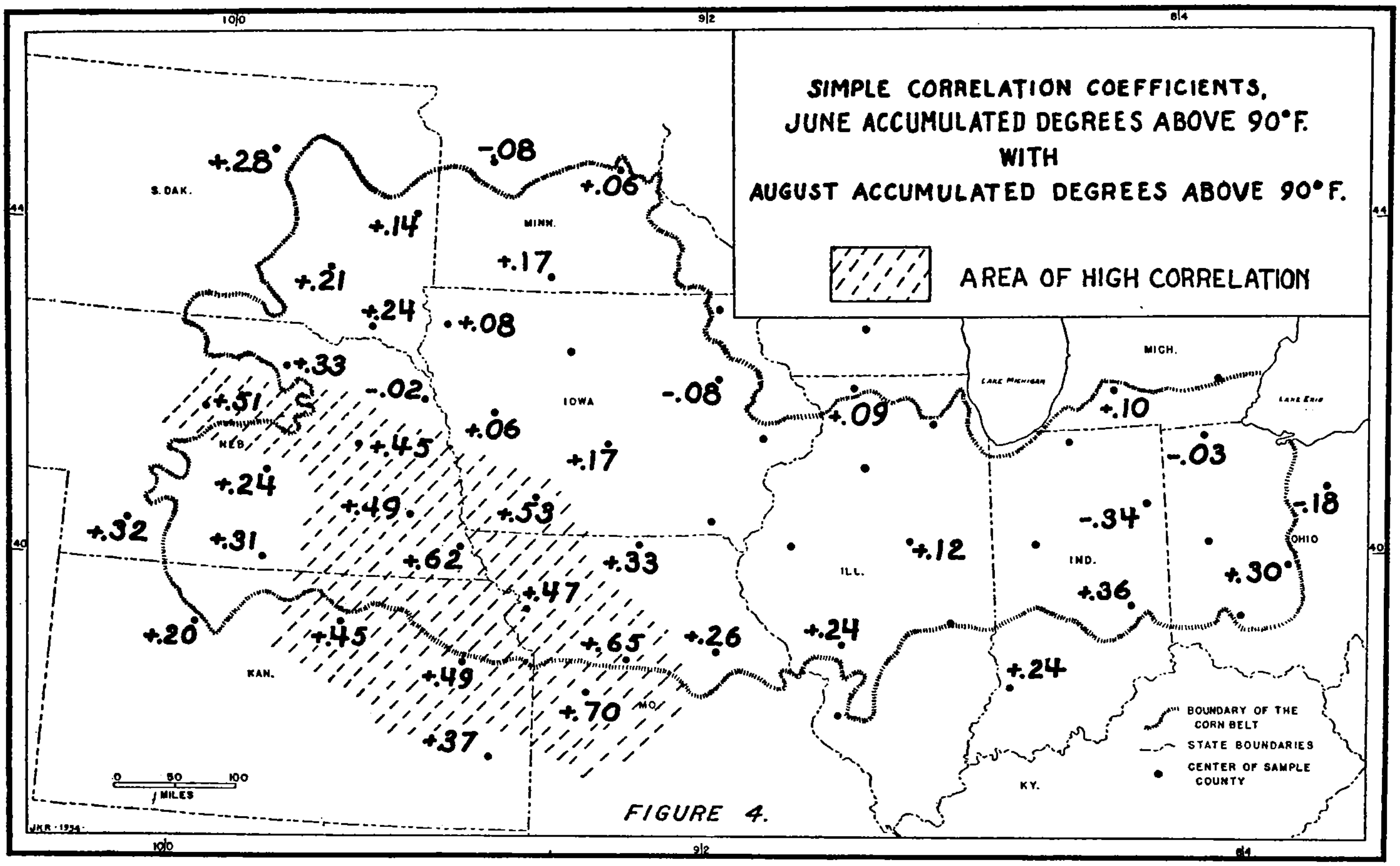

FIGURE 4.

