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PREDICTION OF CORN AND SOYBEAN YIELDS USING WEATHER DATA

by

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INTRODUCTION

The possibility that crop yields could be predicted fairly accurately from readily available monthly weather data has been thoroughly investigated. If a prediction method could furnish a satisfactory degree of accuracy, crop insurance losses, other than from hailstorms, could be adjusted solely from weather data which would, in addition, supply a scientific evaluation of insurance rating procedures. Unfortunately, since precipitation figures, soil temperature, soil moisture, solar radiation, and other such statistics are not readily available on a weekly or daily basis in the United States, the method had to be developed using monthly temperature and precipitation data.

The sole use of these monthly data to predict yields is contrary to many findings (1, 2, 3); in fact, some agricultural experts at present do not consider weather an important factor in determining yields of cash grain crops (4). Others believe that there is a combination of weather factors which affect crop yields. In this study the sole use of monthly temperature and precipitation data is not to refute any of the foregoing, but is an attempt to achieve the prediction of crop yields simply and fairly accurately. If this method does not prove workable, then it is believed that a method for adjusting for crop losses based on weather statistics does not exist.

Thompson (5) has found that there is a strong correlation between monthly weather parameters and crop yields over large areas. His mathematical approach to the subject has served as the basis for determining the equation necessary in the present research. He has established a statistically reliable measure of year-to-year increases in yields due to technology. As a result of this work and subsequent findings it has been possible to develop two equations for predicting soybean and corn yields at 49 rural locations for each year of the period from 1955 through 1963. Work leading to the development of two additional predictive equations is now in progress.

Another important stimulant to this present study was the fact that the State Water Survey has 49 raingages concentrated in a 400-square-mile area of Central Illinois from which vast amounts of rainfall data could be obtained. This raingage network has been operated by the Survey since 1955 as part of its basic data collection program. Data employed in this study were for the nine years in the 1955-1963 period.

This report described the weather data used, the development of the predictive equations, the type of agricultural data available and analyzed, and the results derived so far from the analysis. The yields of the predictive equations were compared to actual yields from farms in the ramgage network. These comparisons gave the degree of accuracy possible with such equations. Predicted yields at a point were compared with actual yields at the same point and with actual yields from farms at varying distances away from the predicted point.

The results indicate that soybean yields at a point and over an area can be fairly accurately predicted using eight weather parameters. These parameters include the preseason precipitation (September-May); precipitation amounts for June, July, and August, and monthly mean termperatures for May, June, July, and August. The prediction of corn yields with the same parameters is not as accurate, but 90 percent of the time the predicted yield at a point is within 25 percent of the actual corn yield at that point. The report also describes weather-yield research planned for the future.

Acknowledgments

This report was prepared under the supervision of Glenn E. Stout, Head of the Meteorology Section of the Illinois State Water Survey, and under the general direction of William C. Ackermann, Chief of the Survey. The author is deeply indebted to Dr. Al Mueller of the University of Illinois who assisted in the area of agricultural information and data collection. Most of the agricultural data collection and routine analyses were capably performed by Gregory Leigh and Lowery Stahl, graduated students in Agriculture. The form of the equation used in the yield predictions was developed by Crop-Hail Insurance Actuarial Association staff members under the supervision of Harry Souza. Under Mr. Souza's direction all of the computer analysis required in the project was quickly and efficiently performed. The assistance of the many farmers who gave their valuable time and information is also gratefully acknowledged. Dr. J. C. Neill, statistician of the Water Survey, assisted in the mathematical interpretations of the analyzed data. Drafting of the figures was under the direction of John Brothers.

DATA

Precipitation and Temperature

Most of the research was based on agricultural data and weather data collected within a 400-square-mile area located in east-central Illinois (Fig. 1). Since 1955 the Illinois State Water Survey has maintained a dense network of 49 recording raingages in this area. The raingages are located about 3 miles apart in a grid pattern and form a square-shaped network 20 miles on a side (Fig. 1). A great many rainfall measurements are needed to furnish an accurate picture of the rainfall variability in the area (6, 7, 8). Temperature data for the 49 gage sites were obtained by regional interpolation of seven U. S. Weather Bureau temperature stations located in and around the network area (Fig. 1). Monthly mean temperatures in this climatic region do not exhibit large variations across 10- or 20-mile distances, and reasonably accurate temperature estimates were obtained for each of the 49 raingage locations. Thus, the weather data used in the study consisted of preseason and monthly data for the nine years in the 1955 through 1963 period.

Agricultural

Agricultural data, including the bean and corn yields, were obtained from 108 farms located in the raingage network (Fig. 2). Seventy of these farms had complete data for the 9-year period, and these are indicated in Figure 2. The total number of farmers was 106 as two of them each farmed two widely separate farms. Thus, the basic data consisted of preseason and monthly mean temperature values and precipitation totals at 49 points plus the crop data from 108 farms distributed throughout the network. The number of farms with data near each raingage is shown in Figure 3.

