NASA Technical Paper 1724

A Comparative Statistical Study of Long-Term Agroclimatic Conditions Affecting the Growth of U.S. Winter Wheat

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All measurement values are expressed in the International System of Units (SI) in accordance with NASA Policy Directive 2220.4, paragraph 4.

ABSTRACT

Researchers at the Beltsville Agricultural Research Center (BARC) in Maryland are making remote sensing measurements of winter wheat growth for use in crop assessment by satellite. Maryland's climate is not typical of important U.S. winter wheat producing areas, e.g., that of Kansas, principally because of its higher fall and winter precipitation; therefore, histograms of average monthly precipitation over 30- and 84-year periods for both Maryland and Kansas were calculated, and methods were indicated for limiting Maryland precipitation values to simulate Kansas conditions.

As a logical second step, a statistical assessment of the effect of average monthly precipitation on Kansas winter wheat yield was made. The data sets covered the three periods of 1941-70, 1887-1970 and 1887-1921. Analyses of the limited data sets used (only the average monthly precipitation and temperature were correlated against yield) indicated that fall precipitation values, especially those of September and October, were more important to winter wheat than were spring values, particularly for 1941-1970. Tests of early winter (November and December) precipitation values produced much lower correlations with yield than fall or spring values for the same 1941-70 period. On the basis of these results, the BARC project should record and modify, if necessary, fall precipitation in simulating the Kansas climate. These results also contradict the methodology of current yield models for Kansas winter wheat that sum precipitation variables for many fall and winter months together behind one coefficient, as though they were all unimportant and of approximately equal value.

This paper also underlines the problem of extrapolating remote sensing data from the climatic environment of an experimental farm to those of more extensive crop areas normally monitored by satellites. Macro-, meso- and microscale meteorological systems all vary in horizontal and vertical distance and time dimensions; however, the agroclimatic research projects surveyed in this paper were conducted in a variety of states of meteorological systems and did not offer a clear solution to whether precipitation, or soil moisture and evapotranspiration, were the more sensitive variables to crop yield. An accounting of these scaling problems is essential to combining crop monitoring with satellite meteorological information for a grain yield assessment.

Average monthly precipitation and temperatures analyzed in this paper represent only two of the many variables positively affecting Kansas winter wheat yield; they were analyzed because they appear in some current yield models. The cumulative multiple regression R^2 values calculated for the fall (37.5%) and spring (21.5%) seasons over the 1941-70 period were judged to be significant if combined in a complete set of dependent variables for a full yield model development, but such a development was not attempted here. However, appendixes on economic and technological factors, slowly varying climatic changes, severe storms, and episodic events in Kansas are included to underline the complexities of a full model development. At the conclusion of the paper, dependent variables combining precipitation and temperature are suggested. An experimental determination of such variables in the important fall season could be made by remote sensing measurements of soil moisture and/or precipitation evapotranspiration rates.

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INTRODUCTION

The NASA/GSFC-BARC field project is a cooperative research venture of the National Aeronautics and Space Administration/Goddard Space Flight Center, which has responsibility for the conceptualization and design of satellite systems to aid in the assessment of agriculture, and the Beltsville Agricultural Research Center of the U.S. Department of Agriculture (USDA). The field project itself was conceived and developed to more efficiently relate remote sensing instrumental design and techniques to the conditions and variability of agricultural growth; this can be carried on and varied most expeditiously at an agricultural research center.

The satellite systems are planned and designed by NASA, in consideration of the needs and requirements of the Department of Agriculture. One of the largest and most profitable of all crops grown in the United States, especially for its export value, is winter wheat. This crop is grown extensively on the Great Plains, which includes the states of Kansas, Oklahoma, and Nebraska, as well as in the northwest corner of the contiguous United States.

The Great Plains region produces a major portion of the U.S. winter wheat crop, which is a significant portion of the purchasable winter wheat and grain crop of the world. In terms of production magnitude, the Great Plains region accounts for approximately 20 percent of the world's grain, while occupying only about 0.7 percent of its surface. This fact alone has generated much interest in the overall climatological behavior of the area, and particularly in precipitation.[1] There is little doubt that soils and climate have been major influences in the evolution of the large grain-producing areas of the world, and the Great Plains must be numbered among these areas.[2]

This study is concerned with the growth of winter wheat on the Great Plains, and with the climatic factors which characterize the region and cause fluctuations in the crop yield. Attention is directed to the ranges of average monthly precipitation that have occurred in the Central Crop Reporting District in Kansas, which can be simulated at the BARC project in Upper Southern Maryland. A secondary objective is to isolate those months of the growing season which account for the greatest fluctuations in winter wheat yield by their variability in average monthly precipitation and temperature. Both of these objectives are related to current remote sensing yield model requirements. The procedure developed for Kansas can be easily adapted to other agricultural regions.

THE PROBLEM

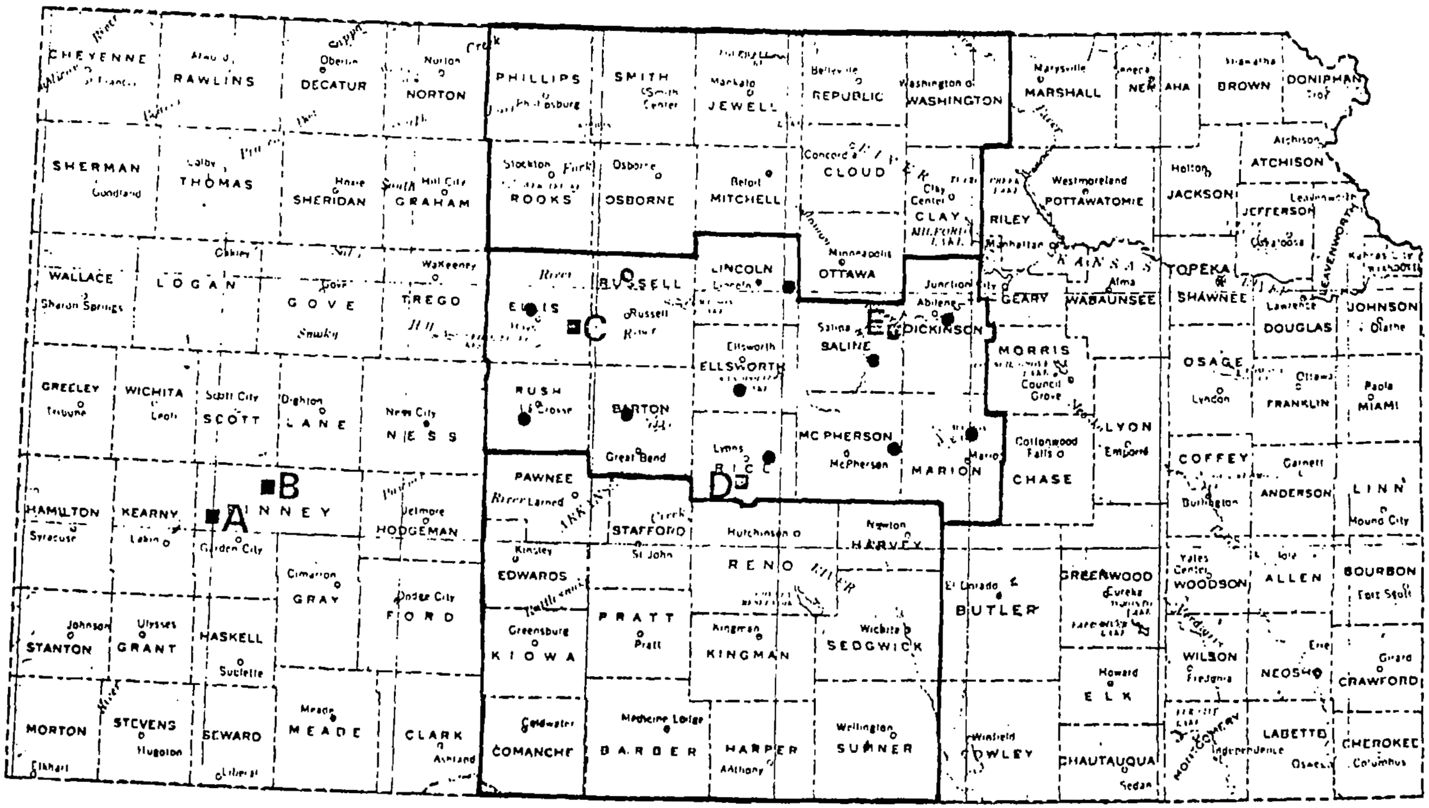
Within the remote sensing community, yield models are currently being devised for the prediction of yield over large substate areas. These models require a variety of conventional data, not all of which are in the open literature. Regional agroclimatic variability and its effect on crop yield are two types of useful data in short supply. The importance of these models became apparent in the recent Large Area Crop Inventory Evaluation (LACIE) project, a cooperative effort by NASA, National Oceanic Atmospheric Administration (NOAA), and USDA to inventory domestic and foreign wheat production.

In a recent paper funded and monitored by Goddard Space Flight Center, Nalepka et al.[3] attempted to use Landsat data for forecasts of winter wheat yield and production. The LACIE test sites, A through E, were used as shown in Figure 1. Sites C, D, and E lie in the Central Crop Reporting District (CCRD) in Kansas; the CCRD is the district statistically analyzed in this paper. In their paper, Nalepka et al. envision the optimal use of Landsat data for yield determination as part of the total model:[4]

Yield = Historical Trend + Landsat Information Perturbation + Meteorological Information Perturbation + Cultural Information Perturbation

One of the principal complaints of the authors from their hybrid model approach is the insensitivity of grouped monthly agrometeorological parameters to winter wheat yield, both for the LACIE models for the United States and for Soviet models.[5] In particular, the grouped August through February precipitation parameter appeared especially insensitive in the agrometeorological yield model which had been developed by the Center for Climatic Environmental Assessment (CCEA) of NOAA.[6] The historical yield trends included in the model spanned the periods 1931-1955 and 1955-1976.[7] Nalepka et al. judged Landsat data to be well correlated to yield, as well as to the amount of irrigation for the irrigated Finney County test sites.[8] Obviously, water was important to yield, but the role of precipitation remained unclear. Another concern of Nalepka et al. was the representativeness of the meteorological data used for the LACIE test sites. This problem arose because of the various geographical locations of meteorological stations with relation to the test sites.[9] The locations and types of data from these stations are shown in Figure 2.[10] The problem is especially acute when dealing with a microclimatic environment such as a test site on an experimental farm, but this is not necessarily the case for an entire crop reporting district, for which data from a number of meteorological stations can be averaged.

The status of remote sensing model development was recently reviewed in the LACIE Symposium, which took place in October 1978, at the Johnson Space Center in Houston, Texas. The current LACIE yield models use multiple linear regression techniques for independent variables formed from monthly averages of air temperature and precipitation. Yield models have been developed for individual substate regions of crop reporting district size. For example, there is a yield model for



Key:

- Sites for which wheat yield information is available

A - Finney Site A
B - Finney Site B
C - Ellis Site
D - Rice Site
E - Saline Site

● - Other sites used in large area investigations

Figure 1. Central crop reporting districts and agricultural test sites in Kansas.[3]

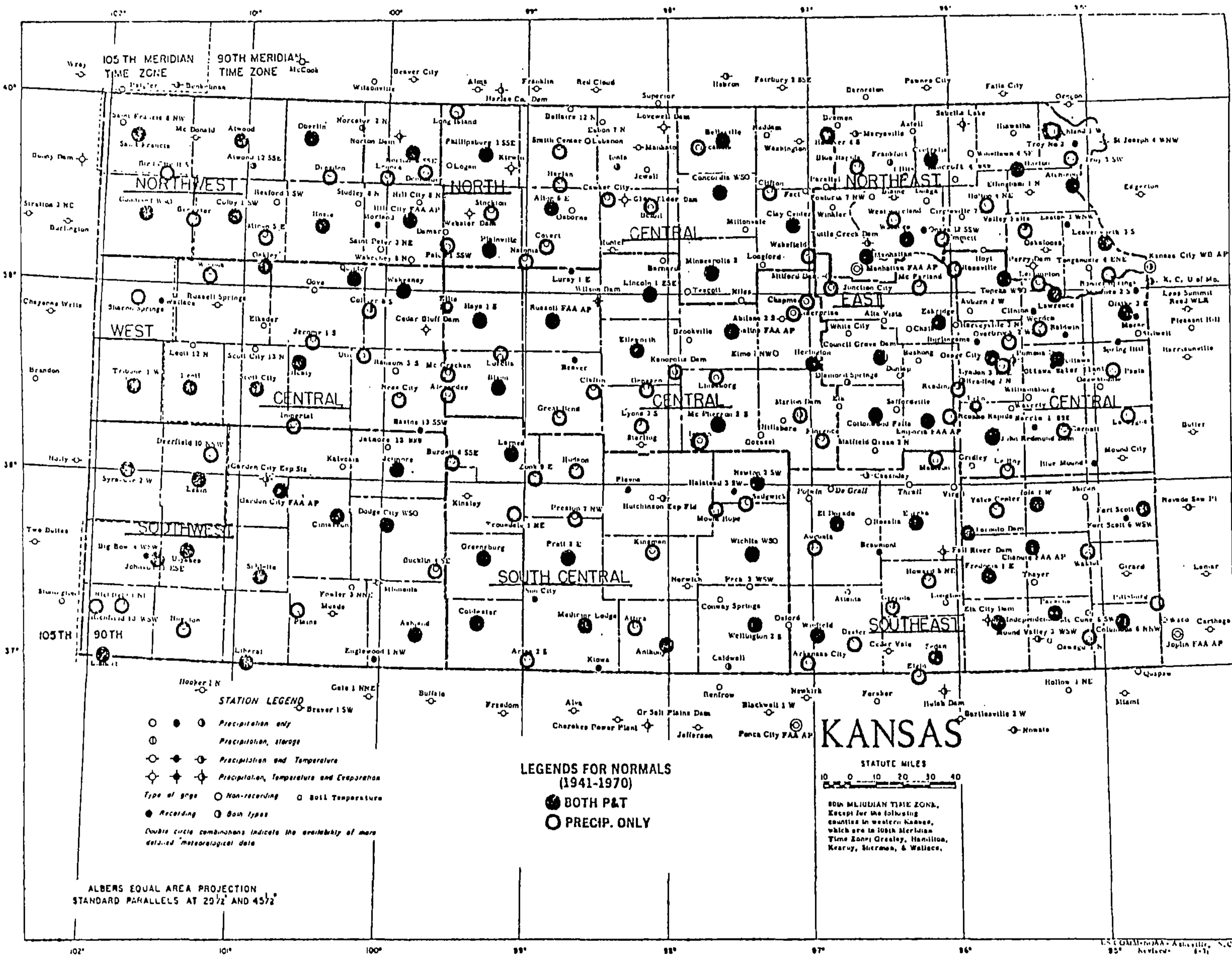


Figure 2. Location and types of data recorded by meteorological stations in Kansas.10

each of the nine crop reporting districts in Kansas.[11] Other assumptions used in the model development include:[12]

a. Crop is in the same phenological stage in the same month of every year and identically susceptible to the same weather impacts on yield,

b. All weather departures from normal are homogeneous over the entire region being modeled,

c. There are no interactions between weather and technology,

d. Over large areas, all short period weather fluctuations and episodic events are averaged out.