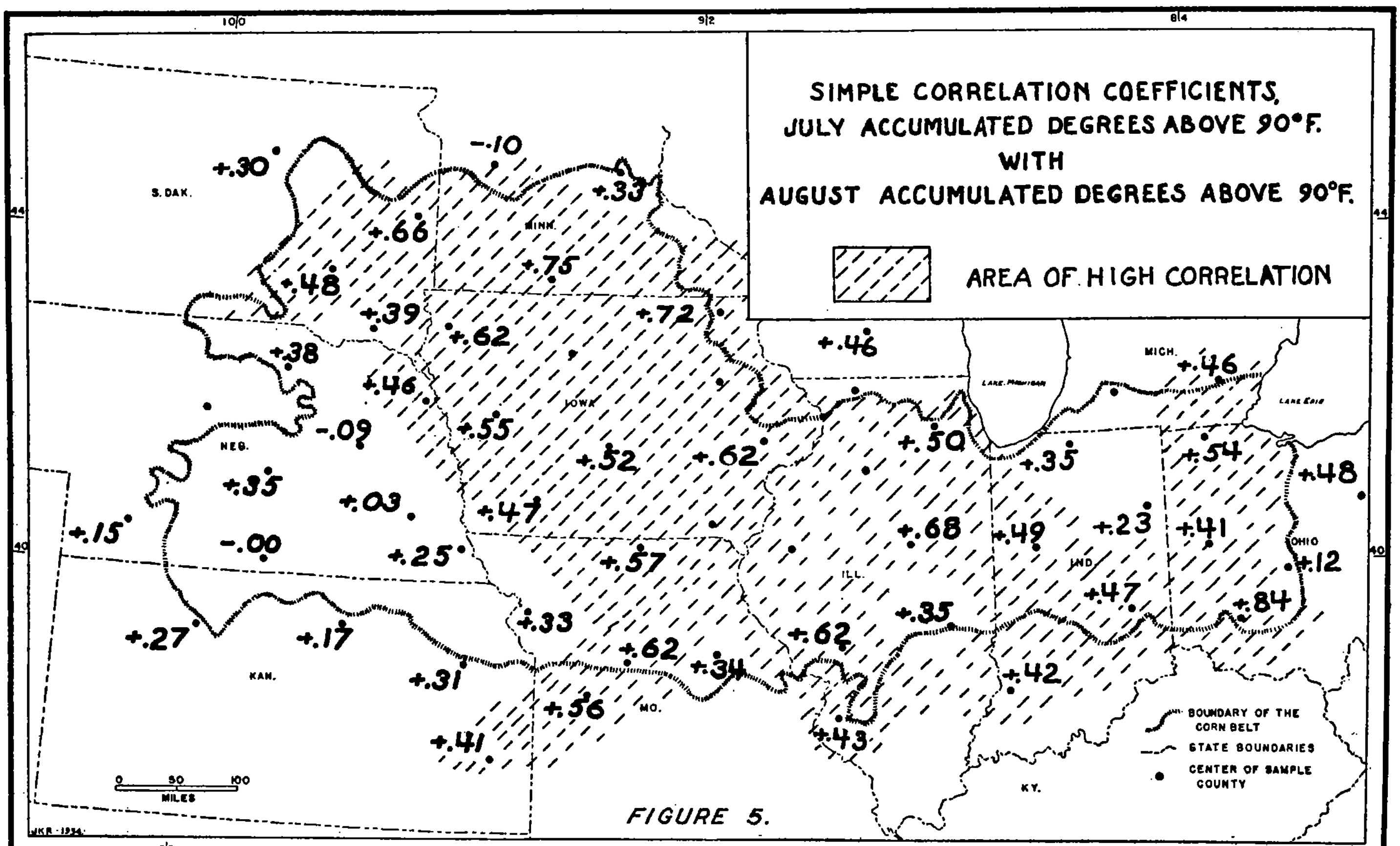

FIGURE 5.