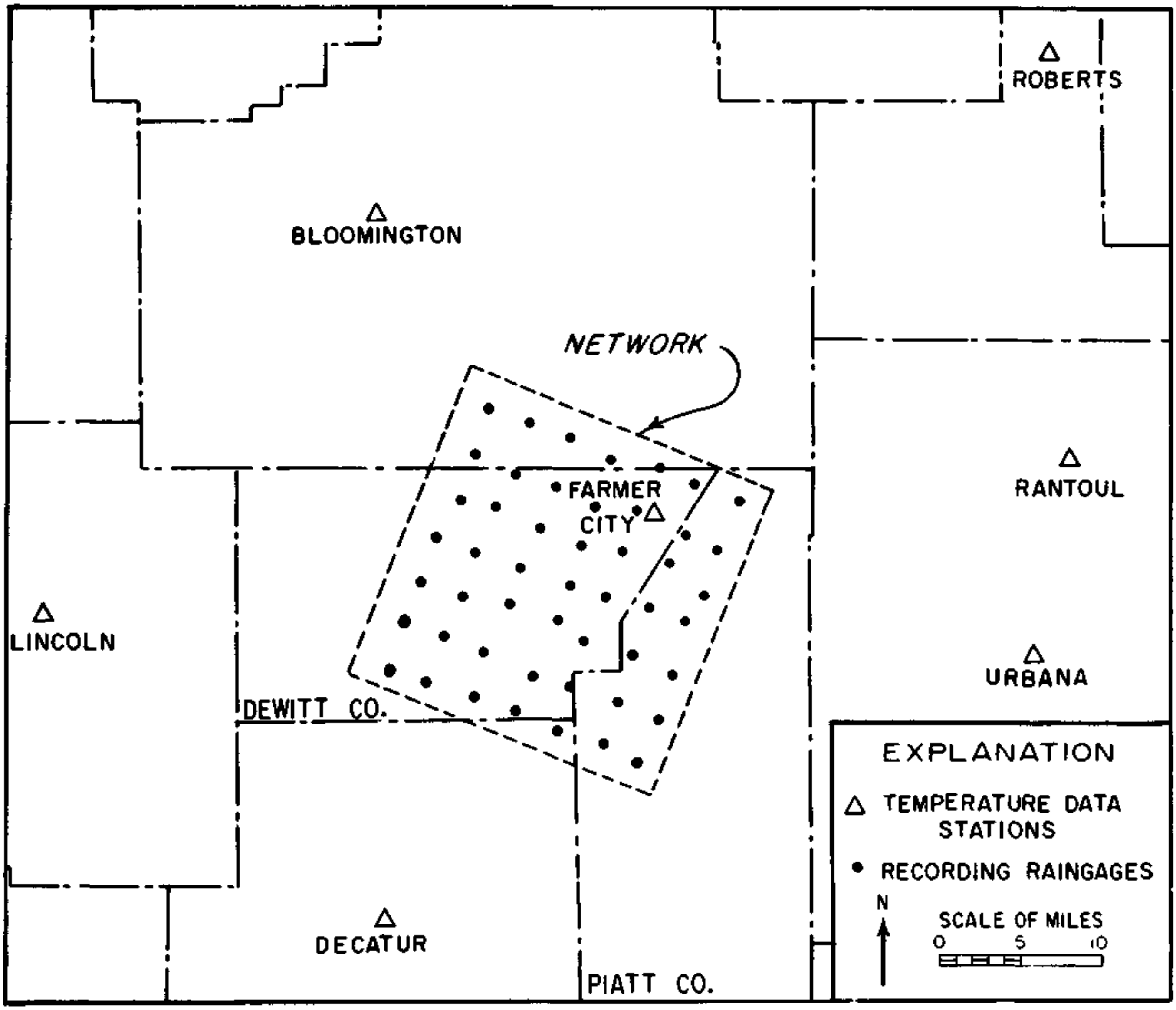

Fig. 1 LOCATION OF RAINGA6E NETWORK IN CENTRAL ILLINOIS

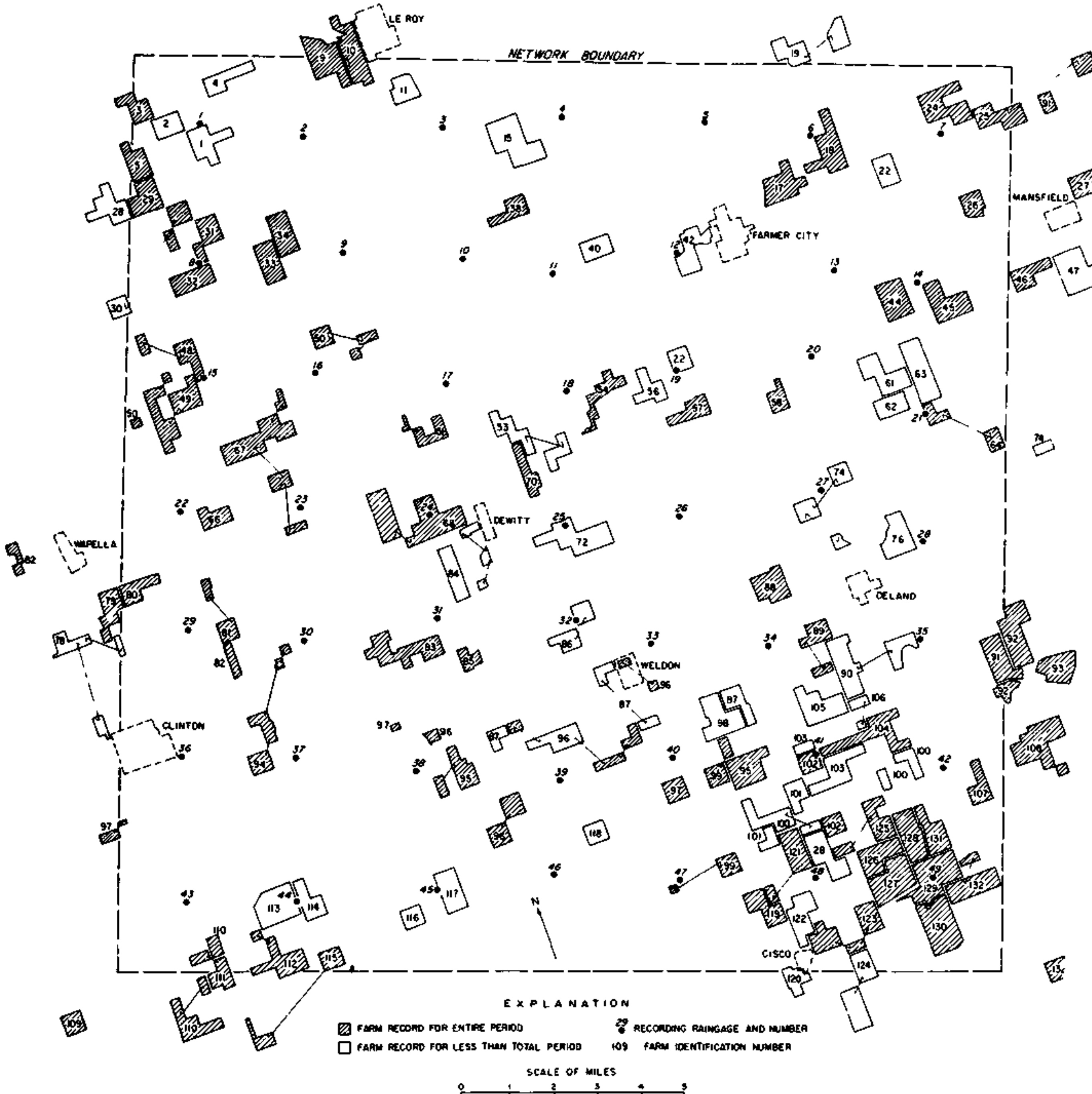

Fig 2 LOCATIONS OF COOPERATING FARMS IN RAINGAGE NETWORK

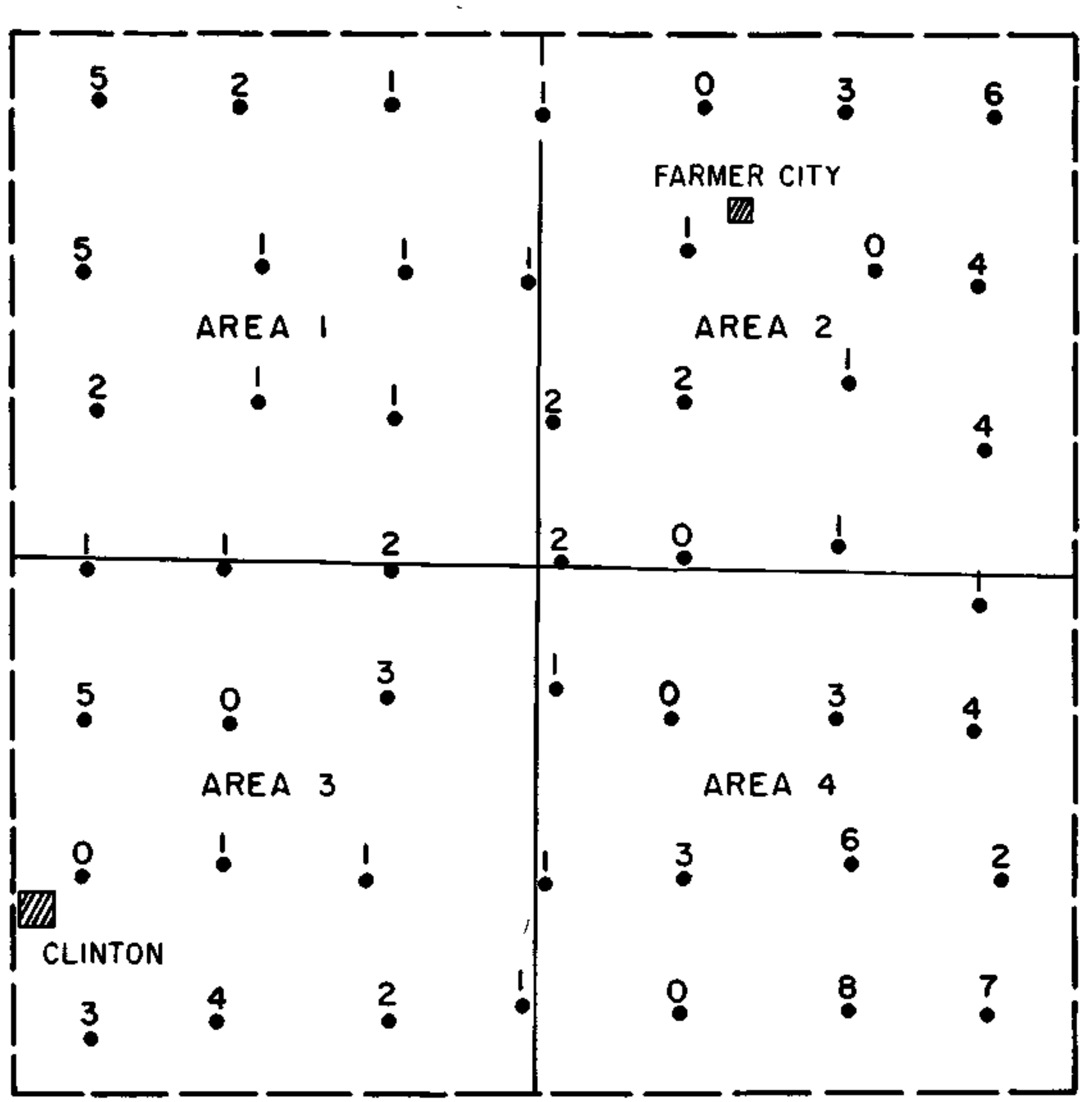

Fig. 3 NUMBER OF FARMS AROUND EACH RAINGA6E AND FOUR 100-SQUARE-MILE AREAS (1-4)

Besides corn and soybean yields, additional data for each year at each farm included information on the amount of corn and soybean acreage, the soil productivity rating, corn plant populations, planting dates, and information which would allow calculation of fertilizer applications. These data were desired for future use in more refined correlative studies of yields, agricultural practices, and weather factors, all of which are most important in explaining yield variations.

The questionnaire used to collect agricultural data is shown in Appendix A. Each of the 106 farmers was visited in the field to obtain the desired agricultural data for the 108 farms. Ninety-eight of those persons furnishing data also kept farm management records for the Farm Bureau-Farm Management Service in a cooperative project with the University of Illinois. These records for 100 farms furnished most of the agricultural data available for analysis. In the summer of 1964, 35 additional farmers were interviewed to obtain data for eight farms, those numbered 15, 24, 38, 40, 58, 74, 76, and 88 on Figure 2.

The lack of specific information in the farm management records on the annual application of nitrogen to corn the one fertilizer considered to be of greatest importance in corn yields, necessitated the calculation of its amount using a method partially developed by Sopher (2) and refined by Leigh. In essence, this empirical method used recorded information on annual fertilizer costs, wheat acreage, average nitrogen application rate per acre of wheat, manure application, and other related parameters. The details of the method of estimating pounds of nitrogen application per acre are listed in Appendix B. A farm soil productivity rating was readily available for the 100 Farm Bureau-Farm Management farms. For those eight farms without a rating, the areas of each farm with different ratings were planimetered on soil-rate maps, and an average farm rating was calculated.