The form of the linear model used is:

Yield = constant + trend + weather effects,

where constant = base yield level before technological enhancement

trend = technological effects on increased yield as a function of chronological time, and

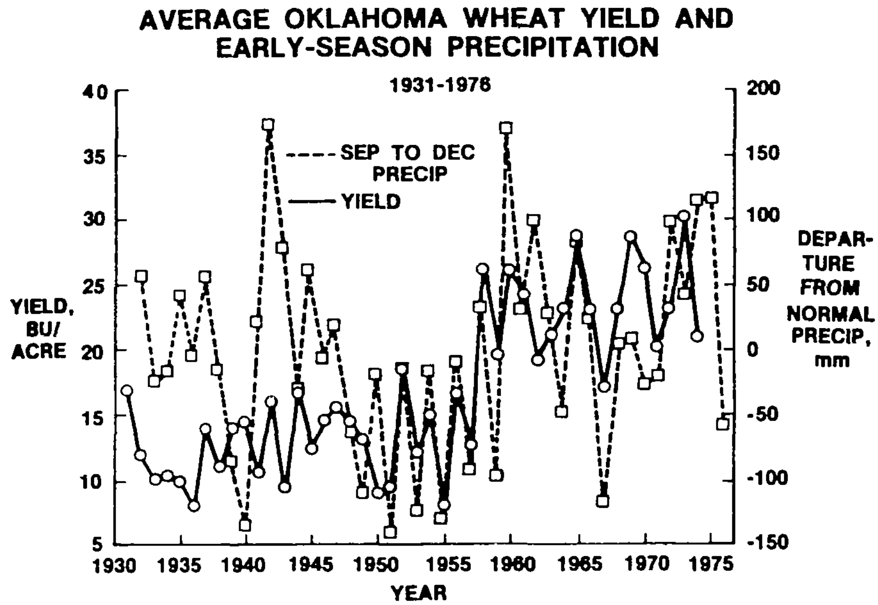
weather effects = yield variations due to fluctuations in the long-term average regional weather.

Yield data sets have been traced back to the 19th century, but owing to some of the assumptions made, the yield models only use the data from the 1930's to the present. Two of the yield data sets used in the LACIE models are shown in Figure 3.[13]

This brief discussion of remote sensing yield models identifies a need for average monthly precipitation and temperature data and their relationship to crop yield. Representative types of data and analyses currently available in the open literature demonstrate the diverse nature of the sources which can be applied to remote sensing modeling.

CURRENT STATUS OF RESEARCH

The State of Maryland falls in a mean annual precipitation range of 40-48 inches, while the State of Kansas, with north/south precipitation isolines, can be divided into a number of zones with progressively smaller mean annual precipitation values from east to west across the state, as shown in Figure 4.[14] The most easterly and highest precipitation zone of the State of Kansas ranges in values from 32-40 inches per year[15] and Kansas as a whole has much drier winters than Maryland.[16] Monthly values of precipitation from 1941-1970 have been published by NOAA for "homogeneous climate regions" for each state, and are the sources of precipitation data for this paper.[17] Monthly precipitation data prior to 1941 and back into the nineteenth century, which also are used in this paper, have been published by the Weather Bureau for larger substate regions than have been



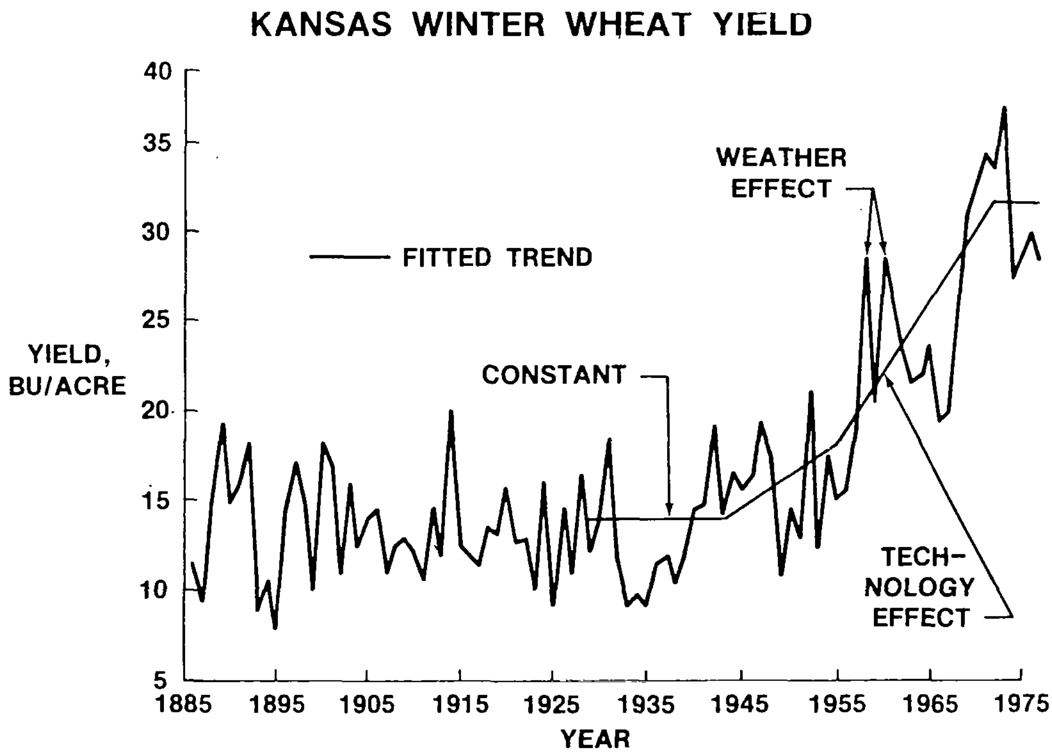


Figure 3. Data sets used in LACIE yield models.[13]

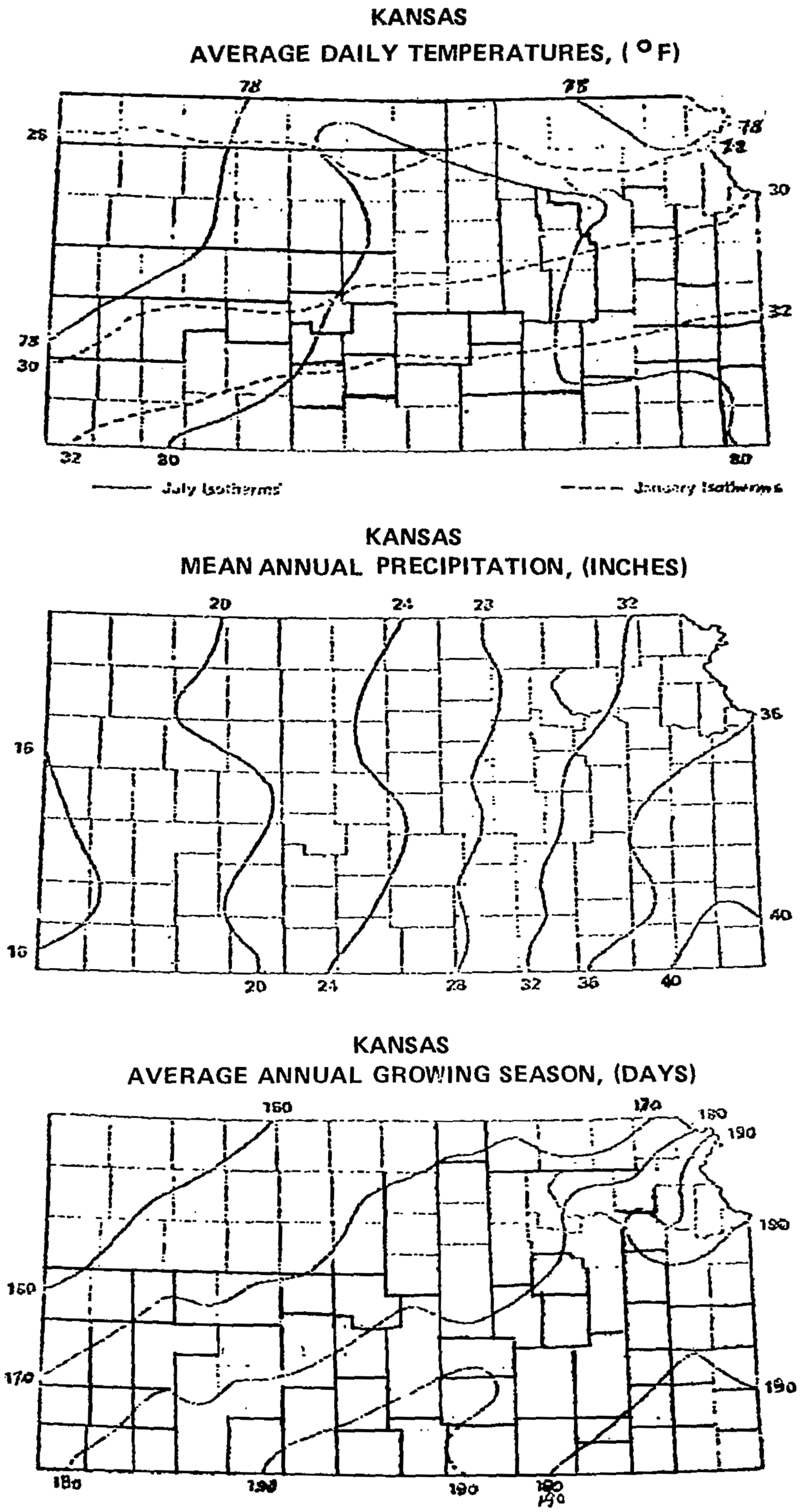


Figure 4. Temperatures, precipitation, and annual growing season for Kansas.[14]

aggregated for the 1941-1970 data.[18] Some of the factors influencing the north/south precipitation isoline structure of the State of Kansas can be understood from the climate models developed for this region.[19]

A large volume of work has been produced on the relationship of climate to grain crop growth and yield, but an increased interest in agroclimate in the late sixties and early seventies accelerated research in this area. Experimental data from growth chambers, experimental farm projects, and especially large grain areas encompassing many states (U.S.) and provinces (Canada) have been obtained and used. Some of the research published during the sixties and seventies will be discussed and is indicative of current research trends.

Using growth chamber data on the development of wheat root structures, E. A. Hurd claims a relationship between root growth development and both drought resistance and high yield under moisture stress.[20] Conflicting results are found by Ray et al. showing the increased ability of small rooted plants to use limited amounts of water more efficiently.[21] Charles Y. Sullivan and Jerry D. Eastin have investigated the nature of plant physiological responses to water stress for small grains, especially sorghum.[22] A number of physiological factors to be considered for conditions of plant moisture stress are discussed by Sullivan and Eastin, especially in relation to the efficiency of different strains of grain in absorbing water under moisture stress conditions. All of the growth chamber experiments cited emphasize availability; the findings of E. A. Hurd suggest that conditions optimizing root growth development may cause higher average yields for dry climate areas.

Some experimental farm data directly relate rainfall distributions to wheat yields in dry climate conditions. In particular, two papers published ten years apart show high correlation between the variability of precipitation and the yields of winter wheat for dry-climate experimental farms in India.[23] Both papers apply the statistical techniques developed by Fisher in the twenties, and utilize polynomials of fifth degree for time series curve fitting prior to the correlation determinations. In the earlier paper, five locations are investigated using 15 years of data, and about 75 percent of the total variations in yield are attributed to the precipitation distribution. Both papers conclude that above average precipitation a month prior to sowing, and during the germination period, is beneficial to winter wheat yields.

Data sets from agricultural regions greater in size than experimental farms can take two different forms: On the one hand, yield values are combined with weather and climate data, and on the other, yield values are combined with soil moisture or evapotranspiration values either derived from weather and climate data, or measured directly. The data analysis can also take two forms: Either the data are statistically analyzed directly, and conclusions are drawn from this analysis, or statistical analysis is combined with model development in order to arrive at the final conclusions. In all cases, the agricultural regions are subnational in extent.

T. G. J. Dyer, a meteorologist with a particular interest in temperature and precipitation data, has collaborated with J. F. Gillooly in a paper relating hay yields to mean seasonal warm and cold temperatures and other variables.[24] The paper emphasizes the recent concern (E. Waggoner) that insufficient use has been made of crop and weather relationships.[25] A stepwise linear regression technique is the statistical analysis employed. In another paper, by R. L. Pitter, a 23-parameter model based on the effects of weather and technology was developed for winter wheat yield in crop reporting districts in Oregon.[26] This model is one of a series of yield models which have been developed within the last ten years. One of the primary concerns of the modelers has been the effects of long-range global cooling trends on crop growth and yields. A third paper, by W. Baier and G. W. Robertson, discusses the efficacy of directly relating crop yield to climatological data.[27] It first compares the relationship of yield to climatic conditions (monthly observations of rainfall and maximum and minimum temperatures). In the paper, the same wheat yields to estimated values of soil moisture are compared, and this second comparison shows higher correlations than the wheat yield to climatic variable approach. The daily soil moisture estimates for each of the six agricultural zones are obtained from a versatile soil moisture budget model which requires standard climatic data, tabulated astronomical values, and soil moisture characteristics as inputs. The overall superiority of correlating wheat yield with soil moisture rather than with climatic variables is clearcut for the methods used. A multiple correlation analysis shows soil moisture to be the most sensitive variable indicating crop yield, followed by minimum and maximum monthly temperatures respectively. Correlations of wheat yield with monthly precipitation values are considered nonsignificant in the Baier and Robertson study.

Finally, in a paper that completely rejects straightforward correlations of climate data to yield, Bridge compares two simulation models to relate "effective climate" to winter wheat yields on the Great Plains.[28] For four locations on the Great Plains, separated by a maximum of 12 degrees latitude and spanning over the State of Kansas to locations in Nebraska to the north and Oklahoma to the south, winter wheat yields are related to "effective climate" by means of stepwise multiple regression for a constant root zone (CRZ) and an expanding root zone (ERZ) water budget model.

The point of the model approach is that the quantities normally designated and measured as climate variables, e.g., temperature and precipitation, interact in a complex and coupled manner during the plant growth cycle to affect plant yield. Other experimenters are cited as contributors to this model approach relating "effective climate" to winter wheat yields.[29] Bridge's model is an improvement over the existing CRZ model because it simulates the increase in the rooting depth of the winter wheat plant from its initial seeding and includes the amount of soil moisture available to the plant because of increased root growth. This new ERZ model, on the average, accounts for an additional 12 percent in the variability of winter wheat yield over the CRZ model. The ERZ model includes the period from the very beginning of plant growth, which implies that the initial growth stages at fall planting are important to eventual yield. The fall hardening period has also been shown by Soviet experimenters to be important for episodic events causing the normal deleterious effects to winter wheat yields, such as winterkill.[30]

The research conditions discussed are quite varied in nature, involving growth chamber experiments, experimental farms, county and substate regions (crop reporting districts), and Canadian provinces. The crop types used in these research projects were also varied and include winter wheat as well as spring wheat and other crops. Some types of the research advocate the use of climatic models relating to winter wheat yield, while others use climatic variables translated into soil moisture values for yield correlations, and still others relate the climatic variables themselves directly to correlations with yield. One conclusion that can be drawn from the results is that sufficient precipitation and resultant soil moisture appear important during the fall planting rooting-hardening period for winter grains. This conclusion is particularly important to the present paper for reasons which will become apparent in the following discussion.

EXTENDED RESEARCH OFFERED

As previously mentioned, Nalepka et al. have adopted a hybrid yield modeling approach to forecast winter wheat yield and production using Landsat data.[31] The yield model requires data for historical trends and meteorological perturbations. The models outlined in the LACIE Symposium and discussed previously assumed a normal level of yield, with year-to-year fluctuations about that level due to variations.[32] These weather variations were monthly average values and not short-term extreme conditions or episodic events. Both modeling efforts used climatic data for central Kansas.

In this study, regional distributions of average monthly precipitation on the Great Plains (especially central Kansas), and in Maryland are analyzed and compared for magnitude and variability and related to yields of winter wheat. The results can be used to modify precipitation values at the BARC test site in Beltsville, Maryland so as to simulate conditions on the Great Plains; this simulation is accomplished by means of automated sliding covers over the test plots, activated by moisture sensing devices. As a second goal, an attempt is made to isolate the range of monthly precipitation magnitude most indicative of changes in winter wheat yield in Kansas over long periods of time. Data sets from three time periods, 1941-1970, 1887-1970, and 1887-1921 have been statistically analyzed using simple correlations, multivariate regression, and factor analysis techniques. These analyses show relatively high correlations between state wheat yield and monthly precipitation and temperature for the CCRD of Kansas over the modern period 1941-1970. The yield variability is especially sensitive to precipitation during the planting-rooting-hardening months in the fall. For the earlier data sets, 1887-1970 and 1887-1921, wheat yield is much less sensitive to variations in monthly precipitation and temperature.