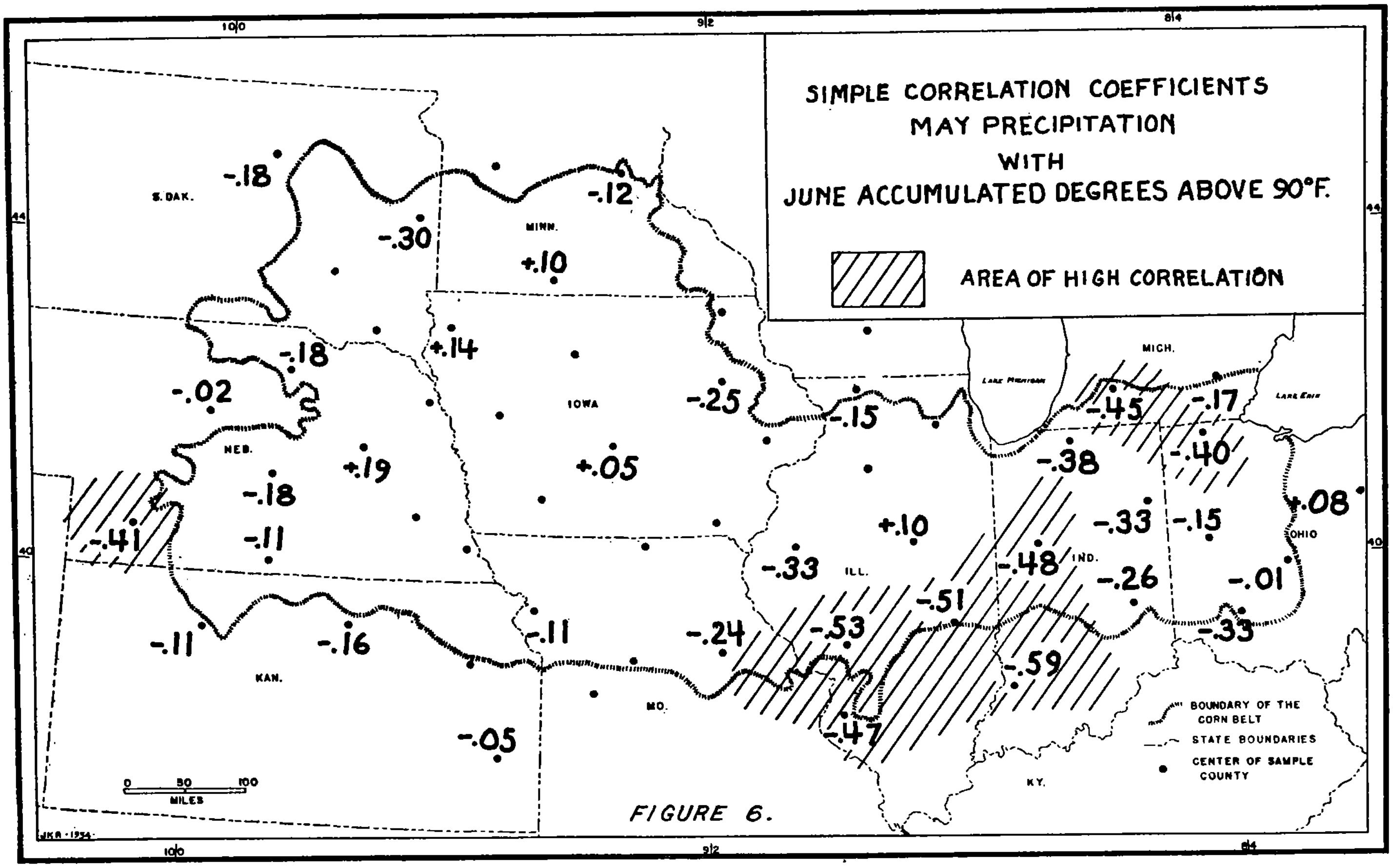

FIGURE 6.