ANALYSIS

Predictions of Yields

The yield predictions were made using a multiple curvilinear regression equation patterned after the equation developed by Thompson (5). The factors in both equations consist of : 1) the yield increase due to technology, 2) the monthly mean temperatures for May, June, July, and August; 3) the monthly precipitation amounts for June, July, and August, and 4) the pre-season (September-May) precipitation. Thompson found that these parameters explained a significant amount of the statewide corn and soybean yields in Illinois as well as those in other corn belt states. He also showed that his form of an equation developed for each of the nine crop-reporting districts in Iowa furnished an excellent correlation with yields in each district. The Crop-Hail Insurance Actuarial Association developed similar equations for the nine crop-reporting districts in Illinois as an aid in establishing all-weather perild insurance rates in Illinois. These equations were computed using each district's corn and bean yields, and its area-mean weather values during the 1931-1962 period. High correlation coefficients between yields and area weather factors were obtained by the Association from these district data.

After the monthly temperature and precipitation data and preseason precipitation data for each of the 49 raingage sites had been calculated and entered on IBM cards (one card for each year and each gage in the 1955-1963 period), the cards were available for computer analysis. Yields at each site were then predicted using the Central Illinois Crop-Reporting District regression equation because the raingage network is located largely within this district. In general, the predicted yields were much lower than the actual yields. The primary reason for these discrepancies appeared to be that the poorer soil areas located in the western part of the district and their related low yields acted to produce a district equation that would predict relatively low yields for an area of high fertility such as where the raingage network is located. It should also be recognized that an equation based on area mean values theoretically should not be used to predict values at points in the area. In other words, to predict point values the predictive equation should be based on point data. However, since weather and yield data were not and could never be made generally available, and if an area equation would give reasonably accurate predictions, it appeared to be a practical, albeit not a true statistical, solution. These findings for the Central District predictions indicated that to achieve maximum accuracy in predicted yields, an equation based on data from smaller regions such as counties would be essential.

In an attempt to solve the problem of-the too-low predicted yields, a second predictive equation was developed based on historical yield data and weather data from the two counties where most of the network is located (Fig. 1). Yield values for the year from 1930 through 1963 for Dewitt and Piatt counties were combined to obtain area-mean corn and bean yields. Since two-thirds of the network is in Dewitt County and the other third in Piatt County, the area mean annual yields were calculated using two-thirds of the Dewitt annual average and one-third of the Piatt average. In most years the yields from both counties were identical (9). The network area's monthly and pre-season weather parameters for the years in the 1930-1963 period were estimated using data from Clinton, Bloomington, Urbana, and Decatur. The area weather and yield values were then entered on IBM cards and supplied to CHIAA. The resulting regression equation was used to make new predictions of the corn and soybean yields for the years in the 1955 through 1963 period at all of the 49 raingage sites. The simple correlation coefficients and linear regression coefficients derived from the network-region predictive equation using the 1930-1963 data are shown in Table 1. Correlation coefficients for the individual variables reveal that the year's category (which represents technology), the July rainfall, and the July temperature are most important in explaining the variability in yields of both corn and beans. The derived correlation coefficients for the area's predicted (weather) yield and actual yields were 0. 97 for corn and 0.92 for soybeans.

TABLE 1

LINEAR REGRESSION COEFFICIENTS AND CORRELATION COEFFICIENTS FOR NINE VARIABLES AND CORN AND SOYBEAN YIELDS IN RAINGAGE NETWORK AREA

	Years (tech.)	Preseason precip.	May temp.	June rain	June temp.	July rain	July temp.	Aug. rain	Aug. temp.
	Linear regression coefficients (bu/acre/yr.)								
Corn	1.75	-0.67	0.21	0.46	-1.03	6.00	-3.96	-2.95	-2.07
Soybeans	0.44	-0.20	0.32	0.12	-0.06	1.64	-0.72	-0.01	-0.56
	Correlation coefficients								
Corn	0.89	-0.19	0.04	0.05	-0.16	0.57	-0.51	-0.19	-0.25
Soybeans	0.85	-0.21	0.21	0.05	-0.04	0.60	-0.35	-0.01	-0.26

The regression coefficients reveal an increase or decrease in yield (bu/acre), with a one-degree or one-inch departure above the average condition. For instance, the 6. 00 corn value for July rain in Table 1 indicates that for each inch of rain above the July normal the corn yield will be increased by six bu/acre. Conversely, the -2.07 for corn and August temperature means that for each degree the temperature is above the August average the corn yield will be decreased by 2. 07 bu/acre. It must be remembered that linear regression theory assumes that each additional degree of temperature or inch of rain has the same effect on yields as have all such previous departures, but actually such is not the case. Nevertheless, these regression coefficients do serve as a basis for comparing weather effects on yields. The ideal condition to derive high yields in this area would be a combination of above-normal May temperatures, June rainfall, and July rainfall; and below normal values for the preseason precipitation, June temperatures, July temperatures, August rainfall, and August temperatures.

The most important variables or determinants for corn yields are methodology (years), July rainfall, July temperature, August rainfall, and August temperature. The most important variables for soybean yields are shown to be July rainfall, July temperature, and August temperature.

Comparison of Predicted and Actual Yields

Several different types of comparisons of yields were made. For each year of data, network maps based on actual and predicted yields were prepared, and examples of these for 1962 are shown in Figures 4-7. These served as a basis for pattern comparisons in individual years. As shown in Figure 3, the network was divided into four equal square-shaped areas, each comprising 100 square miles. Predicted yields for these four areas and for the entire network were calculated and compared with actual average yields for the areas. Detailed point comparisons of yields were made using the predicted annual yields at each raingage site and the actual yields for the farms immediately surrounding each site. These point comparisons served as a basis for determining the average and extreme differences between point predictions. Another form of comparison consisted of comparing the predicted yield at a gage site with actual yields at farms located at different distances away. This final comparison furnished some measure of the ability of point predictions of yield to estimate the actual yields at farms located several miles from the point.

Pattern Comparisons. Patterns of predicted yields and actual yields were prepared for each year in the 9-year period. The patterns from the 1962 data were included in the report because they represent the poorest relationships found between predicted and actual yields in the 9-year period. The summer, 1962, had below normal rainfall and slightly below normal temperatures, June was warm and quite dry, July quite cool and very wet, and August moderately dry and cool.

Figure 4 is based on predicted soybean yields for 1962. The pattern shows that the predicted values ranged from a low of less than 30 bu/acre between gages 27 and 33, to a high of more than 34 bu/acre in two separate areas, near gage 1 and between gages 45 and 49. The soybean yield map based on actual data for 1962 is portrayed in Figure 5. This pattern has more variability than Figure 4, and has a greater range of values, from a