The problem of regional scaling of agroclimate is also considered. Macro-, meso-, and microclimatic scaling are viewed with respect to the range of sensitivity of winter wheat yield to changes in climatic variables in regions of substate size; regions of sufficient extent that patterns of climatic variations can be monitored by satellite systems. The role that microclimatic regions can play under controlled crop growth conditions in establishing generalized yield-climate dependencies is also discussed.

RANGE AND VARIABILITY OF AVERAGE MONTHLY PRECIPITATION FOR THE SOUTHERN GREAT PLAINS AND THE STATE OF MARYLAND

Appendix A shows histograms of average monthly precipitation for the CCRD of Kansas over the period 1941-1970. There are 12 cells for each histogram. Each of the first 12 histograms represents 30 years' data for each month of the year. The last four histograms combine the 30-year data sets for the months of March through May, June through August, September through November, and December through February.

The histograms for the months of November, December, January, and February, in particular do not appear to be symmetrically distributed on either side of a maximum value of precipitation, but these are the four months of the year with the lowest value for the standard deviation of the histogram distributions. May and June are the two months with the most symmetrically shaped distributions in the precipitation histograms. The most striking characteristic of any of the histograms is the occurrence of two or three maxima for particular months over the 30-year period. Because the monthly precipitation for only a 30-year period was distributed among 12 cells in the histograms, new monthly precipitation histograms were also formed for an 84-year period, 1887-1970, and are shown in Appendix B. The histograms over the 84-year period do not exhibit the two or three maxima characteristics of those of the 30-year period, but both sets of values for the mean monthly precipitation remain nearly the same, as shown in Figure 5. The mean values from both periods indicate maximum precipitation in June, with a less drastic change in precipitation during the months of July, August, and September, than at any other time during the spring, summer and fall seasons.

In Appendix C, histograms of the mean monthly values for precipitation have been plotted for Upper Southern Maryland, the location of the BARC Project. The data used were for the period 1941-1970. The mean value for each monthly histogram has been calculated and compared with those for the CCRD of Kansas over the same period. These mean values are plotted in Figure 6. The values for Upper Southern Maryland for the months of October through April are much higher than those of the CCRD of Kansas, indicating the relatively higher winter rainfall and wetness in Maryland. The highest value for mean monthly precipitation in Upper Southern Maryland is in August, rather than the June high for the CCRD in Kansas.

However, the plots in Figure 6 actually contrast two precipitation profiles, one on the southern Great Plains and the other on the east coast of the U.S., the Middle Atlantic Coast Region. In order to ensure the supposition that the precipitation profile of the CCRD of Kansas is representative of the southern Great Plains region, mean monthly precipitation values were calculated from monthly precipitation histograms for the East Central Crop Reporting District of Nebraska and the North Central Crop Reporting District of Oklahoma. The results, shown in Figure 7, indicate mean monthly precipitation profiles similar in shape to that of the CCRD of Kansas, as shown in Figure 6. Precipitation profiles for Nebraska and Oklahoma, lying north and south of Kansas respectively, were chosen to test precipitation profiles on the southern Great Plains because of the north-south orientation of precipitation isolines, which were predicted by Harnack and are shown in Figure 4. The East Central Nebraska profile indicates peak precipitation during June, as does the Kansas profile, and all three precipitation profiles, from Kansas, Nebraska, and Oklahoma, have an "elbow" characteristic shape for the July through September period.

Figure 6 and 7, combined with the monthly histograms plotted in Appendixes A, B, and C, demonstrate the normal range and variability of precipitation for the CCRD of Kansas compared to that of Upper Southern Maryland, the location of the BARC Project. From these data, simulation studies of winter wheat growth precipitation conditions characteristic of the southern Great Plains can be conducted at the BARC site.

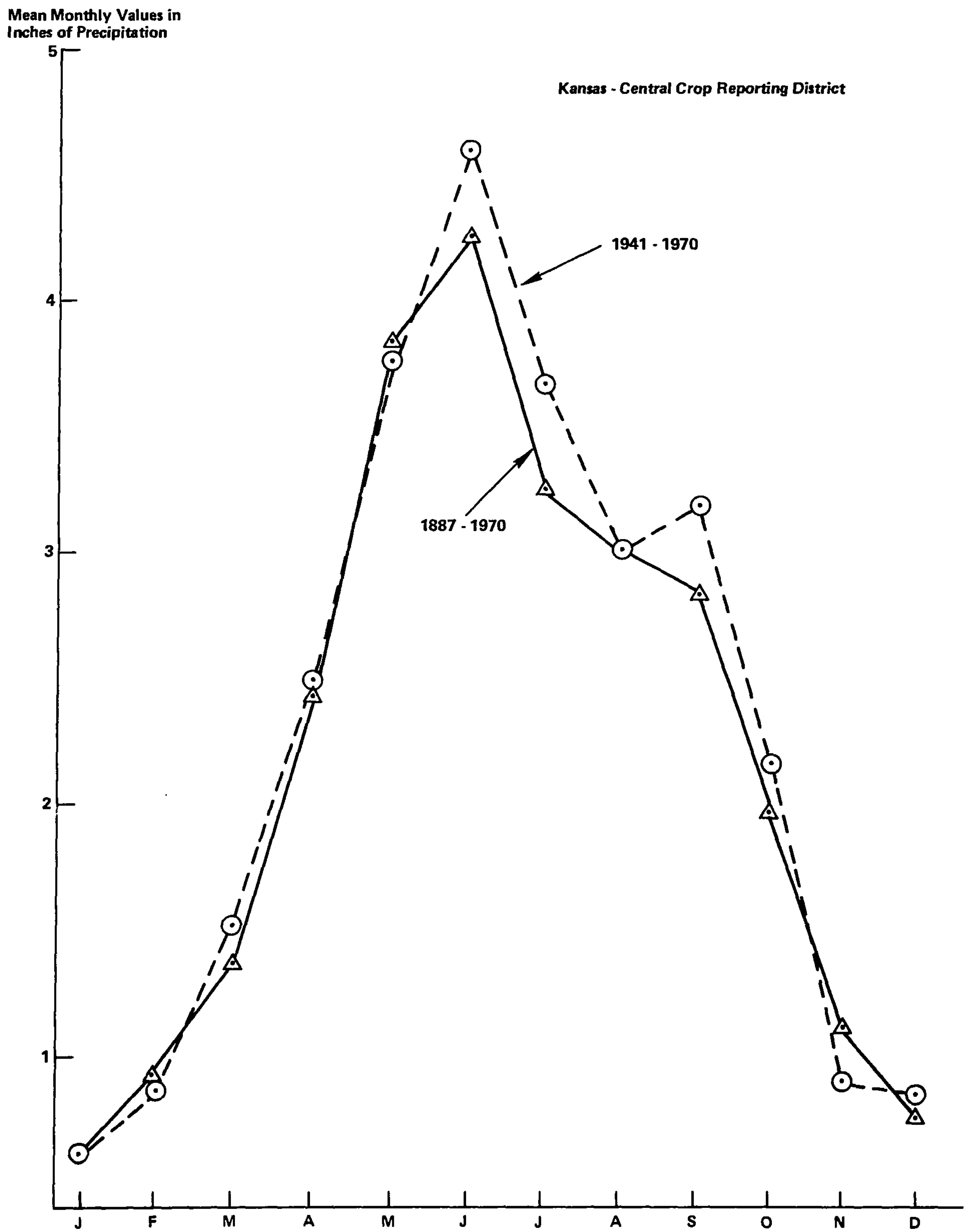


Figure 5. Mean monthly precipitation values for the Central Crop Reporting District for two periods.

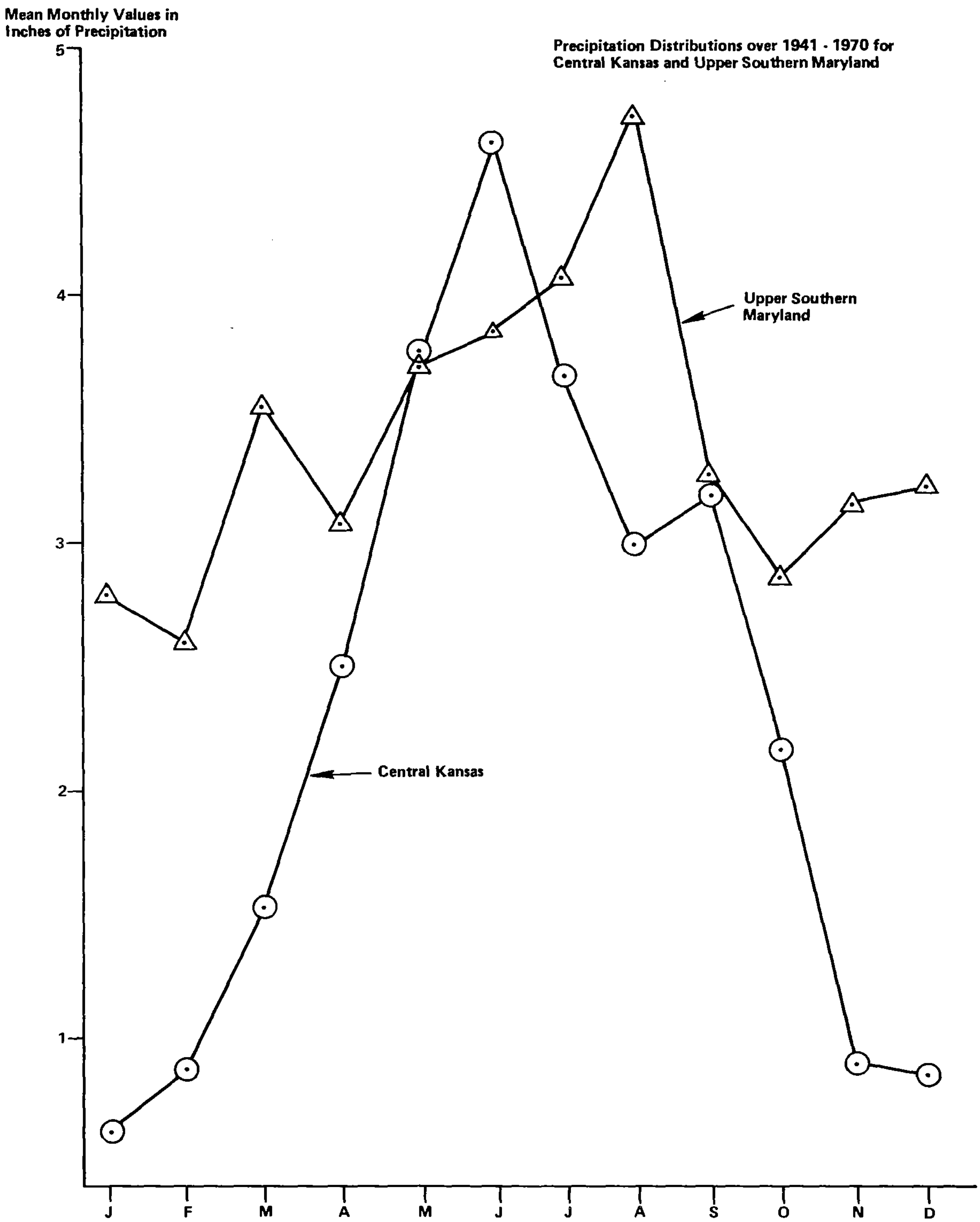


Figure 6. Mean monthly precipitation values for the Central Crop Reporting District of Kansas, and Upper Southern Maryland.

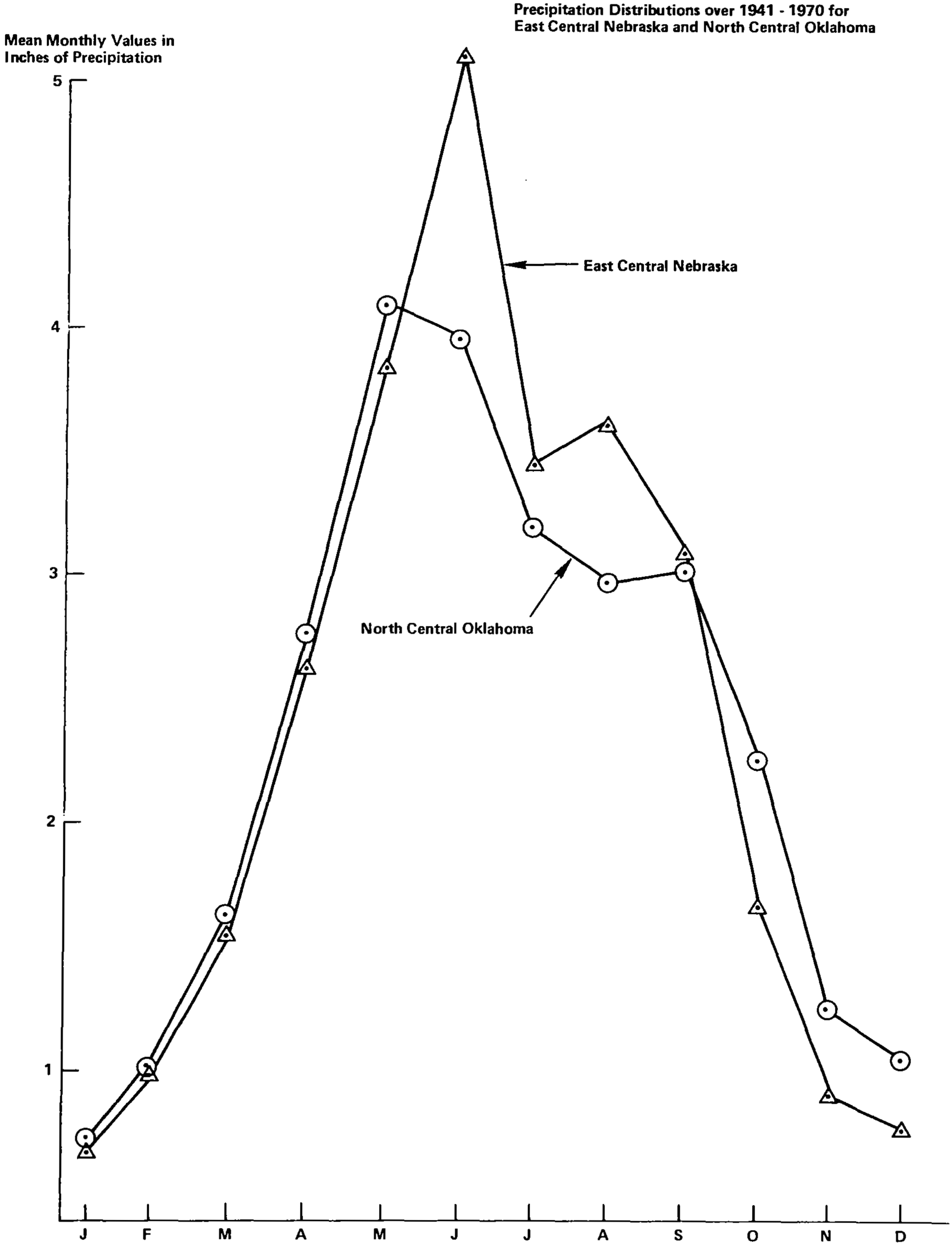


Figure 7. Mean monthly precipitation values for the Crop Reporting Districts of East Central Nebraska and North Central Oklahoma.

AVERAGE MONTHLY PRECIPITATION AND TEMPERATURE IN KANSAS AND THEIR ASSOCIATION WITH WINTER WHEAT YIELD VARIABILITY, 1941-1970

In this segment of the study, basic agroclimatic factors are sought which indicate changes in Kansas winter wheat yield, specifically those factors over the CCRD of Kansas.

Both factor analysis and stepwise multiple linear regression analyses were performed for the 1941-1970 period, on agrometeorological variables for the CCRD of Kansas along with yield values for the entire state of Kansas. The agrometeorological variables were assigned to three seasonal groupings: fall including the months of July, August, September, and October; spring including March, April, May, and June; and early winter including November and December values. January and February were not included because average monthly temperature and precipitation values are not the appropriate variables indicative of winter wheat yield for these months. Depth of snow cover, maximum and minimum diurnal temperature readings, etc., are much more closely related to yield variability for these winter months. Both the fall and early winter agrometeorological values were compared to the yields for the following year. As was previously mentioned, the agrometeorological variables consist of average monthly values of precipitation and temperature for each month in the season. For the fall and spring, the data matrices consist of either nine columns for the precipitation and temperature variables for each month of the season, plus the appropriate annual yield values, or five columns for the precipitation variables for each month of the season, combined with the annual yield value. For both the nine- and five-column data matrices, the number of rows are 30, representing annual values for the period 1941-1970. The nine-column fall data matrix is shown in Figure 8. For the statistical analyses, yield was designated as the dependent variable, and the average monthly precipitation and temperature values were the independent variables.