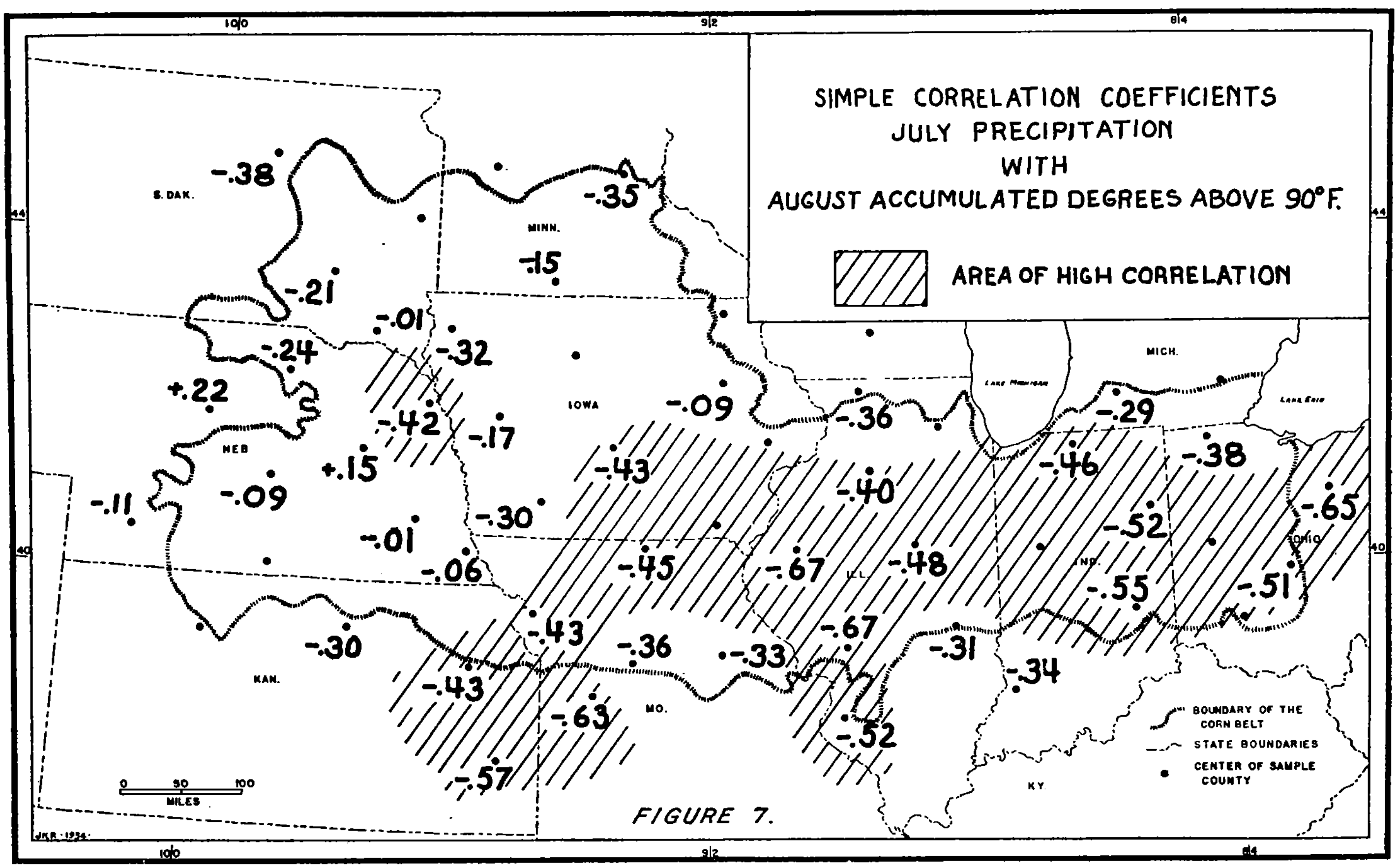

FIGURE 7.