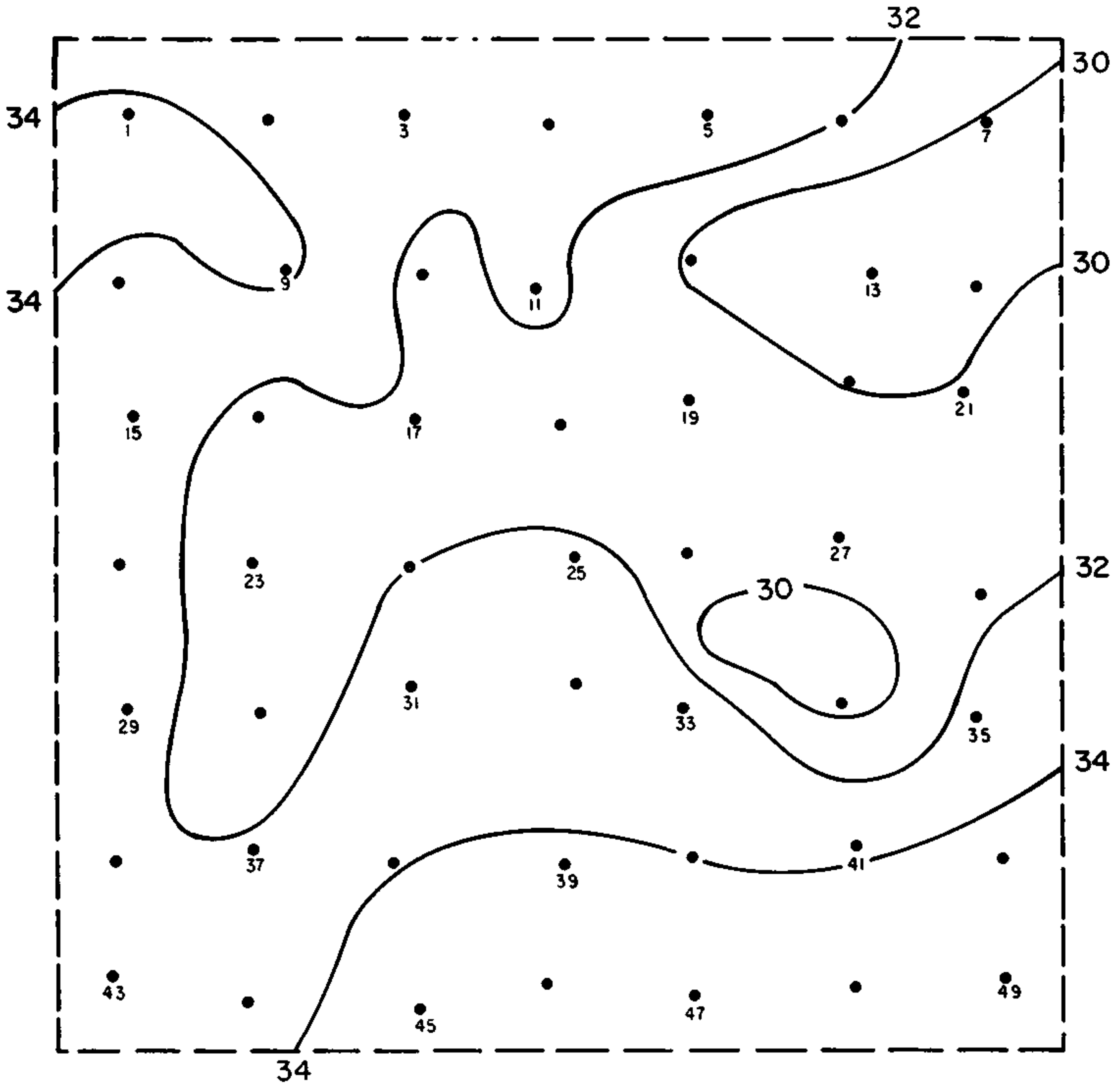

Fig 4 PREDICTED SOYBEAN YIELDS (BU/ACRE) FOR 1962

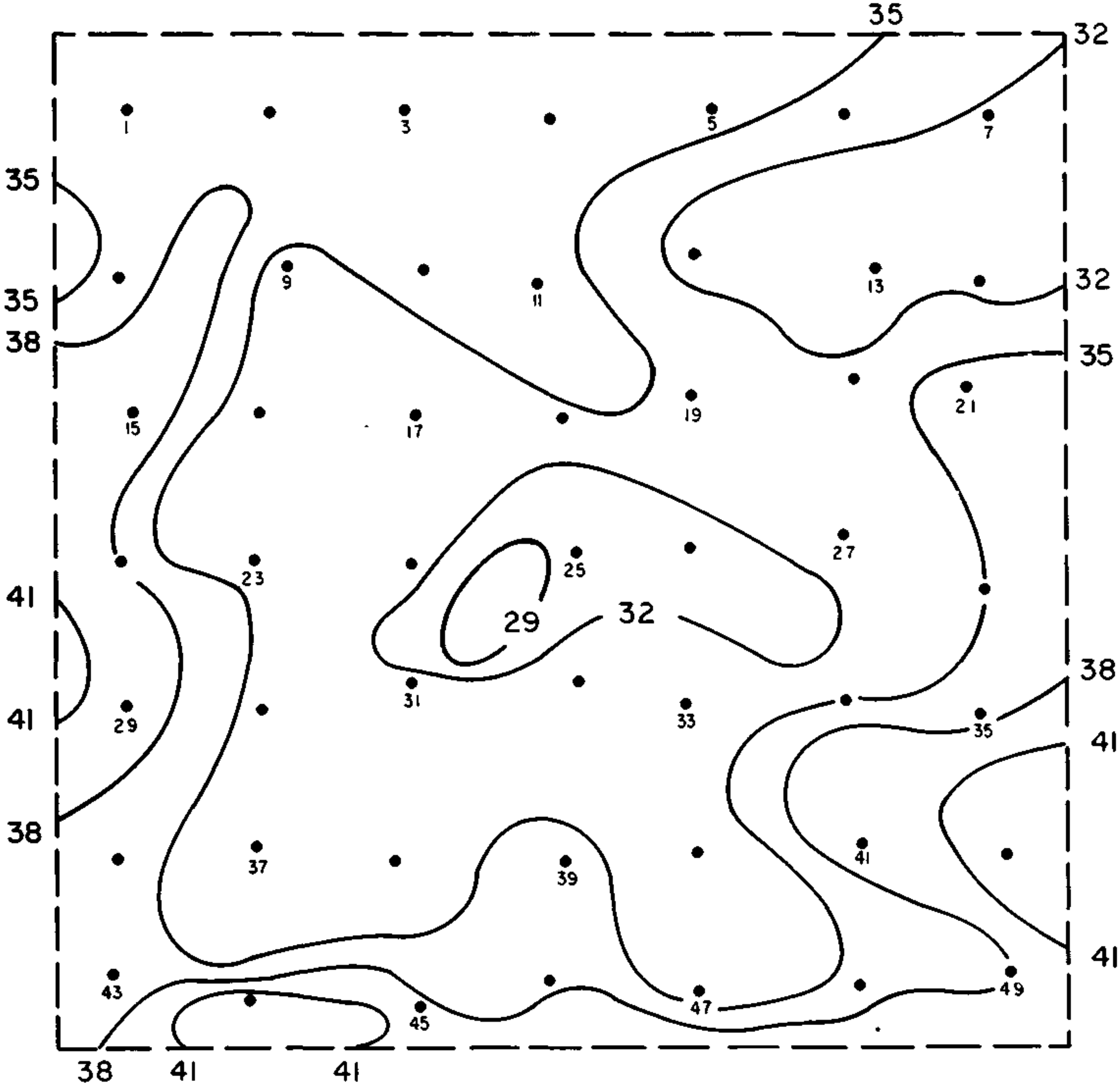

Fig 5 ACTUAL SOYBEAN YIELDS (BU. / ACRE) FOR 1962

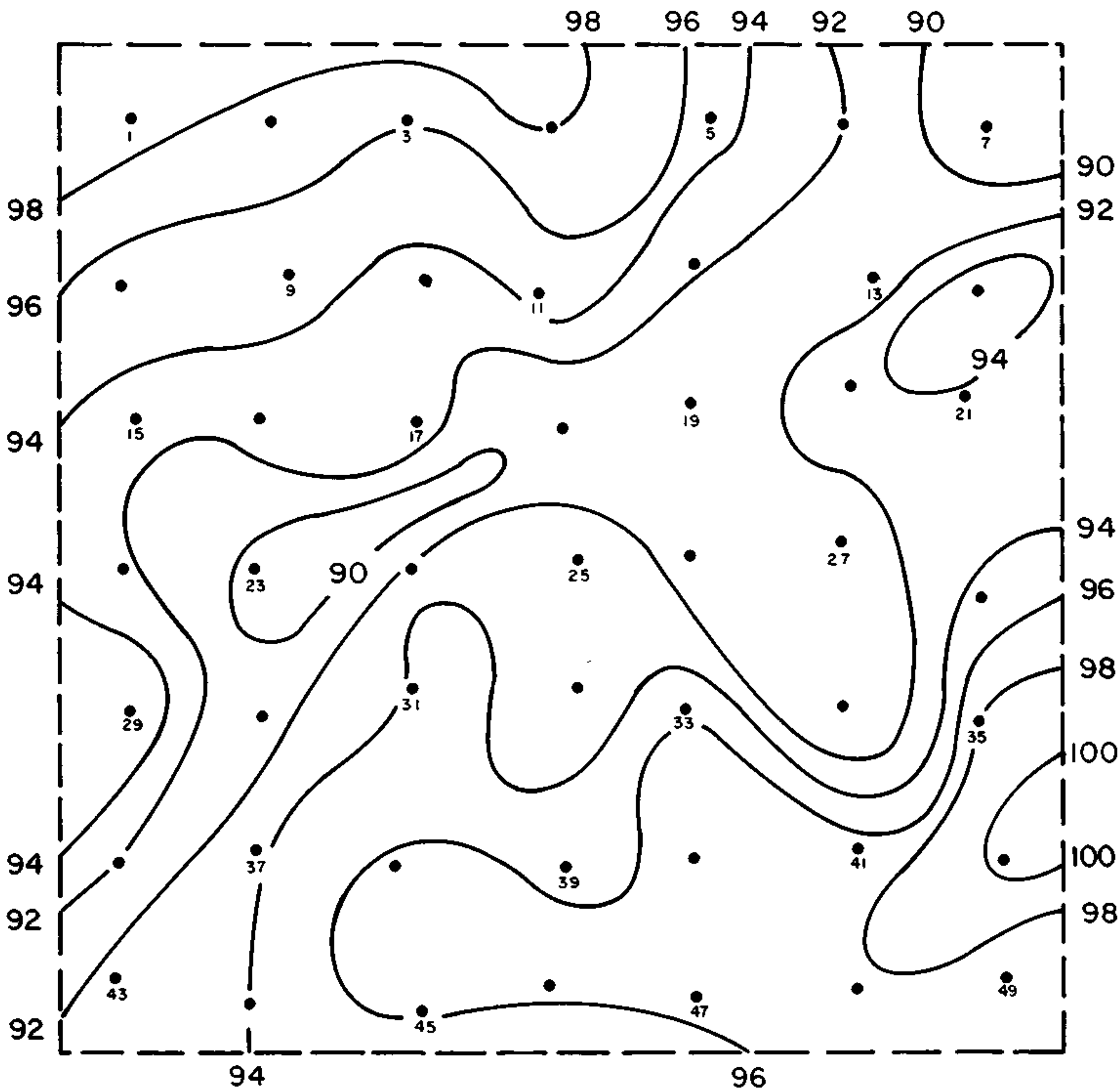

Fig 6 PREDICTED CORN YIELDS (BU /ACRE) FOR 1962

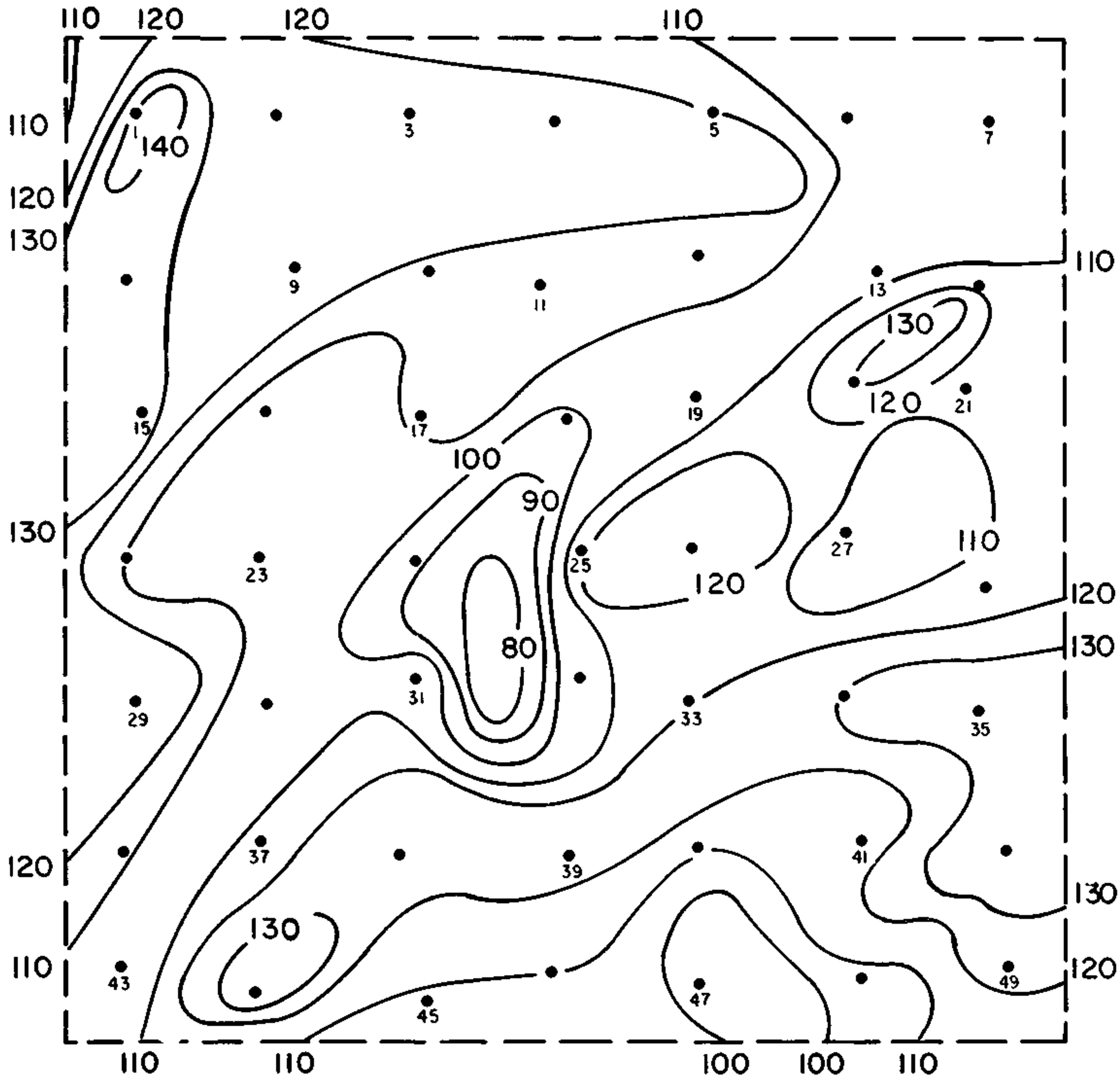

Fig 7 ACTUAL CORN YIELDS (BU /ACRE) FOR 1962

low 29 bu/acre between gages 25 and 31 to a high of 41 bu/acre near gages 45 and 49. In general, the patterns are similar although different in magnitude. The low yield areas extend generally from the network center toward gages 7 and 21, and the area of highest yields on both maps is located along the lower boundary (gages 45 to 49). In each of the nine years the predicted patterns of soybean yields closely matched the patterns derived from actual yields.

Figure 6 is an iso-yield map based on predicted corn yields for 1962. Point values ranged from a low of 89 bu/acre at gages 7 and 23, to 101 bu/acre between gages 35 and 49. Figure 7 is the iso-yield map based on actual corn yields in 1962. Actual yields varied from a low of 78 bu/acre east of gage 31 to a high of 146 bu/acre near gage 1. The greater range in reported corn yields makes the pattern on Figure 7 more complex than that on Figure 6, and therefore a comparison of these maps is somewhat difficult. For this reason, the 49 predicted yields were ranked and then equally separated into three classes: lowest, moderate, and highest, and the actual yields were also separated in a similar fashion.