Both factor analysis and stepwise multiple linear regression analysis for SPSS (Statistical Package for the Social Sciences) programs are discussed elsewhere, and standard statistical texts are suggested.[34] Texts treating the methodology and examples of uses of such statistics for quantitative spatial analysis are also in the open literature.[35] The stepwise multiple regression analysis produces R^2 values, which are a measure of the capability of the independent variables – monthly precipitation and temperature values – to account for the variability of the dependent variable, the winter wheat yield. Each independent variable is loaded separately, in a stepwise fashion, the ordering of the variables corresponding to the highest remaining values of R^2. That is, the independent variable with the highest value of R^2 is loaded first, et cetera. It is important to note that if the independent variables were loaded with a different ordering, the results would be somewhat different, the amount of difference depending on the degree of correlation between the independent variables themselves. For this purpose, the individual correlations between any two variables in the data matrix have been determined and are shown in the factor analysis printout in Appendix D as the matrix entitled Correlation Coefficients.

Our discussions on factor analysis computations will be confined to the results of the orthogonal factor analysis program, primarily the "correlation coefficients" matrix and the "matrix using principal factor with iterations," shown in Appendix D. The "varimax rotated factor matrix" merely accentuates the difference between significant and negligible factor correlations of the

Fall Data Matrix – 1941-1970 – 9 columns X 30 rows.

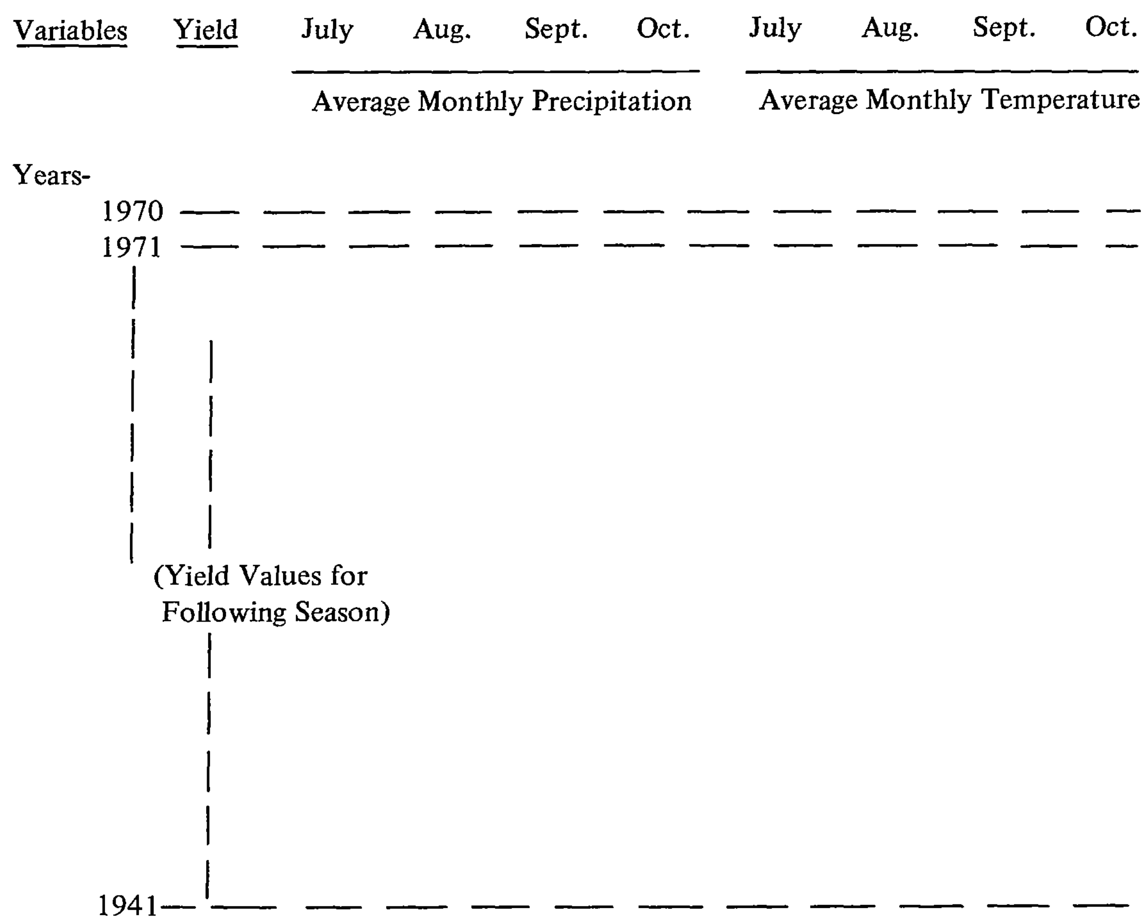


Figure 8. Data matrix used in the statistical analysis – Fall Season.

"matrix using principal factor with iterations;" thus it will be considered only cursorily. The oblique factor analysis program results contained in Appendix D are to be consulted only when appropriate, and are included as a check on the results of the orthogonal factor analysis program.

Table 1 summarizes the results of the stepwise multiple regression analysis for the fall; the independent variables are listed in decreasing order of their importance in accounting for the variability in yield. Out of eight independent variables, which are the average monthly values of temperature and precipitation during July, August, September, and October, the first seven in importance accounted for a cumulative R^2 value of 37.5 percent of the winter wheat yield variability over the 1941-1970 period. The most important two variables were October and September precipitation values, in that order, with October temperature and August precipitation ranking third and fourth. The October, September, and August precipitation values can be interpreted in terms of the supply of soil moisture during the important fall rooting and hardening period for winter wheat. Good root growth and proper hardening produce healthy plants which have a better chance of higher yield than plants grown under less advantageous conditions. The importance of October temperature, as well as precipitation, may indicate that an evapotranspiration model combining precipitation and temperature values may be a better way to represent soil moisture than using the raw values independently of one another. In any case, precipitation appeared much more important than temperature in accounting for yield variability from fall season indicators. The same July-through-October average monthly values of precipitation alone, without the temperature variables, when regressed against winter wheat yield, accounted for a cumulative R^2 of 30.9 percent.

The results of the orthogonal factor analysis for the fall season support the conclusions drawn from the stepwise multiple regression analysis. From the "matrix using principal factor with iterations" for eight independent variables, yield is primarily associated with Factor 2, and the dependent variables of October, September, August and July precipitation, and October temperature in that order of importance. The other three factors show correlations between monthly temperature and precipitation values. The factor analysis with only the four independent precipitation variables again indicates yield to be most strongly related to first October, and then September precipitation. Thus, the above discussion has demonstrated a close qualitative agreement between the results for the two types of analyses, factor and stepwise multiple regression. Factor analysis does not produce a cumulative R^2 as does stepwise multiple regression analysis, and is therefore not directly amenable to quantitative comparison.

The results of the stepwise multiple regression analysis for March, April, May and June are shown in Table 2. A cumulative R^2 for seven of the eight independent variables in the spring accounts for only 21.5 percent of the yield. The average monthly temperatures are more important independent variables in the spring than are precipitation variables. In particular, the March temperature alone accounts for a cumulative R^2 of 14.4 percent. All the same precipitation variables together without the temperature variables, shown in Table 2B, produce a total cumulative R^2 of only 8.2 percent.

The results of the regression analyses, summarized in Tables 1 and 2, indicate that yield fluctuations have their highest dependency on fall precipitation, especially for October and September. During the spring, temperature values are more related to yield fluctuations, especially for the month of March.

Table 1
Stepwise Multiple Regression Analysis for Fall Season, Including the Months of July through October; Data Ranges over 1941-1970

Independent Variable		Cumulative R^2 for Dependent Variable of Yield
Month	Average Monthly Measurement	(units in percent)
October	Precipitation	19.7
September	Precipitation	28.7
October	Temperature	32.8
August	Precipitation	35.3
July	Temperature	36.2
July	Precipitation	37.1
September	Temperature	37.5

A. Regression Analysis for Eight Independent Variables; Four Average Monthly Values of Temperature and Precipitation, Fall Season.

October	Precipitation	19.7
September	Precipitation	28.7
August	Precipitation	30.5
July	Precipitation	30.9

B. Regression Analysis for Four Independent Variables; Four Average Monthly Values of Precipitation Alone, Fall Season.

Table 2
Stepwise Multiple Regression Analysis for Spring Season, Including the Months of March through June; Data Ranges over 1941-1970.

Independent Variable		Cumulative R^2 for Dependent Variable of Yield
Month	Average Monthly Measurement	(units in percent)
March	Temperature	14.4
May	Precipitation	15.5
June	Temperature	17.2
March	Precipitation	19.6
April	Precipitation	20.5
April	Temperature	21.2
June	Precipitation	21.5

A. Regression Analysis for Eight Independent Variables; Four Average Monthly Values of Temperature and Precipitation. Spring Season.

March	Precipitation	3.1
May	Precipitation	6.3
June	Precipitation	7.8
April	Precipitation	8.2

B. Regression Analysis for Four Independent Variables; Four Average Monthly Values of Precipitation Alone, Spring Season.

Again, the orthogonal factor "matrix using principal factor with iterations" and the "varimax rotated factor matrix" for the eight independent variables over the spring season generally supports the results of the multiple regression analysis. In the "matrix using principal factor with iterations," yield is related to Factor 3, which in turn is related to March and May temperatures. Yield is also related to Factor 1, which had high values for June temperature and May and March precipitation. Factor 3 in the "varimax rotated factor matrix" relates yield to March temperature, March precipitation and June temperature. The independent variables listed above, with the exception of May temperatures, are identical to the first four most important variables identified in the stepwise multiple regression analysis for the spring season.

Finally, average monthly temperature and precipitation values were statistically analyzed for the months of November and December, the early winter season. The results of the stepwise multiple linear regression analysis for four independent variables are shown in Table 3 and Appendix D. Only the contributions from temperatures are shown, because the contributions from precipitation were negligible. The independent variables for those two months were collectively unable to account for a cumulative R^2 of 9 percent, which indicates that the average monthly precipitation and temperature values during these months contribute little to yield variability. Even so, temperature variables are more important for November and December. The factor analysis results, included in Appendix D, substantiate the weak correlations between yield variability and the temperature and precipitation variables of the early winter season.

Table 3
Stepwise Multiple Regression Analysis for Early Winter Season, Including the Months of November and December; Data Ranges over 1941-1970.

Independent Variable		Cumulative R^2 for Dependent Variable of Yield
Month	Average Monthly Measurement	(units in percent)
November	Temperature	7.4
December	Temperature	8.5

A. Regression Analysis for Four Independent Variables; Two Average Monthly Values of Temperature and Precipitation, Early Winter Season.

AVERAGE MONTHLY PRECIPITATION AND TEMPERATURES FOR THE FALL SEASON IN KANSAS AND THEIR ASSOCIATION WITH WINTER WHEAT YIELD VARIABILITY 1887-1921 AND 1887-1970

In the previous section, yield for the state of Kansas was regressed against average monthly precipitation and temperature values which had been averaged over the Central Crop Reporting District of the state. The results imply that average monthly precipitation values in the fall, especially for October and September, are important indicators of annual winter wheat yields.

In order to test this result further, but not exhaustively, additional statistical analysis was undertaken. Continuous yield data were obtained for the state of Kansas back to 1887, and average monthly precipitation and temperature values for the central one-third region of the state were also obtained.[36] This central one-third region includes not only the Central Crop Reporting District, but the North and South Central Crop Reporting Districts as well, as is shown in Figure 1.

With this new, enlarged data set extending back to 1887, stepwise multiple linear regression and orthogonal and oblique factor analyses were again performed, but over the fall season alone, for the periods 1887-1921 and 1887-1970. The results of these analyses in general tend to diminish the importance of the average monthly October and September precipitation, and October temperature variables, in accounting for yield variability.

The results of the stepwise multiple regression analysis for the fall season over the period 1887-1970 are shown in Table 4. Again, as had been the case for the 1941-1970 period shown in Table 1, September and October precipitation rank as the most important two independent variables, but now in the reverse order from the 1941-1970 period. The third and fourth most important variables over the 1887-1970 time span, however, are July temperature and July precipitation, in that order, which are different from the results of the 1941-1970 period. Also different is the total yield variability accounted for by the fall season variables, only 21.9 percent compared to the 37.5 percent obtained from the 1941-1970 data. This 21.9 percent cumulative R^2 value is low, principally owing to the failure of the major two variables, October and September precipitation, to account for more than 19.4 percent of the yield variability; in the 1941-1970 period these two variables collectively accounted for 28.7 percent of yield variability. The results of both the orthogonal and oblique factor analyses supported the importance of September and October precipitation, in that order, to account for yield variability over the 1887-1970 period.

A logical subset of the 1887-1970 yield time series is the data for 1887-1921. This period encompasses the "Golden Years of American Agriculture," 1887-1915, so called because of the dramatic improvement in the economic status of the American farmer, followed by the years through World War I and its aftermath. The historical justification for the use of this period is discussed in Appendix E.

The independent variables of average monthly precipitation and temperature were tested against yield over the years 1887-1921 in a stepwise multiple regression analysis. Because of the high correlations between precipitation and temperature variables for some of the months, the results

Table 4
Stepwise Multiple Regression Analysis for Fall Season, Including the Months of July through October; Data Ranges over 1887-1970

Independent Variable		Cumulative R^2 for Dependent Variable of Yield
Month	Average Monthly Measurement	(units in percent)
September	Precipitation	13.0
October	Precipitation	19.4
July	Temperature	20.1
July	Precipitation	21.2
October	Temperature	21.4
August	Temperature	21.6
August	Precipitation	21.9

A. Regression Analysis for Eight Independent Variables; Four Average Monthly Values of Temperature and Precipitation, Fall Season.

September	Precipitation	13.0
October	Precipitation	19.4
July	Precipitation	19.5

B. Regression Analysis for Four Independent Variables; Four Average Monthly Values of Precipitation Alone, Fall Season.

for the stepwise loading of the eight independent variables are considered invalid. The cumulative R^2 total for all eight variables taken together is valid, however, and amounts to 20.3 percent. This cumulative R^2 value is comparable in value to the fall season R^2 computed for the 1887-1970 period shown in Table 4, and it is lower than the fall season R^2 for the 1941-1970 period shown in Table 1, for the same sets of independent variables. When precipitation variables are considered alone, the results shown in Table 5B indicate that September is the most important month, with October in third place.

The 1887-1921 period is the first of the three yield time series tested in this paper to indicate that temperature variables are more important than precipitation variables for assessing yield over the fall season. There is no ready explanation for this temperature dependence but in Figure 9, a plot of temperature behavior of the major portions of land areas of the Northern Hemisphere for nearly the last four centuries is shown.[37] The post-1900 period was warmer than the pre-1900 years, providing some indication that long-term temperature effects may have had some impact on crop yields over these years.

In general, the effects of many climatic factors, severe storms, and phenologic variations have greatly altered plant growth conditions in Kansas over the 1887-1970 yield time series. The magnitudes of the fluctuations of some of these factors are indicated in Appendix F.

The results of the orthogonal and oblique factor analyses on the 1887-1921 data set were inconclusive. The slightly stronger of the two factors associated with yield supported the contention that fall precipitation variables were more important than those of temperature. The most important single variable was October precipitation. A second, weaker factor associated with yield generally supported temperature over precipitation variables in importance, and implied that the variables for July and August were more important than those of September and October.

ASSUMPTIONS, APPROXIMATIONS, AND SCALINGS OF YIELD VARIABILITY FOR LARGE AREAS (SUBSTATE REGIONS) AND EXPERIMENTAL FARMS

The statistical analyses over the yield time series include many assumptions and approximations. One of the most important factors for the American agricultural system is the relative magnitude of the prices paid to the farmer for agricultural produce versus his production costs. For example, episodic events which cause some modest degree of crop damage can involve very substantial losses to crop production if prices are not high enough to warrant salvaging a crop. These varying economic conditions and the technological inputs to the American agricultural sector are discussed in Appendix E.

In addition to economic factors, a whole class of climatic variations have affected the Kansas yield time series. Some limited data on three types of climate variations are shown in Appendix F. They include data on long-term (multiple decades) changes in climate, severe storms, and episodic events. The LACIE yield models discussed previously assume that short-period weather fluctuations and episodic events are averaged out over large areas, and that there is a homogeneity of weather departures from normal over the entire region being modeled. These, of course, are approximations for complicated processes.

Table 5
Stepwise Multiple Regression Analysis for Fall Season, Including the Months of July through October; Data Ranges over 1887-1921

Independent Variable		Cumulative R^2 for Dependent Variable of Yield
Month	Average Monthly Measurement	(units in percent)

Stepwise loading of independent variables is invalid because of the high correlations between precipitation and temperature variables. Cumulative total R^2 for all eight average monthly precipitation and temperature variables is 20.3 percent.

A. Regression Analysis for Eight Independent Variables; Four Average Monthly Values of Temperature and Precipitation, Fall Season.

September	Precipitation	4.8
August	Precipitation	6.5
October	Precipitation	7.2

B. Regression Analysis for Four Independent Variables; Four Average Monthly Values of Precipitation Alone, Fall Season.

Some data on the normal annual growing degree days throughout the United States and phenological variations on an experimental farm in Kansas are also included in Appendix F. The LACIE models have assumed that a particular crop is in the same phenological stage each month of every year, and is identically susceptible to the same weather impacts on yield, which is another approximation.

Other factors important to the growth of winter wheat include varieties of wheat grown, cropping practices, plant diseases, insect damage, etc. Many of these factors are discussed in a recent article authored by L. P. Reitz of BARC.[38] In this article, Reitz points to the many distinctions in winter wheat cultivation for both the eastern United States and the southern Great Plains region, which includes Kansas. A careful consideration of all these types of factors would be essential to the design of simulations of the Great Plains Region at BARC.

One of the major assumptions used in this paper is that average monthly values of precipitation and temperature for the central regions of Kansas are characteristic of winter wheat yields for the state. The data sets for the 1941-1970 period consisted of precipitation and temperature values which had been drawn from meteorological station data in the Central Crop Reporting District of the

INTERVALS IN WHICH MAJOR PORTIONS OF THE LAND AREAS OF THE NORTHERN HEMISPHERE WERE NOTABLY WARM OR COOL (1600 - 1975)

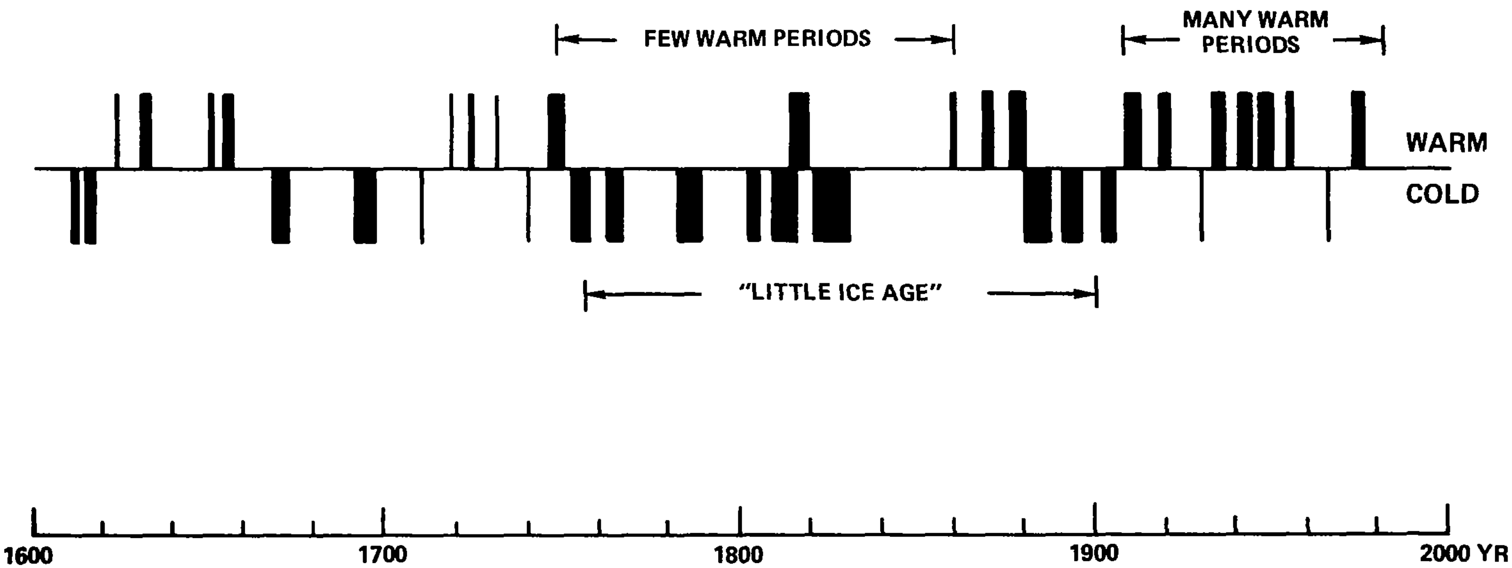


Figure 9. Average temperature of the Northern Hemisphere over the last four centuries.[37]

state. The average monthly values of precipitation and temperature employed to represent the data for the 1887-1941 period had been drawn from meteorological stations located in the three central crop reporting districts collectively, namely the Central District used for the 1941-1970 period, as well as the North and South Central Crop Reporting Districts of the state. Climate data from central Kansas should be representative of yield for the state because, historically, the main wheat area has been located in the center of the state, as is indicated by Figure 10.[39] Wheat yield data by Kansas county for the period 1962-1976 has been statistically processed elsewhere, and the ordered rankings by county and crop reporting district are shown and mapped in Appendix G.[40] Also shown are the counties' ordered ranking by total wheat production. Nine out of the first 11 wheat producing counties in the CCRD rank in the highest 33 wheat producing counties in the state for the 1962-1976 period.

A final major problem in relating yield variability for large areas (substate regions) to yield data obtained on experimental farms involves the scaling of meteorological systems. Adopting the conventions of Barry, three climatic meteorological motion systems will be defined as follows:[41]

Motion System	Horizontal Scale (km)	Vertical Scale (km)	Time Scale (hr)	Total Energy*
Planetary Waves 1. Macroscale Synoptic Variations	5×10^3	>10	$2-4 \times 10^2$	Av. Depresions 10^{-3}
2. Mesoscale phenomena	$5 \times 10^2 - 2 \times 10^3$	1–10	1–10	Av. Thunderstorm: 10^{-8}
3. Microscale phenomena	10^{-1}	10^{-2}	$10^{-2}-10^{-1}$	Av. Wind Gust 10^{-17}

*Base 1 = daily solar energy intercepted by the earth.

The smallest sized regions with economic significance and requirements for publicly available statistics most probably have the dimensions of a county, unless individual farms are being monitored for farm management information. The current LACIE yield model regions are characteristically of crop reporting district size. The rectangular dimensions of crop reporting districts in Kansas are in the range of 96 by 208 kilometers, 60 by 130 miles; these regional sizes are smaller than mesoscale phenomena but certainly larger than microscale dimensions, by Barry's horizontal scale convention. On the vertical scale, crop growth is affected by the climate within the first 10 meters above the ground, which falls within the microscale of meteorological motion systems. The time scale for the various crop calendar stages of wheat growth is within the boundaries of macroscale meteorological motions, ∿200 to 400 hours or longer. Thus, the growth and eventual yield of winter wheat, which is planted in the fall and harvested in the summer, is affected by all three types of meteorological motion systems.

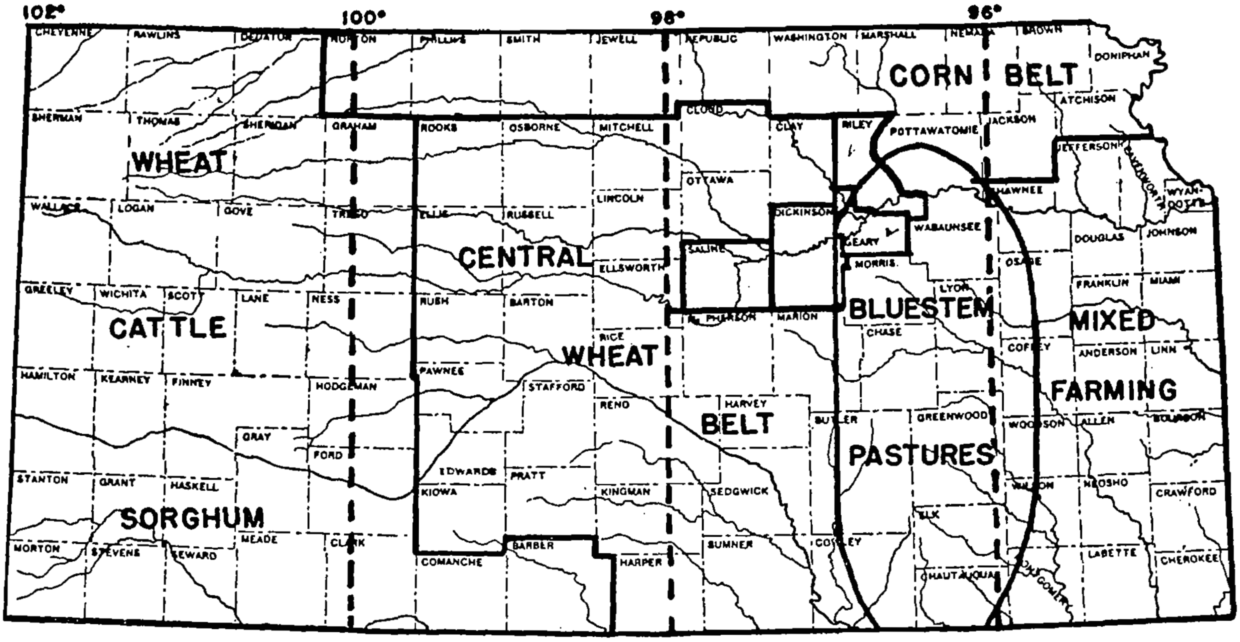


Figure 10a. Map of Kansas, showing the types of farming areas, circa 1930.[39]

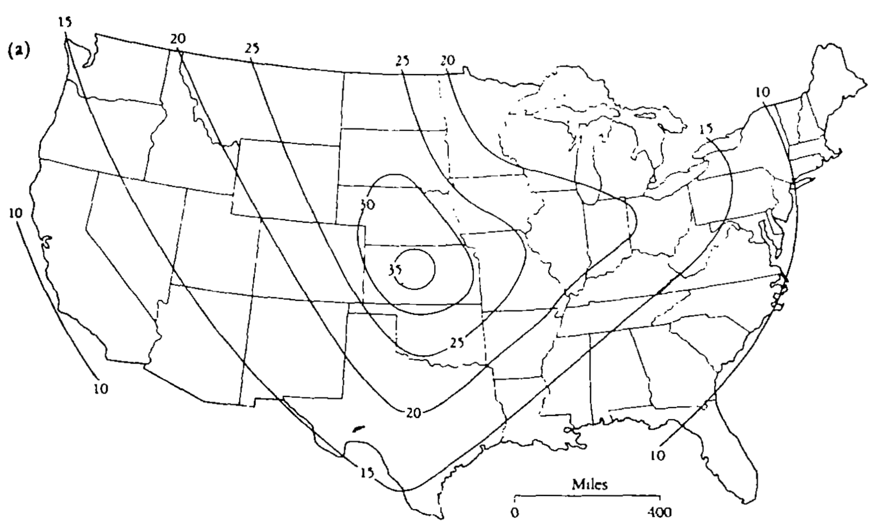


Figure 10b. Wheat production potential in the United States (1940-1949 average) in tens of millions of bushels per hundred miles.[39]

Another complication of scaling climate data for agricultural use is that the political boundaries of agricultural regions which report statistical data, e.g., counties or crop reporting districts, are not usually coincident with regions having specific climatic characteristics. The needs of regional climatology and its agricultural applications could conflict directly with the goals and aims of synoptic and physical climatology, if there were insufficient resultant spatial resolution over the agricultural regions. This may prove to be especially true for expanded climate, hydrologic, and severe storms satellite programs whose new and improved data will become available for agricultural applications. These newly available data sources can be most expeditiously utilized for agriculture if the aims of the agricultural applications and the requirements for the regional data sets can be defined prior to the design stages of new satellite systems.

This paper and the current LACIE yield models have bypassed the whole issue of scaling climatic data to agricultural regions by the simple expedient of using average monthly meteorological station data which have been geographically averaged over the desired regions.[42] An experimental farm, on the other hand, offers the possibility of continuous monitoring of the microclimatic environment, which has resulted from the meso- and macroscale meteorological motions around it. These data, in conjunction with crop growth assessment through its various stages, can then be modeled to systematically isolate the effects of climate changes on crop yield. The usual approach is to build an agronomic or growth stage model which measures the boundaries of "normal" precipitation, such as temperature, degree-days, and evapotranspiration over the crop season, past which there are degrees of crop damage. These "normal" climatic conditions can then be varied over the historical magnitude and seasonal ranges of fluctuations in a particular agricultural region, such as the ranges of precipitation fluctuations in Kansas which have been outlined here. Thus an experimental farm can be utilized to simulate a wide range of agroclimatic conditions in many larger agricultural regions, and to isolate the relative importance of these many conditions on crop yields. The effects of extreme climatic conditions, such as severe storms, drought, winterkill and other episodic events, can be specifically simulated under controlled conditions in growth chambers. For example, a winter crop can be grown in a growth chamber under conditions of varying precipitation, temperature, soil moisture, et cetera, during the planting-rooting-hardening stages; under varying snow depths, ice cover thicknesses, diurnal temperature extremes, and wind velocities, during the dormancy stages; and under varying degrees of soil saturations, occasional water-freezing ice thicknesses, and diurnal temperature extremes, or during the reemergence stages. Thus, the effects of a wide range of winterkill conditions on winter crop yield can be systematically assessed. In addition, the plant container can be periodically removed from the growth chamber and situated under controlled lighting conditions for required radiometric monitoring.

CONCLUSIONS

Long-term agroclimatic conditions in central Kansas have been statistically compared to winter wheat yield variability for the entire state. Three time series have been analyzed: those of 1941-1970, 1887-1970, and 1887-1921. For the first two time series, October and September average monthly precipitation values have been identified as the most important variables; for the 1887-1921 period, average monthly temperature variables seem more important than precipitation variables for the months of July, August, September, and October.

This paper has processed statistics on average monthly precipitation and on yield as a function of average monthly precipitation and temperatures for Kansas over an 83-year period, 1887-1970. During this time, many complex and related factors and conditions have interacted to affect both the climatic and the agricultural yield data sets. Nevertheless, these data sets do represent the real-life situation in regions in Kansas, regions over which future satellite monitoring of winter wheat growth and yield is anticipated. No experimental farm can simulate or duplicate these total ranges of conditions. However, an experimental farm can be adapted to simulate a number of the conditions which have been encountered over long time periods for such agricultural regions and, in doing so, can provide the capability to sort, isolate, and evaluate the relative importance of these conditions on agricultural yield.

The obvious methodology for approximating the yield of a region is to build a model which incorporates the variety of relevant variables and produces a good approximation of the actual results when tested with a historical data set. LACIE, with its yield approximations for crop reporting size districts in the Great Plains regions, presumably is developing such models. These models should incorporate all variables pertinent to yield, which were labeled by Nalepka et al. under the headings of historical trend, and meteorological and cultural perturbations.[43] The effects on yield of meteorological perturbations alone can be logically separated into long-term climatic changes over decades, shorter-term variations in "normal conditions," and the extreme variations in severe storms and episodic events.