The resulting pattern based on the predicted yield data is presented in Figure 8, and the pattern based on actual yields is seen in Figure 9. The basic pattern of the actual yield data is similar to that derived from the predicted data. Both patterns have their highest yield areas in opposite network corners, centering around gages 1 and 49. A trough, or low yield region, extends diagonally across the network from gage 43 to gage 7 on both maps. In general, the predicted corn yield patterns in the other eight years also matched those based on the actual data. However, the predicted corn yield values, particularly in the years after 1960, failed to exhibit the range of values shown by the actual data. The predicted patterns for 1955, 1956, and 1957 were in close agreement with the actual yield patterns. The inability of the equation to predict yields with as much variability as the actual data is not necessarily an insurmountable problem in its potential use as an insurance adjusting technique.

Comparisons of Area Yields. In each year predicted corn and bean yields for the 400-square-mile area were developed from the 49 gage site values, and a mean area yield for each crop was calculated using all of the individual farm actual yield values. The resulting annual values are shown in Table 2. In each year the predicted yields for the 400-square-mile area were less than the actual yields, although the differences for soybeans were generally small, quantitatively.

TABLE 2

NETWORK AREA CORN AND SOYBEAN YIELDS, 1955-1963

	Corn yields, bu/acre			Soybeans yields, bu/acre		
Year	Predicted	Calculated from sample farms[1] data	Calculated from county data	Predicted	Calculated from sample farms[1] data	Calculated from county data
1955	66	71	65	30	31	29
1956	86	90	80	32	35	33
1957	77	89	76	30	32	29
1958	74	88	76	30	32	30
1959	73	82	76	29	31	29
1960	80	95	81	30	34	32
1961	86	103	87	32	36	32
1962	96	114	98	33	36	33
1963	95	114	99	33	37	35

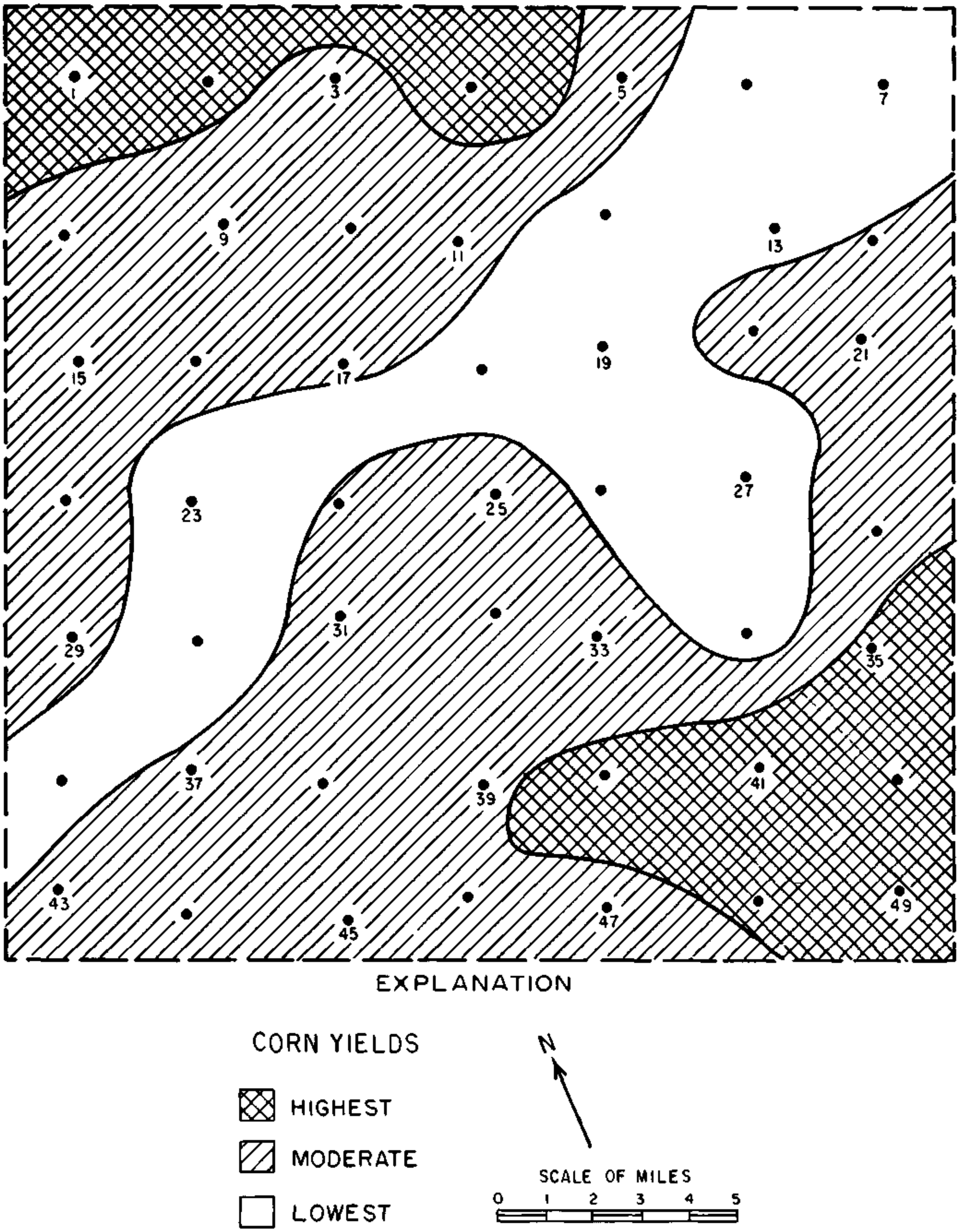

Fig 8 PATTERN OF PREDICTED CORN YIELDS FOR 1962

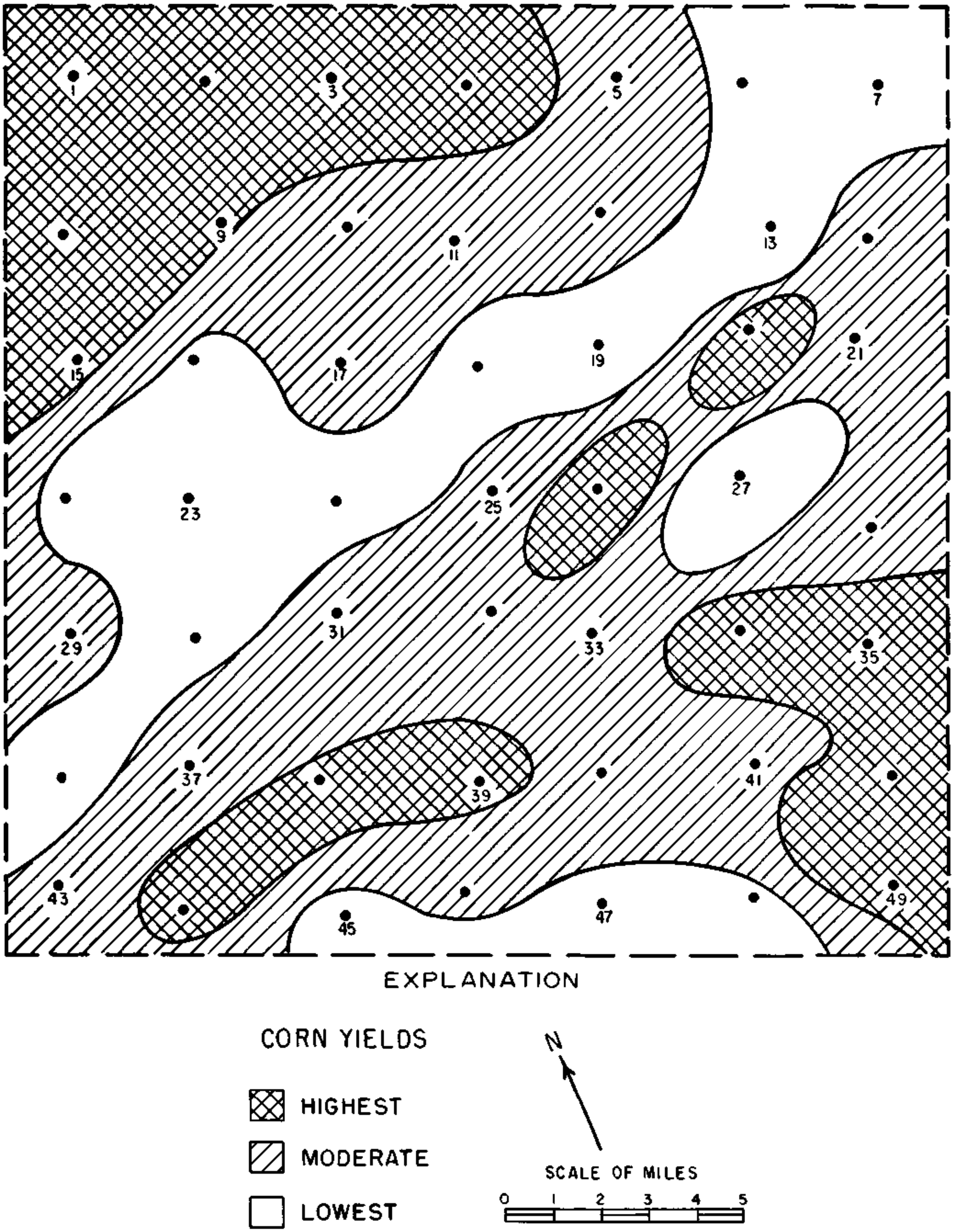

Fig. 9 PATTERN OF ACTUAL CORN YIELDS FOR 1962

The differences between corn yields were not too great in the early years of the sample period, but these differences increased with time. The average area yield values calculated using two-thirds of the Dewitt County average and one-third of the Piatt County average are also shown in Table 2. These "actual" yields are much closer to the predicted values than are the actual values determined from the 108 farms used in the study. The difference between the county-derived yields and those from the sampled farms indicates that these farms generally represent an above-average level of management for farms in the area. Thus, differences in yields presented here and in the remainder of the report probably represent a greater range of differences than would exist in an area between predicted values and most actual yields. In applications in other regions predicted yields are likely to be better estimates of actual yields than is shown in this report.

The average and extreme differences between the predicted and actual yields for the 400-square-mile area are shown in Table 3 (corn) and Table 4 (beans). Also shown in these tables are the differences between the predicted and annual yield values expressed as a percent of the actual value. For corn (Table 3) the average area difference in yields is 12.6 bu/acre although the difference was as great as 19 bu/acre in 1963 (Table 2) and as small as 4 bu/acre in 1956. This average difference in bushels is shown to represent 13 percent of the actual yield-value. The average difference in soybeans (Table 4) for the network area was 3 bu/acre, or 8 percent of the actual area yield.

The same type of comparison was performed using the predicted and actual yield data for the four 100-square-mile areas within the network (Figure 3). The average difference in yields of corn, based on data from all four areas, was 13 (Table 3), although maximum regional differences ranged from 23 bu/acre to a low of only 1 bu/acre. Area number 1 (Fig. 3) had an average difference of 15 bu/acre, whereas area 2 had an average difference of only 11 bu/acre. The maximum difference of 23 bu/acre occurred in area 1 in 1962 and again in area 4 in 1963.

Comparison of Point Yields. To ascertain the accuracy of yield predictions at a point, the predicted yields at each gage site with data from surrounding farms were compared with the actual yields at these farms (Fig. 3.). The nine years of data furnished 786 individual point comparisons of corn yields and 714 point comparisons of bean yields.

The predicted corn values were sorted into eight ranges or classes of bushels per acre, and the actual yield data associated with each of these ranges were analyzed separately. The average and maximum differences between the predicted and actual yields were determined, and the standard deviation around the average difference in the point yields also was calculated. Data in Table 3 show that when the predicted point yield was in the range of 60-65 bu/acre on the average it was 13 bushels less than the actual yield. In one extreme instance, the predicted yield was 48 bu/acre below one of the actual nearby yields, whereas the least difference showed the predicted value to be 1 bu/acre higher than the actual value. The standard deviation shown in Table 3 for the 60-65 class is ± 12 bushels around the -13 bu/acre average, which means that 67 percent of the time the predicted yield was in the range from 1 to'25 bu/acre lower than the actual yield at a point. The average and extreme bushel differences in Table 3 were also expressed as percentages of the actual yields. Thus the average difference of 13 bushels shown for the 60-65 range becomes 15 percent of the actual yield. The greatest measured difference at a point is translated as 44 percent of the actual yield. However, most of the maximum percentage values shown in Table 3 were not associated with the large negative differences, but were derived from point situations where the predicted value was considerably greater than the actual value. For instance, the +81 percent maximum value shown for the 76-80 bu/acre class was derived from a case where the predicted value was 76 bu/acre and the actual yield was 42 bu/acre, and the (P-A) difference of 34 bu/acre is 81 percent of the actual yield.