The role of the experimental farm in these large-area models is to simulate experimentally, test and evaluate the relevant variables and their effects on yield. For example, an evapotranspiration/crop growth model can be implemented on an experimental farm to test the importance of fall season precipitation and evapotranspiration rates on winter wheat yields, using average monthly precipitation and temperature values over the range of historical data for crop reporting districts in Kansas. Systematically, questions about the range of "normal conditions" of precipitation and temperature which produce little or no crop damage, or about the value of short, intense rainfall periods versus light continuous rainfall on winter wheat yields for a particular month and growth stage, could be answered. Simultaneously, spectral measurements of crop conditions could be made at BARC in which the climatic variables affecting crop growth and yield are determined. Extreme climatic simulations can be varied under controlled conditions in laboratory or growth chamber environments, and their effects on yield determined. In any case, when these climatic effects on yield have been established for the experimental farm situation, they must then be scaled upward and integrated into regional models of substate areas[44]; examples of the use of climatic data in regional yield models have already been discussed. Specifically, the models of Bridge for winter wheat on the Great Plains, Baier and Robertson for spring wheat in Canadian provinces, and Pitter for wheat yields in Oregon are good examples.[45] Pitter's model, in particular, folds in levels of constant technology and looks for global warming and cooling trend effects.

In summation, a great deal of new and different data on regional agroclimatology are necessary for the construction of regional yield models for remote sensing requirements. Simulation of the historical ranges of regional agroclimatic conditions and their bounded effects on crop yield for remote sensing needs can be accomplished at an experimental farm such as BARC. As the extensive publications of the American Institute of Crop Ecology in Silver Spring, Maryland, have demonstrated, many agricultural regions throughout the world are already long-term agroclimatic analogs of one another, without any climate modification.[46] Modifications of the microclimate over agricultural field test plots would greatly broaden the extensibility of experimental farm research for regional climatological simulations.

In the procedure outlined in this paper, a starting point for climatic simulations at BARC would be the modification of the range of precipitation in central Kansas simulations through the use of sliding covers over field plots. As is shown in Table 1, the raw average monthly precipitation variables for October and September alone have a cumulative R^2 of 28.7 percent, which is significant for two variables out of the 20 or 30 possible independent variables usually regressed against yield in a regional model. The best procedure to test the relative significance of the independent variables would be to build the complete regional yield regression model with the totality of pertinent raw or suitably modified dummy variables. This approach was not used in this paper.

An example of a dummy variable is the aridity index developed by Angstrom.[47] He found that the index of aridity was proportional to the duration of precipitation, which in turn was proportional to the amount of precipitation and inversely proportional to an exponential of temperature. Thus, his expression for an index of aridity, I, is:

$$I = \frac{P}{1.07^{T}}$$

For this expression, the denominator doubles with each 10°C increase in temperature. Thus, Angstrom's aridity index varies similarly to Van't Hoff's Law for the velocity of a chemical reaction as a function of an exponential of temperature, the law which is the basis for Thornthwaite's expression for plant growth.[48] Angstrom's aridity index has the additional advantage of being continuous for negative values of temperature, and should be, all in all, much more indicative of soil moisture and plant yield than the raw, simple variables of average monthly precipitation and temperature used in this paper.

By a procedure similar to that used in this paper for relating the average monthly precipitation in central Kansas to wheat yield, other variables and agricultural regions could be tested and simulated, or addition of the significance of solar radiation hours, for example, could be statistically analyzed,, as were the ranges of average monthly precipitation in this paper; their magnitudes could also be varied by the use of sliding covers over field plots at BARC. Once these procedures were established, they could be extended to other agricultural regions besides Kansas, especially with the utilization of growth chambers to simulate extreme or unusual episodic climatic conditions. Such a methodology could eventually provide pertinent data necessary for remote sensing regional yield models, with a substantial cost savings over an approach requiring data gathering *in situ* in each agricultural region of interest. This experimental farm simulation methodology should also be very useful for developing regional yield models in agricultural areas inaccessible to ground truth testing.

REFERENCES

1. R. P. Harnack, "Summer Season Prediction of Great Plains Precipitation" (Ph.D. Dissertation, University of Maryland, 1976).

2. D. B. Grigg, *The Agricultural Systems of the World: An Evolutionary Approach* (London: Cambridge University Press, 1974).

3. R. F. Nalepka, J. E. Colwell, and D. P. Rice, *Forecasts of Winter Wheat Yield and Production Using Landsat Data,* ERIM Report 114800-39-F on NASA Contract NAS 5-22389, p. 14 (Ann Arbor, Michigan: Environmental Research Institute of Michigan, December 1977).

4. Ibid., p. 96.

5. Ibid., p. 88-91.

6. Ibid., p. 90-91.

7. Ibid., p. 90.

8. Ibid., p. 65.

9. Ibid., p. 85-86.

10. United States Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, *Climatology of the United States No. 81 (by State) Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1941-1970* (Asheville, North Carolina: National Climate Center, August 1973), Kansas section by alphabetical listing.

11. D. Phinney, "Accuracy and Performance of LACIE Yield Estimates," United States, National Aeronautics and Space Administration, *The LACIE Symposium Briefing Materials for Technical Presentations* Vol. B, NASA/JSC-14557, Houston, Texas (October 1978), p. 320.

12. C. Sakamoto, "Wheat Yield Model Development," United States, National Aeronautics and Space Administration, *The LACIE Symposium Briefing Materials for Technical Presentations,* Vol. A, NASA/JSC-14557, Houston, Texas (October 1978), p. 35.

13. Ibid., pp. 36-37.

14. R. P. Harnack, "Summer Season Prediction of Great Plains Precipitation," p. 20a; Institute for Social and Environmental Studies, *Kansas Statistical Abstract* (Lawrence, Kansas: University of Kansas, 1970).

15. John D. Chapman and John C. Sherman, *Oxford Regional Economic Atlas, The United States and Canada* (London: Oxford University Press, 1975), pp. 64-65.

16. Ibid., pp. 66-67.

17. U.S. Department of Commerce, NOAA Environmental Data Service, *Climatology of the United States No. 85 (by State) Monthly Averages of Temperature and Precipitation for State Climatic Divisions 1941-1970.*

18. U.S. Department of Agriculture/Weather Bureau, *Climatological Data for the United States by Sections,* Volume XXVII, Parts I, II, III, IV. (Washington, D.C.: Weather Bureau, 1940).

19. R. P. Harnack, "Summer Season Prediction of Great Plains Precipitation," p. 20a.

20. E. A. Hurd, "Phenotype and Drought Tolerance in Wheat," *Agricultural Meteorology* 14, No. 1/2 (November 1974), pp. 39-55.

21. L. L. Ray, C. W. Wendt, B. Roark and J. E. Quisenberry, "Genetic Modification of Cotton Plants for More Efficient Water Use," *Agricultural Meteorology* 14, No. 1/2 (November 1974), pp. 31-38.

22. Charles Y. Sullivan and Jerry D. Eastin, "Plant Physiological Responses to Water Stress," *Agricultural Meteorology* 14, No. 1/2 (November 1974), pp. 331-350.

23. M. Gangopadhyaya and R. P. Sarker, "Influence of Rainfall Distribution on the Yield of Wheat Crop," *Agricultural Meteorology* 2 (1965), pp. 331-350; and P. S. Sreenivasan, "Influence of Rainfall on Wheat Varieties at Jalgaon and Niphad," *Agricultural Meteorology* 13 (1974), pp. 267-278.

24. T. G. J. Dyer and J. F. Gillooly, "On a Technique to Describe Crop and Weather Relationships," *Agricultural Meteorology* 18 (1977), pp. 187-202.

25. P. E. Waggoner, "What to Do?" *Agricultural Meteorology* 15 (1975), pp. 161-164.

26. R. L. Pitter, "The Effect of Weather and Technology on Wheat Yields in Oregon," *Agricultural Meteorology* 18 (1977), pp. 115-131.

27. W. Baier and G. W. Robertson, "The Performance of Soil Moisture Estimates as Compared with the Direct Use of Climatological Data for Estimating Crop Yields," *Agricultural Meteorology* 5 (1968), pp. 17-31.

28. Daniel W. Bridge, "A Simulation Model Approach for Relating Effective Climate to Winter Wheat Yields on the Great Plains," *Agricultural Meteorology* 17 (1976), pp. 185-194.

29. J. C. Albrecht, "A Climatic Model of Agricultural Productivity in the Missouri Basin," *Pub. Climatol.* 24 No. 2, (1971), and W. Baier, "Crop Weather Analysis Model: Review and Model Development," *Journal of Applied Meteorology* 12 No. 6, (1973), pp. 937-947, and Baier and Robertson, "The Performance of Soil Moisture Estimates as Compared with the Direct Use of Climatological Data for Estimating Crop Yields," (1968), pp. 17-31.

30. E. S. Ulanova, *Agrometeorological Conditions and Winter Wheat Yields,* trans. by Joint Publications Research Service, Arlington, Virginia JPRS-66418, (December 18, 1975), pp. 126-138.

31. R. F. Nalepka et al., *Forecasts of Winter Wheat Yield and Production Using Landsat Data,* p. 96.

32. C. Sakamoto, "Wheat Yield Model Development," p. 35.

33. R. P. Harnack, "Summer Season Prediction of Great Plains Precipitation," p. 20a.

34. Norman H. Nie, C. Hadlai Hull, J. C. Jenkins, Karin Steinbrenner, and Dale H. Bent, *Statistical Package for the Social Sciences, Second Edition* (N.Y.: McGraw-Hill Book Company, 1970). The stepwise linear multiple regression analysis is covered on pages 320-367 and the factor analysis on pages 468-512.

35. Peter J. Taylor, *Quantitative Methods in Geography: An Introduction to Spatial Analysis* (Boston: Houghton Mifflin Co., 1977), pp. 231-281. On pages 280-1 is an annotated bibliography of a wide range of additional references applying factor analysis to problems of spatial analysis.

36. Continuous yield data back to 1887 for Kansas were obtained from the following sources: *United States Department of Agriculture, Bureau of Crop Estimates, Wheat Yields Per Acre and Prices by States 50 Years 1866-1915* (Washington, D.C.: USDA Bulletin No. 514, February 13, 1917), p. 11; United States Department of Commerce, Bureau of Census, *Statistical Abstracts of the United States* (Washington, D.C.: for the years 1915-1926); Kansas State Board of Agriculture, Division of Statistics, *Kansas Wheat Production by Counties 1926-1977* (Topeka, Kansas: Kansas Crop and Livestock Reporting Service, 1977). Climate data before 1941 was obtained from the United States Department of Agriculture and the Weather Bureau, *Climatological Data for the United States by Sections,* Vol. XXVII, Parts 3 and 4 (Washington, D.C.: Weather Bureau, 1940). The historical climatological data sets back to 1887 are listed on the first page of the 12 different State of Kansas reports, one report for each of the 12 months of the year.

37. Figure kindly provided prior to publication by Professor Helmut E. Landsberg, University of Maryland, College Park, Maryland.

38. L. P. Reitz, "Wheat in the United States," U.S. Department of Agriculture, Agricultural Research Service, Agricultural Information Bulletin No. 386, Washington, D.C.: Government Printing Office, February 1976, p. 2.

39. Figure 10a is a simplification of Figure 18, Bulletin 251, Kansas State Experimental Station, 1930, as shown in Malin, *Winter Wheat,* Frontispiece; and Figure 10b is taken from W. Warntz, *Toward a Geography of Price* (Philadelphia: University of Pennsylvania Press, 1959), pp. 67-69, as shown in Taylor, *Quantitative Methods in Geography,* p. 193.

40. Private communication with Dr. David Wood, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland.

41. Definition of meteorological motion systems and their interpretation based on R. J. Barry, "A Framework for Climatological Research with Particular Reference to Scale Concepts," *Trans. Instit. of British Geog.* 49 (1970): pp. 61-70 and E. C. Barrett, *Climatology from Satellites* (London: Methuen and Co., Ltd., 1974), pp. 8-9.

42. United States Department of Agriculture and the Weather Bureau, alphabetical listing for the state of Kansas for each month of the year.

43. R. F. Nalepka et al., *"Forecasts of Winter Wheat Yield and Production Using Landsat Data,"* p. 96.

44. Radiometer data taken on an experimental farm may also require upward scaling or integration, when the field of view encompasses larger areas. This year, in research under contract, remote sensing techniques using low altitude-high resolution sensors are being studied for their applicability to larger area viewing from spacecraft platforms. Specifically, the research is attempting to predict the effects of the non-homogeneities of scene and sensor parameters over larger areas, of linear dimensions of 25 kilometers or more, on soil moisture measurements from a spaceborne microwave sensor. This research was described in a private communication with Dr. Vincent Salomonson, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland.

45. Daniel W. Bridge, "A Simulation Model Approach for Relating Effective Climate to Winter Wheat Yields on the Great Plains," W. Baier and G. W. Robertson, "The Performance of Soil Moisture Estimates as Compared with the Direct Use of Climatological Data for Estimating Crop Yields," R. L. Pitter, "The Effect of Weather and Technology on Wheat Yields in Oregon."

46. M. Y. Nuttonson, over the years since World War II, has contracted many studies on agroclimatic analogs throughout the world under the publication heading of the American Institute of Crop Ecology of Silver Spring, Maryland. Reference 75 of this paper quotes his *"Wheat-Climate Relationships"* which is an example of one of his agroclimatic analog studies. A listing of other publications from the American Institute of Crop Ecology is usually listed on the inside cover of each published text.

47. Anders Angstrom, "A Coefficient of Humidity of General Applicability," *Geografiska Annaler,* 18 (Stockholm, 1936). For a general discussion of agrometeorological model development, crop forecasting and weather forecasting for agriculture, consult: Jen-Yu Wang, *Agricultural Meteorology,* (Milwaukee: Pacemaker Press, 1963), pp. 334-455.

48. C. W. Thornthwaite, "An Approach Toward a Rational Classification of Climate," *The Geographical Review* (January 1948).

49. Plotted Data from Fredrick Strauss and Louis H. Bean, *Gross Farm Income and Indices of Farm Production and Prices in the United States, 1869-1937,* Technical Bulletin 703 (Washington, D.C.: U.S. Department of Agriculture, 1940) as quoted by Ross M. Robertson, *History of the American Economy, Third Edition* (N.Y.: Harcourt Brace Jovanovich, Inc., 1973), p. 307.

50. Data from Edwin Frickey, *Economic Fluctuations in the United States* (Cambridge, Massachusetts: Harvard University Press, 1942) and adapted by A. G. Hart, *Money, Debt and Economic Activity* 1st Edition (Englewood Cliffs, New Hampshire: Prentice-Hall, 1948), as quoted by Robertson, *History of the American Economy,* p. 309.

51. The top half of Figure E.2 is taken from the U.S. Bureau of Census, *Historical Statistics of the United States, Colonial Times to 1957* (Washington, D.C.: U.S. Government Printing Office, 1960), Series K 122-138, and the U.S. Department of Agriculture, *Agricultural Statistics, 1971* (Washington, D.C.: U.S. Government Printing Office, 1972), p. 478, as quoted in Albert W. Niemi, Jr., *United States Economic History: A Survey of the Major Issues* (Chicago: Rand McNally College Publishing Company, 1975), p. 238. The bottom half of Figure E.2 is taken from data from the United States Department of Agriculture as quoted by G. W. Robertson, *History of the American Economy,* p. 517. This plot is also used in standard texts on economics, as for example Paul A. Samuelson, *Economics: An Introductory Analysis, Sixth Edition* (N.Y.: McGraw-Hill Book Company, 1964), p. 401.

52. G. W. Robertson, *History of the American Economy,* p. 310.

53. Ibid., pp. 515-516.

54. Ibid., p. 518.

55. Plotted data taken from the U.S. Bureau of Census, *Historical Statistics.* Series K 1-7, and the U.S. Department of Agriculture, *Agricultural Statistics, 1973* (Washington, D.C.: U.S. Government Printing Office, 1974), p. 585, as quoted in Niemi, *United States Economic History,* p. 225.

56. G. W. Robertson, *History of the American Economy,* p. 311.

57. Harold Barger and Hans H. Landsberg, *American Agriculture, 1899-1939. A Study of Output, Employment and Productivity* (N.Y.: American Book-Stratford Press, Inc., 1942), p. 194.