Table 4 contains information for soybeans presented in a manner identical with that for corn in Table 3. The predicted values of soybeans at point were divided into four ranges, and the average and extreme differences between the predictions and the actual yields are shown for each range. Point predictions of bean yields are low by either 3 or 4 bu/acre in all instances. The average deviation of ± 4. 7 bu/acre for the 32 bu/acre or greater predicted range means that 67 percent of the predicted yields will be in a 9-bushel range extending from 8 bu/acre less than the actual yields to 1 bu/acre more than the actual. The average differences expressed as a percent of the actual yields reveal that a predicted bean yield at a point is usually 8 or 9 percent lower than the actual point yield.

The values appearing in Tables 3 and 4 illustrate the magnitude of the average and extreme differences that occur between predicted and actual corn and bean yields when weather data are available to make a point prediction.

Comparison of Point-Area. The principal practical application of the yield prediction method for adjusting crop losses appears to depend on the ability of available U. S. Weather Bureau station data to predict yields at farms located several miles away from the stations. Since these weather stations are normally spaced so that each represents 200-300 square miles, very few point weather data are available to predict yields for most potential insurees.

Gage 25 (Fig. 2) was selected to make an initial comparison of point yield predictions and actual yields from varying surrounding areas. Gage 25 was chosen because it is located near the center of the network area and thus offers a more uniform sampling of actual yield data in all directions away from its location. Yields at all farms located in three concentric rings around gage 25 (0-5 miles, 5-10 miles, and 10-15 miles) were compared with the predicted yields at gage 25. An example of these comparisons for each year and for the corn data from the 0-5 mile range area is presented in Table 5. Differences between the predicted yields and the average yield based on all farm data for the individual years ranged from a low of 0 bu/acre in 1959 to a high of 16 bu/acre in 1963. In 1959 when the difference was 0, the extreme yield differences exhibited by the 12 farms varied from a positive difference (actual yield greater than predicted) of 21 bu/acre, to a negative difference (predicted greater than actual value) of 35 bu/acre. The standard deviation of ± 10 bu/acre around the predicted

TABLE 3. DIFFERENCES BETWEEN PREDICTED (P) AND ACTUAL (A) CORN YIELDS AT A POINT AND OVER AN AREA

Area	Number	Difference (predicted-actual), bu/acre: Average	Maximum	Minimum	Standard deviation (around average)	Percent $(\frac{P-A}{A})$: Average	Maximum	Minimum
400 sq. mi.	9	-12.6	-19	-4	--	-13	-17	-4
100 sq. mi.	36	-13	-23	-1	--	-13	-21	-1
Point predicted value range, bu/acre								
60-65	60	-13	-48	+1	±12	-15	-44	+2
66-70	93	-13	-38	+1	±14	-12	+94	+1
71-75	71	-13	-43	0	±14	-12	+85	0
76-80	152	-14	-43	0	±14	-13	+81	0
81-85	125	-13	+51	0	±14	-11	+154	0
86-90	110	-14	-50	0	±13	-12	+52	0
91-95	110	-22	-48	0	±15	-17	+60	0
≥ 96	65	-17	-48	+1	±14	-14	+43	+1
Average		-14.7			±13.8	-13.2	—	—

TABLE 4. DIFFERENCES BETWEEN PREDICTED (P) AND ACTUAL (A) SOYBEAN YIELDS AT A POINT AND OVER AN AREA

Area	Number	Difference (predicted-actual) bu/acre				Percent $(\frac{P-A}{A})$		
		Average	Maximum	Minimum	Standard deviation (around average)	Average	Maximum	Minimum
400 sq. mi.	9	-3	-4	-1	+ 1.1	-8	-12	-3
100 sq. mi.	36	-2. 9	-6	0		-8	-17	0
Point predicted value range, bu/acre								
≤ 27	27	-4	-14	0	±4.7	-9	+59	0
28-29	137	-4	-21	0	±4. 6	-9	-42	0
30-31	273	-3	-24	0	±4.9	-7	+ 150	0
≥ 32	277	-4	-31	0	±4.7	-8	+ 155	0
Average	--	-4		--	±4.7	-8. 2		

yield means that about 67 percent of the actual yields occurred within the range from 65-85 bushels in 1959.

TABLE 5

DIFFERENCES IN PREDICTED AND ACTUAL, CORN YIELDS FROM ALL FARMS WITHIN 5 MILES OF GAGE 25

	1955	1956	1957	1958	1959	1960	1961	1962	1963
Number of farms	9	9	11	11	12	13	16	17	17
Predicted yield (bu/acre)	67	85	77	63	75	83	86	94	92
Average actual yields (bu/acre)	69	88	83	75	75	84	96	106	108
Yield difference (bu/acre)	-2	-3	-6	-12	0	-1	-10	-12	-16
Standard Deviation about predicted (bu/acre)	± 5	± 10	± 17	± 17	± 10	± 13	± 14	± 25	± 23
Maximum A> P difference (bu/acre)	+13	+24	+36	+39	+21	+24	+27	+30	+39
Maximum P> A difference (bu/acre)	-7	-21	-30 '	-21	-35	-33	-28	-20	-5
Average difference as a percent of actual yield	3	3	7	16	0	1	10	11	15

In Table 6 various other expressions of the differences between the gage 25 predicted yields and those for farms in the three different areas surrounding the gage are shown. The average values for corn and beans based on all nine years of data reveal that the difference between the predicted and actual yields increased considerably when the location of the farm data changed from 0-5 miles to 5-10 miles. However, there was no appreciable difference in the values as the distance increased from the 5-10 mile area to the 10-15 mile area. That is, the predicted yields of corn and soybeans at gage 25 were as good for those at farms located 5-10 miles away as they were for those at farms 10-15 miles distant.

DIFFERENCES BETWEEN PREDICTED YIELDS AT GAGE 25 AND AVERAGES OF ACTUAL YIELDS FOR AREAS AROUND GAGE 25

	Yield difference, actual-predicted, bu/acre									
Area rings at gage 25 (miles)	1955	1956	1957	1958	1959	1960	1961	1962	1963	Average
					Corn					
0-5	-2	-3	-6	-12	0	-1	-1	-12	-13	-8
5-10	-5	-5	-14	-26	-10	-19	-19	-23	-25	-17
10-15	-4	-6	-14	-28	-7	-10	-17	-21	-23	-15
					Soybeans					
0-5	-1	-2	-1	-5	-1	-1	-2	+1	-2	-1
5-10	-2	-3	-3	-8	-2	-5	-5	-3	-4	-4
10-15	+1	-2	-2	-6	-2	-4	-4	-6	-5	-4

The final analysis of the ability of predicted yields at a point to accurately measure actual yields at farms located varying distances away was performed using data from five network raingages. In addition to the data from gage 25, predicted yields at gages 1, 7, 43, and 49 (Fig. 2) also were compared with actual yields at farms at different distances away from each of them. Use of the four gages located in the network corners enabled a comparison of predicted point yields with actual yields for farms located in areas 15-20 miles and 20-25 miles away from the gages. Data from these raingages were combined to obtain various measures of the differences between actual and predicted yields, and the results are shown in Table 7. The data for corn yields reveal that on the average the

TABLE 7

DIFFERENCES BETWEEN POINT PREDICTED YIELDS AND ACTUAL YIELDS IN AREAS LOCATED AT VARYING DISTANCES AWAY FROM THE POINT

Location of area of actual yields from point (miles)	Average yield difference, pred. - act., (bu/acre)	Maximum difference, (bu/acre)		Deviation (bu/acre) about average difference	
		Pred.>Act.	Act.>Pred.	1 standard	2 standard
		Corn			
0-5	-11.1	37	52	±13	±29
5-10	-15.1	52	59	±14	±30
10-15	-13.5	45	53	±13	±32
15-20	-13.6	40	68	±13	±28
20-25	-13.1	32	51	±13	±30
		Soybeans			
0-5	-2.5	30	20	±4	±8
5-10	-3.8	31	24	±4	±9
10-15	-3.2	32	24	±4	±10
15-20	-3.2	28	21	±4	±10
20-25	-3.1	11	17	±5	±11

predicted point yield is 11.1 bu/acre lower than the actual yield from a farm located within 5 miles of the point (gage). The standard deviation around this difference is ±13 bu/acre, and two standard deviation is ±29 bu/acre.

Thus, if the predicted corn yield was 100 bushels, the actual yield at a farm within five miles, on the average, would be 111 bushels. Sixty-seven percent of the actual yields in the area would be in the range from 98-124 bu/acre, and 95 percent of the actual yields (in the 0-5 mile area) would be in the range from 82-140 bu/acre.

The predictability of soybean yields in the 20-to-25 mile area away from the predicted point is also shown in Table 7. If the predicted point bean yield was 30 bu/acre, on the average, the actual yield 20-25 miles away would be 33 bu/acre. Sixty-seven percent of the actual bean yields in this area would range from 28-38 bu/acre, and 95 percent of the actual yields would be in the range from 22-44 bu/acre.

Inspection of the average difference in predicted and actual yields reveals that the point predictions are best for farms in the area ranging from 0-5 miles away, and are poorest for farms located 5-10 miles away. The predictions estimate the actual yields at 20-25 miles away as well as they predict those in the 10-to-15 and 15-to-20 mile areas. The maximum differences shown in Table 7 reveal that large differences between predicted and actual yields occurred at all distances.