58. For discussions of developments of farm machinery and scientific improvements affecting agriculture in the United States, consult the following sources: G. W. Robertson, *History of the American Economy,* pp. 302-305, pp. 532-533; Harold Barger and Hans H. Landsberg, *American Agriculture,* pp. 193-277; and Wayne Rasmussen, "The Impact of Technological Change on American Agriculture, 1862-1962," *Journal of Economic History* 22, December, 1962, pp. 578-591. For a discussion of the same topic in the state of Kansas, consult: James C. Malin, *Winter Wheat in the Golden Belt of Kansas, A Study in Adaption to Sub-humid Geographical Environment* (N.Y.: Octagon Books, 1973), pp. 210-247.

59. G. W. Robertson, *History of the American Economy,* pp. 532-533.

60. D. Phinney, "Accuracy and Performance of LACIE Yield Estimates," United States, National Aeronautics and Space Administration, *The LACIE Symposium Briefing Materials for Technical Presentations* Vol. B, NASA/JSC-14557, Houston, Texas (October 1978), p. 320. Figure 9 is an exact copy of page 320.

61. C. Sakamoto, "Wheat Yield Model Development," pp. 36-37.

62. Ibid.

63. For example, consult the works of H. H. Lamb: H. H. Lamb, *The Changing Climate: Selected Papers* (Methuan and Co. Ltd., 1966) and H. H. Lamb, *Climate: Present, Past, and Future* Vols. 1 and 2, (London: Methuen and Co. Ltd., 1972).

64. E. W. Wahl and T. L. Lawson, "The Climate of the Mid-19th Century United States Compared to Current Normals," *Monthly Weather Review* 98 (1970), as quoted by R. A. Bryson and F. Kenneth Hare, eds., in *Climates of North America* (Amsterdam: Elsevier Scientific Publishing Co., 1974), pp. 42-45. This volume is Volume 11 of the set of 15 published as the series *World Survey of Climatology,* whose editor-in-chief is H. E. Landsberg, College Park, Maryland, U.S.A.

65. Arnold Court, "The Climate of the Conterminous United States," in *Climates of North America,* R.A. Bryson and F. Kenneth Hare, eds., p. 235. In Volume 11 of *World Survey of Climatology,* H.E. Landsberg, editor-in-chief.

66. G. W. Robertson, *History of the American Economy,* p. 533.

67. Arnold Court, "The Climate of the Conterminous United States," in *Climates of North America,* R.A. Bryson and F. Kenneth Hare, eds., p. 230. In Volume 11 of *World Survey. of Climatology,* H.E. Landsberg, editor-in-chief.

68. Ibid., p. 231.

69. The data from Tables F.1 and F.2 come from a variety of sources as discussed in the Chapter entitled "The Crop Record, 1883-1902," James C. Malin, *Winter Wheat in the Golden Belt of Kansas,* pp. 141-161. Tables F.1 and F.2 are found on pages 157 and 159, respectively, in the same source. Bracketed data in Table F.1 is derived from "Wheat in Kansas," 7. *Report of the Kansas State Board of Agriculture for the Quarter Ending September, 1920* (Topeka, Kansas, 1921).

70. James C. Malin, *Winter Wheat in the Golden Belt of Kansas,* p. 166 and Reitz, *Wheat in the United States,* p. 4.

71. James C. Malin, *Winter Wheat in the Golden Belt of Kansas,* pp. 156-157.

72. For a discussion of the factors contributing to winterkill, consult E. S. Ulanova, *Agrometeorological,* pp. 126-138.

73. Arnold Court, "The Climate of the Conterminous United States," *Climates of North America,* R.A. Bryson and F. Kenneth Hare, eds. pp. 240, 248, 222, and 223, respectively, Volume 11 of *World Survey of Climatology*, H.E. Landsberg, editor-in-chief.

74. Ibid., p. 253.

75. M. Y. Nuttonson, *Wheat-Climate Relationships and the Use of Phenology in Ascertaining the Thermal and Photo-Thermal Requirements of Wheat Based on Data of North America and Some Thermally Analogous Areas of North America in the Soviet Union and in Finland.* Study sponsored by the United States Weather Bureau under Contract Cwb-8535 (Washington, D.C.: American Institute of Crop Ecology, 1955), pp. 84 and 85.

BIBLIOGRAPHY

Adem, Julian, "Experiments Aiming at Monthly and Seasonal Numerical Weather Prediction," *Monthly Weather Review* 93, 1965, pp. 495-503.

Albrecht, J. C., "A Climatic Model of Agricultural Productivity in the Missouri Basin," *Pub. Climatol.* 24, No. 2, 1971.

Angstrom, Anders, "A Coefficient of Humidity of General Applicability," *Geografiska Annaler*, 18, Stockholm, 1936.

Baier, W. and G. W. Robertson, "The Performance of Soil Moisture Estimates as Compared with the Direct Use of Climatological Data for Estimating Crop Yields," *Agricultural Meteorology* 5, 1968, pp. 17-31.

Barger, Harold and Hans H. Landsberg, *American Agriculture, 1899-1939: A Study of Output, Employment and Productivity*, American Book-Stratford Press, Inc., New York, 1942.

Barrett, E. C., *Climatology from Satellites*, Methuen and Co. Ltd., London, 1974.

Barry, R. J., "A Framework for Climatological Research with Particular Reference to Scale Concepts," *Trans. Instit. of British Geog.* 49, 1970, pp. 61-70.

Bridge, Daniel W., "A Simulation Model Approach for Relating Effective Climate to Winter Wheat Yields on the Great Plains," *Agricultural Meteorology* 17, 1976, pp. 185-194.

Brooks, C. E. P., *Climate Through the Ages*, Benn, London, 1926. Second edition, McGraw-Hill, Inc. New York, 1949.

Bryson, Reid A. and Thomas J. Murray, *Climates of Hunger, Mankind and the World's Changing Weather*, University of Wisconsin Press, Madison, 1977.

Bryson, Reid A. and F. Kenneth Hare, eds., *Climates of North America*, Vol. 11 of *World Survey of Climatology*. Editor-in-Chief, H. E. Landsberg, Elsevier Scientific Publishing Co., Amsterdam, 1974.

Central Intelligence Agency, National Foreign Assessment Center, *Relating Climate Change to Its Effects. A Research Paper*, GC 78-10154, August 1978.

Chang, Jen-Hu, *Climate and Agriculture: An Ecological Survey*, Aldine Publishing Co., Chicago, 1968.

Chapman, John D. and John C. Sherman, *Oxford Regional Economic Atlas, The United States and Canada*, Oxford University Press, London, 1975.

Dondlinger, Peter Tracy, *The Book of Wheat: An Economic History and Practical Manual of the Wheat Industry*, Orange Judd, New York, 1908.

Dyer, T. G. J. and J. F. Gillooly, "On a Technique to Describe Crop and Weather Relationships," *Agricultural Meteorology* 18, 1977, pp. 197-202.

Feyerherm, Arlin M., "A Winter Wheat Yield Model Responsive to Surface and Satellite-Derived Meteorological Observations," *Special Report Prepared for NASA Contracts NAS9-14282 and NAS9-14533*, Department of Statistics, Kansas State University, Manhattan, Kansas.

Fitzpatrick, E. A. and H. A. Nix, "A Model for Simulating Soil Water Regime in Alternating Fallow-Crop Systems," *Agricultural Meteorology* 6, 1969, pp. 303-319.

Gangopadhyaya, M. and R. P. Sarker, "Influence of Rainfall Distribution on the Yield of Wheat Crop," *Agricultural Meteorology* 2, 1965, pp. 331-350.

Geiger, Rudolf, *The Climate Near the Ground*, Harvard University Press, Cambridge, 1957.

Gilman, C. S. and J. T. Riedel, "Persistence of Extremely Wet and Extremely Dry Months in the United States," *Monthly Weather Review* 79, 1951, pp. 45-49.

Gribbin, John, *Forecasts, Famines, and Freezes: Climate and Man's Future*, Walker and Co., New York, 1976.

Grigg, D. B., *The Agricultural Systems of the World: An Evolutionary Approach*, Cambridge University Press, London, 1974.

Harley, C. Knick, "Western Settlement and the Price of Wheat, 1872-1913," *The Journal of Economic History* XXXVIII, No. 4, December 1978, pp. 865-878.

Harnack, R. P., "Summer Season Prediction of Great Plains Precipitation," Ph.D. Dissertation, University of Maryland, 1976.

Hay, R. F. M., "Spring Temperature–Anomalies and Summer Rainfall," *Weather* 21, 1966, pp. 219-227.

Hurd, E. A., "Phenotype and Drought Tolerance in Wheat," *Agricultural Meteorology* 14, 1974, pp. 39-55.

Johnson, D. Gale, and Robert L. Gustafson, *Grain Yields and the American Food Supply: An Analysis of Yield Changes and Possibilities*, The University of Chicago Press, Chicago, 1962.

Kansas Institute for Social and Environmental Studies, *Kansas Statistical Abstract 1970*, University of Kansas, Lawrence, Kansas, 1970.

Kansas State Board of Agriculture, Division of Statistics. *Kansas Wheat Production by Counties 1926-1977*, Kansas Crop and Livestock Reporting Service (typed document), Topeka, Kansas, 1977.

Lamb, H. H., *Climate: Present, Past and Future, Vol. 1 and 2*, Methuen and Co. Ltd., London, 1972.

Lamb, H. H., *The Changing Climate: Selected Papers*, Methuen and Co. Ltd., London, 1966.

Lamb, H. H., "Climate in the 1960's," *Geographical Journal*, 132, 1966, pp. 183-212.

Malin, James C., *Winter Wheat in the Golden Belt of Kansas: A Study in Adaption to Subhumid Geographical Environment*, Octagon Books, New York, 1973.

Mitchell, J. M., Jr., "A Preliminary Evaluation of Atmospheric Pollution as a Cause of the Global Temperature Fluctuation in the Past Century," *Global Effects of Environmental Pollution*, S. F. Singer, ed., Springer-Verlag, New York, 1970, pp. 139-155.

Munn, R. E., *Descriptive Micrometeorology*, Academic Press, New York, 1966.

Nalepka, R. F., J. E. Colwell and D. P. Rice, *Forecasts of Winter Wheat Yield and Production Using Landsat Data*, ERIM Report 114800-38-F on NASA Contract NAS 5-22389, Environmental Research Institute of Michigan, Ann Arbor, Michigan, December 1977.

Nie, Norman H., C. Hadlai Hull, Jean C. Jenkins, Karin Steinbrenner and Dale H. Bent, *Statistical Package for the Social Sciences, Second Edition*, McGraw-Hill Book Company, New York, 1970.

Niemi, Albert W., Jr., *United States Economic History: A Survey of the Major Issues*, Rand McNally College Publishing Company, Chicago, 1975.

Nix, H. A. and E. A. Fitzpatrick, "An Index of Crop Water Stress Related to Wheat and Grain Sorghum Yields," *Agricultural Meteorology* 6, 1969, pp. 321-337.

Nuttonson, M. Y., *Wheat-Climate Relationships and the Use of Phenology in Ascertaining the Thermal and Photothermal Requirements of Wheat Based on Data of North America and Some Thermally Analogous Areas of North America in the Soviet Union and Finland*, American Institute of Crop Ecology, Washington, D.C., 1955.

Pitter, R. L., "The Effect of Weather and Technology on Wheat Yields in Oregon," *Agricultural Meteorology* 18, 1977, pp. 115-131.

Rasmussen, Wayne, "The Impact of Technological Change on American Agriculture, 1862-1962," *Journal of Economic History* 22, December 1962, pp. 578-591.

Rasmussen, Wayne, ed., *Readings in the History of American Agriculture*, University of Illinois Press, Urbana, Illinois, 1960.

Rasmussen, Wayne, ed., *Agriculture in the United States: A Documentary History, Volume 4*, Random House, Inc., New York, 1975.

Ray, L. L., C. W. Wendt, B. Roark and J. E. Quisenberry, "Genetic Modification of Cotton Plants for More Effective Water Use," *Agricultural Meteorology* 14, 1974, pp. 31-38.

Reitz, L. P., "Wheat in the United States," *U.S. Department of Agriculture, Agricultural Research Service, Agricultural Information Bulletin No. 386*, Government Printing Office, Washington, D.C., February 1976.

Robertson, Ross M., *History of the American Economy*, Harcourt Brace Jovanovich, Inc., New York, 1973.

Samuelson, Paul A., *Economics: An Introductory Analysis, Sixth Edition*, McGraw-Hill Book Company, New York, 1964.

Sellers, William D., *Physical Climatology*, University of Chicago Press, Chicago, 1965.

Sellers, William D., "Climatology of Monthly Precipitation Patterns in the Western United States, 1931-1966," *Monthly Weather Review* 96, 1968, pp. 585-595.

Sreenivasan, P. S., "Influence of Rainfall on Wheat Varieties at Jalgaon and Niphad," *Agricultural Meteorology* 13, 1974, pp. 267-278.

Stringer, E. T., *Foundations of Climatology: An Introduction to Physical, Dynamic, Synoptic and Geographical Climatology*, W. H. Freeman and Company, San Francisco, 1972.

Stringer, E. T., *Techniques of Climatology*, W. H. Freeman and Company, San Francisco, 1972.

Sullivan, Charles Y. and Jerry D. Eastin, "Plant Physiological Responses to Water Stress," *Agricultural Meteorology* 14, 1974, pp. 113-127.

Taylor, James A., *Weather and Agriculture*, Pergamon Press, London, 1967.

Taylor, Peter J., *Quantitative Methods in Geography: An Introduction to Spatial Analysis*, Houghton Mifflin Co., Boston, 1977.

Thompson, Louis M., "Weather Variability, Climatic Change and Grain Production." *Science* 188 No. 4188, May 9, 1975, pp. 535-541.

Thornthwaite, C. W., "An Approach Toward a Rational Classification of Climate," *The Geographical Review*, January 1948, pp. 55-94.

Ulanova, E. S., *Agrometeorological Conditions and Winter Wheat Yields*, trans. by Joint Publications Research Service, Arlington, Virginia, JPRS 66418, December 18, 1975.

United States Department of Agriculture, Bureau of Crop Estimates, *Wheat Yields Per Acre and Prices by States 50 Years 1866-1915*, USDA Bulletin No. 514, Washington, D.C., February 13, 1917.

United States Department of Agriculture and the Weather Bureau, *Climatological Data for the United States by Sections, Vol. XXVII, Parts 3 and 4*, Weather Bureau, Washington, D.C., 1940.

United States Department of Commerce, Bureau of Census, *Statistical Abstracts of the United States*, U.S. Government Printing Office, Washington, D.C., pp. 1915-1926.

United States Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, *Climatology of the United States No. 81 (by State) Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1941-1970*, National Climate Center, Asheville, North Carolina, August 1973.

United States Department of Commerce, NOAA Environmental Data Service, *Climatography of the United States No. 85 (by State) Monthly Averages of Temperature and Precipitation for State Climatic Divisions, 1941-1970*, National Climatic Center, Asheville, North Carolina, July 1973.

United States, NASA/Goddard Space Flight Center, *Proposed NASA Contribution to the Climate Program*, Greenbelt, Maryland, November 1977.

United States, National Aeronautics and Space Administration, *The LACIE Symposium Briefing Materials for Technical Presentations, Volumes A & B*, Johnson Space Flight Center, Houston, Texas, NASA JSC-14557, October 1978.

Ventskevich, G. Z., *Agrometeorology*, Hydrometeorological Publishing House, Leningrad, 1958; English Publication-Israel Program for Scientific Translations Ltd., Jerusalem, 1961.

Waggoner, Paul E., "What to Do?" *Agricultural Meteorology* 15, 1975, pp. 161-164.

Wahl, E. W., "A Comparison of the Climate of the Eastern United States during the 1830's with the Current Normals," *Monthly Weather Review*, 96, 1968, pp. 73-82.

Wahl, E. W. and T. L. Lawson, "The Climate of the Mid-19th Century United States Compared to Current Normals," *Monthly Weather Review* 98, 1970, pp. 259-265.