The differences between the predicted point yields and the actual yields in areas at differing distances away also were expressed as a percent of the predicted yields. The average and extreme differences for the five areas are shown in Table 8 for corn and beans.

The average error in corn predictions increased from 13.6 percent below the actual yields in the 0-5 mile area to 15. 8 percent in the 20-25 mile area. These percentage errors are only slightly greater than the average percent difference obtained for point predictions of actual yields at the point (Table 3). Maximum percentage differences in corn yields are shown to range from 48 to 81 percent. The average percentage differences for soybeans show very little difference with distance. The values in Table 8 are only slightly greater than the -8.2 percent average difference found between point predictions of yield at the same point (Table 4).

TABLE 8

DIFFERENCES BETWEEN POINT PREDICTED YIELDS AND ACTUAL YIELDS IN DIFFERENT AREAS AWAY EXPRESSED AS A PERCENT OF THE PREDICTED YIELD

Location of area of actual yields from point (miles)	Average difference, %	Maximum differences, %	
		Pred.> Act.	Act.>Pred.
	Corn		
0-5	-13.6	48	61
5-10	-17.3	60	64
10-15	-16.2	57	81
15-20	-15.9	54	80
20-52	-15.8	48	62
	Soybeans		
0-5	-8.3	93	111
5-10	-9.0	94	77
10-15	-8.8	94	77
15-20	-8.6	93	72
20-25	-8.5	35	59

SUMMARY AND FUTURE RESEARCH

Using equations based on easy-to-acquire regional yield and weather data, corn and bean yields at 49 raingage sites in central Illinois were predicted over a 9-year period and these have been compared in various ways with actual yield data from 108 farms near the gages. The regional equations based on county data from the raingage network area provided the better predictions, and thus indicated the value of determining and using county equations rather than crop-district equations if the yield prediction scheme is to be used in insurance applications including adjusting and rating of all-weather peril insurance.

The predicted yields of corn and soybeans were usually less than the actual yields. Predictions for the raingage network area (400 square miles) and for four 100-square-mile areas revealed an average error of -13 percent for corn and -8 percent for beans. Point predictions of corn yields averaged 13.2 percent lower than the actual, whereas the point predictions for corn yields 20-25 miles away averaged 16 percent too low. Point predictions of yields from adjacent bean fields averaged 8.2 percent lower than the actual values, whereas the predictions of actual yields 20-25 miles distant were 8. 5 percent too low. Thus, bean predictions were more accurate than corn yields, but both were quite accurate when one considers the simplicity of the input information (a technology-year factor and eight monthly-seasonal weather variables).

The patterns of predicted yields in the raingage network computed for each of the nine years in the data sample compared quite favorably with the annual patterns derived from actual yield data. However, the extremely high and low corn yields reported in recent years (since 1958) were not accurately predicted, and led to numerical as well as pattern disagreements between the actual and predicted data. These extreme differences in this rural area appear to be a result of farm management practices which are considerably different (better and worse) from most of those in the area. In application of the yield prediction procedure in other areas, a few similar large discrepancies would be expected. Such discrepancies will be an insurance adjustment problem whether or not this scheme of adjusting is ever employed. Possibly predicted yields could be used to evaluate questionable claims of low yields.

Future research will be aimed at completing the investigation of two aspects of the weather-crop yield studies. Historical yield data (1930-1963) for each Illinois county is to be correlated with county weather parameters (precipitation and temperature) to determine predictive equations for each county and other regions of Illinois. To obtain county-area estimates of monthly weather conditions over a 34-year period will be an extensive analytical process. These individual county equations will reveal which counties have similar crop-weather relationships, and thus rate-areas in Illinois could be identified on this basis rather than on the present crop-reporting district basis. The county weather-yield data also will be used to determine new state and crop-district predictive equations, and these equations derived from "point" (eounty) data will be compared with the previously derived predictive equations based on "area-mean" yields and weather data. This comparison should resolve statistical questions concerning the use of the area-mean predictive equations to predict point yields.

The other future research planned is a detailed correlative analysis between the actual yield data from the network area and the rainfall data from the 49 raingages. Rainfall data will be analyzed using weekly and monthly totals. The unique crop and weather data made available by this study provide an excellent opportunity to make a detailed study into the effect of rainfall on corn and soybean yields. This information will also aid in the determination of the amount of water required to obtain maximum yields.

Appendix A

STATE WATER SURVEY QUESTIONNAIRE
WEATHER-CROP RESEARCH PROJECT

County______________________Page______Plot________________

Operator____

Mailing Address____

Legal Description T_____R_____Sec.______________________

Location to near gage #_____Dir_____Dist__________________

Tillable Acres____

Total Acreage (present)_________if varied, list

____

Productivity rating (soil)____Visit__________

Arrangement -Centralized______Within one mile______Over one mile______________

Soil type classification____

Topographic Description____

Comments____

		1955	1956	1957	1958	1959	1960	1961	1962	1963
Acreage										
Corn	A									
Soybeans	B									
Wheat	C									
Hay & Past.	D									
Yields										
Corn	E									
Soybeans	F									
Fertilizer										
Cash Exp. ($)	G									
Wheat (factor)	H									
Wheat (calc.)	I									
Corn (calc,)	J									
Nitrogen (factor)	K									
Corn Applied Nitrogen	L									
Corn Planting Dates	M									
Corn Planting Population	N									
Feed/Tillable Acre	O									
Nitrogen From Manure	P									

Appendix B

DETERMINATION OF FERTILIZER APPLICATIONS FOR THE WEATHER-CROP RESEARCH PROJECT USING FARM BUREAU-FARM MANAGEMENT RECORDS

Gregory Leigh

Introduction

The principal statistic needed for this study was the annual amount of nitrogen applied to corn fields. Unfortunately, the FBFM records on fertilizer application are incomplete, and it was necessary to obtain this information by extrapolation from previously reported relationships between acreage, feed, and fertilizers.

For the purpose of this study it is assumed that very little fertilizer is used on crops other than corn and wheat. For this study nitrogen is considered the most important fertilizer variable because phosphate and potash are assumed to be kept up in the optimum range through avcerage management.

Nitrogen for crops is available in commercially applied fertilizer, livestock manure, and legume crops. Carryover from year to year from sources other than legumes is assumed to be constant, and therefore is not studies.

Calculation of Commercial Nitrogen Applied to Corn

The fertilizer information available on the summary sheets is total fertilizer cost. When it is assumed that all of this fertilizer cost goes to corn and wheat, a standard fertilizer cost per acre of wheat may be multiplied by wheat acreage and subtracted from total fertilizer cost, leaving corn fertilizer cost.

By observation of fertilizer amounts applied to wheat on 29 farms studied by Sopher (2) a usual fertilizer analysis of 20 pounds of nitrogen and 30 pounds of phosphate and potash is seen. From this observation, the following cost per acre of wheat is determined:

	N	P	K	
Analysis	20	30	30	
Price per pound	.10	.10	.05	
	$2.00	$3.00	$1.50	= $6.50 per acre

This amount multiplied by the wheat acreage and subtracted from total fertilizer cost leaves a value termed estimated corn fertilizer cost.

A ratio is obtained between the corn fertilizer determined above, and the pounds of nitrogen applied to corn on 21 farms in the area. These 21 farms were a portion of Sopher's sample. These ratios show an upward trend as time progresses, so three time periods were used in the 1955-63 period studied. The ratio determined between pounds of nitrogen applied to corn, and dollars spent for fertilizer are as follows:

1955-1956	1957-1958	1959-1963
2.30	3.10	3.65

This ratio multiplied by estimated corn fertilizer cost gives calculated total pounds of commercial nitrogen applied to corn.

Calculation of Nitrogen Applied to Corn From Manure

According to Sopher: "Approximately three dollars of feed fed per tillable acre were equivalent to one percent of the tillable land on a farm being covered with an application of ten tons per acre of manure. On the basis of the work of Rust and Odell, and personal conferences with staff members of the University of Illinois, it was estimated that a ton of average barnyard manure contained 5 pounds of nitrogen, 3.5 pounds of P_2O_5, and 7 pounds of K_2O." This statement may be simplified to the following expression for use in this study:

For every dollar's worth of feed fed, 0.167 pounds of nitrogen is gained from livestock manure.

This factor may be multiplied by total dollars of feed fed the previous year to obtain the total amount of nitrogen gained from manure. All manure is assumed spread on ground which will be planted in corn.

<u>Calculation of Nitrogen Derived from Legumes</u>

Sopher gives average amounts of nitrogen added to the soil by given legume crops. Assuming a 2/3 legume mixture, which is half pastured and half cut for silage or hay, it is determined that 50 pounds of nitrogen are added per acre of legume crop. Soybeans, assumed to be combined, are not included in the calculation. This figure multiplied by acreage of legume in the former year gives total amount of nitrogen fixed by legumes.

The nitrogen application per acre of corn from all three sources may be calculated by adding nitrogen from each source, and dividing by corn acreage.

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