Wang, Jen-Yu, *Agricultural Meteorology*, Pacemaker Press, Milwaukee, 1963.

Yao, Augustine Y. M. "Agricultural Potential Estimated from the Ratio of Actual to Potential Evapotranspiration," *Agricultural Meteorology* 13, 1974, pp. 405-417.

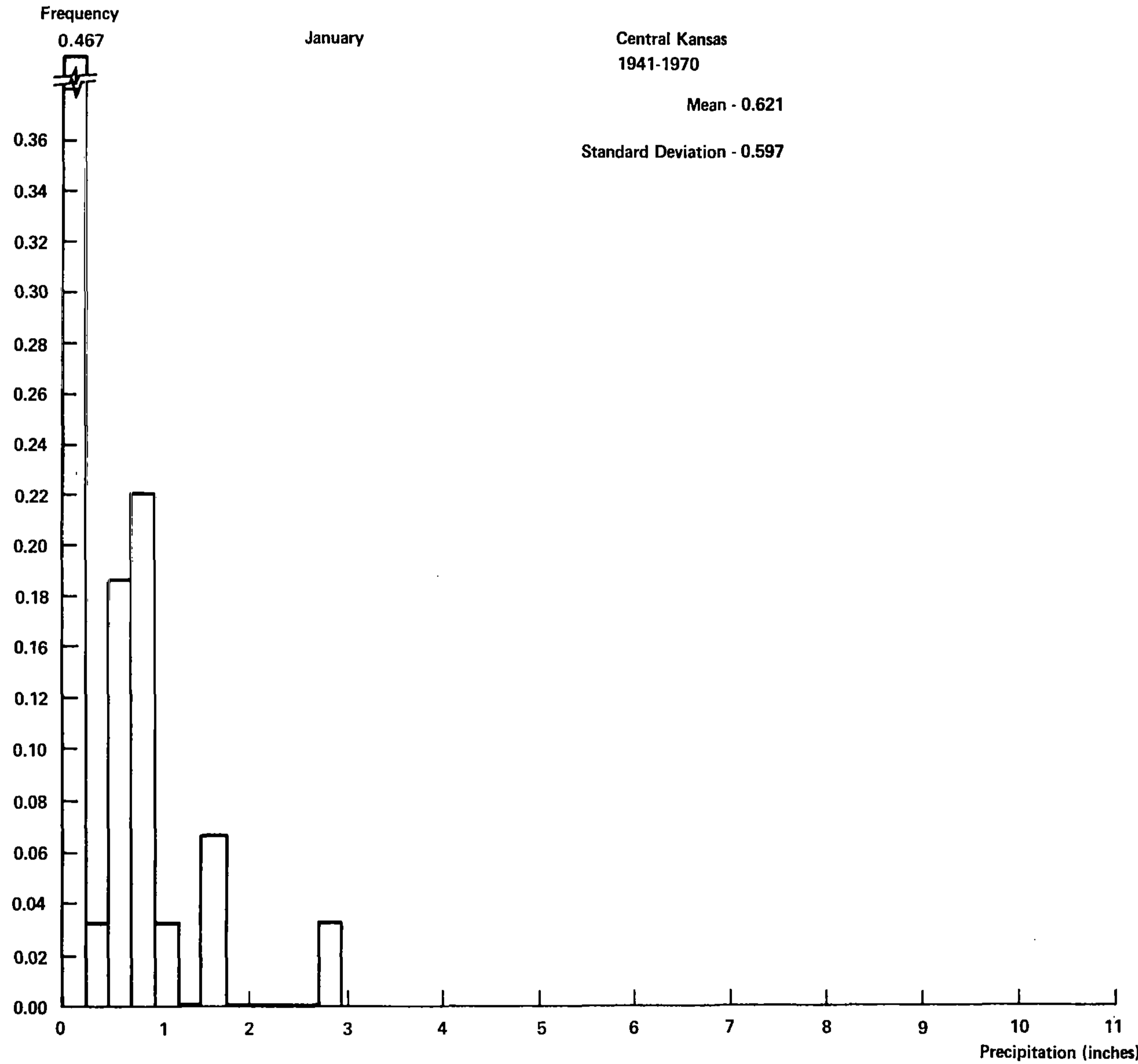
Yao, Augustine Y. M., "Evaluating Climatic Limitations for a Specific Agricultural Enterprise," *Agricultural Meteorology* 12, 1973, pp. 65-73.

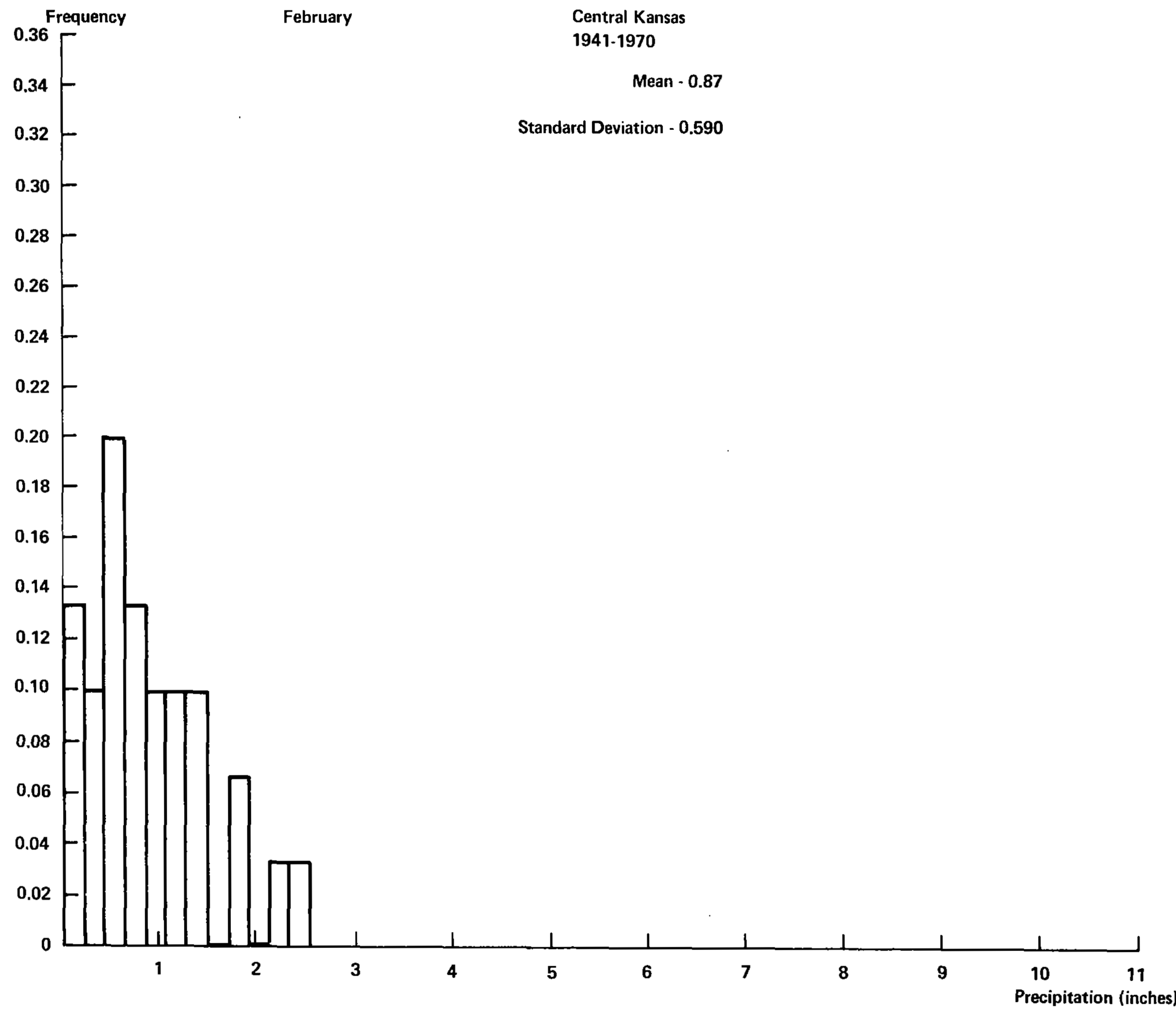
Yao, A. Y. M., "The *R* Index for Plant Water Requirement," *Agricultural Meteorology* 6, 1969, pp. 259-273.

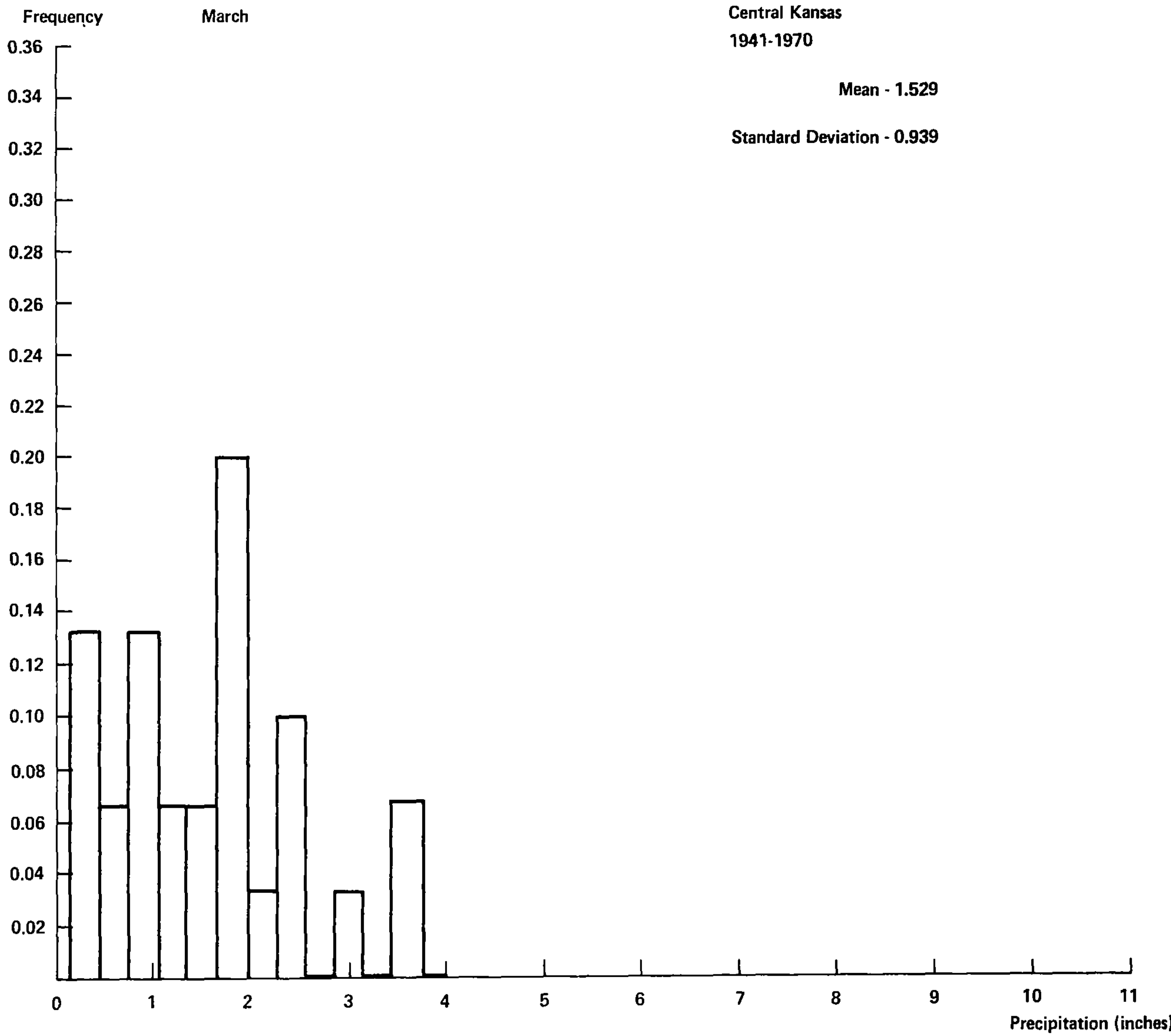
Zabijaka, Valentine. "A Preliminary Weather-Crop Yield Model for Soviet Grain," *Foreign Demand and Competition Division Working Paper*, Economic Research Service, U.S. Department of Agriculture, Washington, D.C., January 1974.

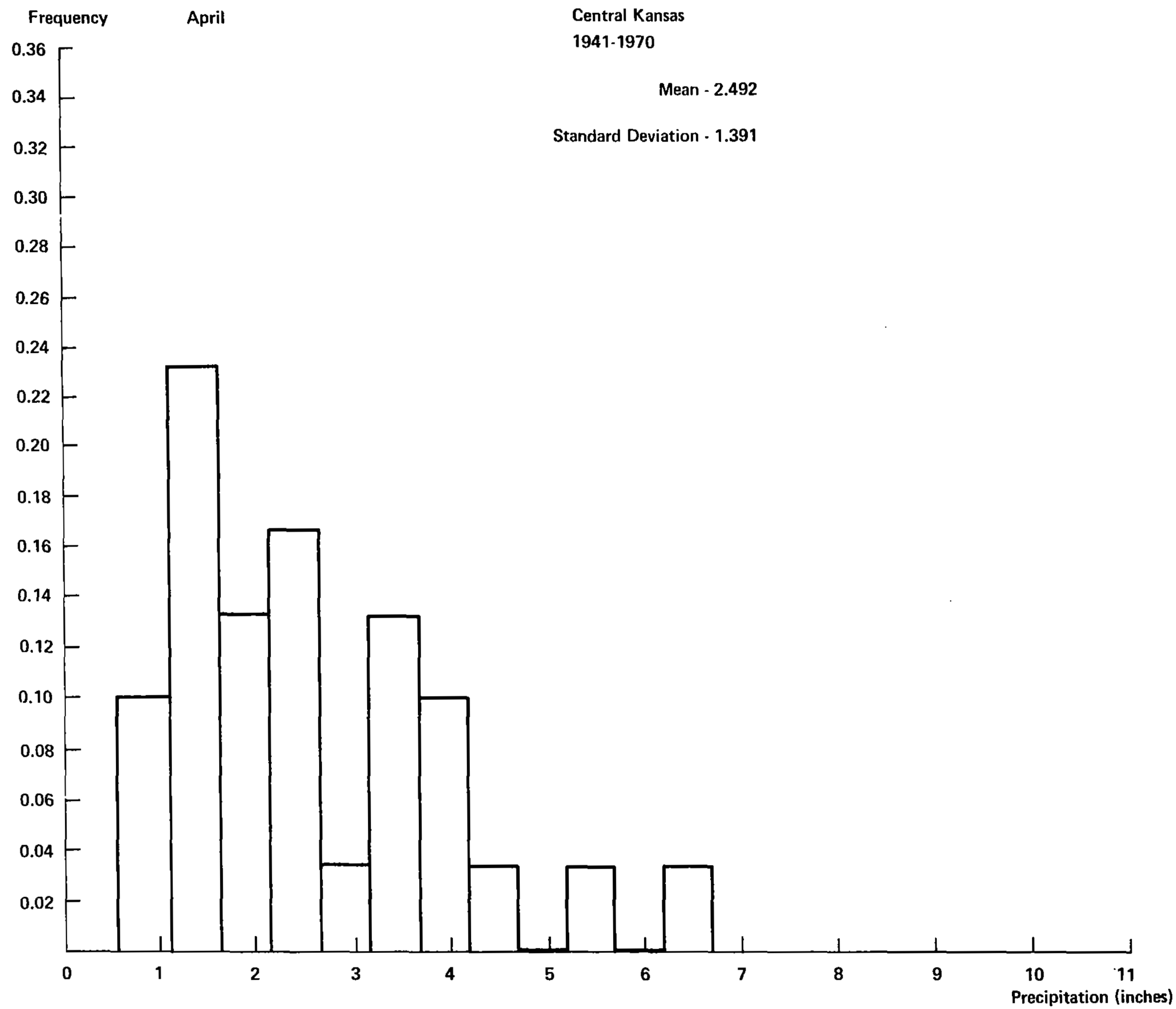
APPENDIX A

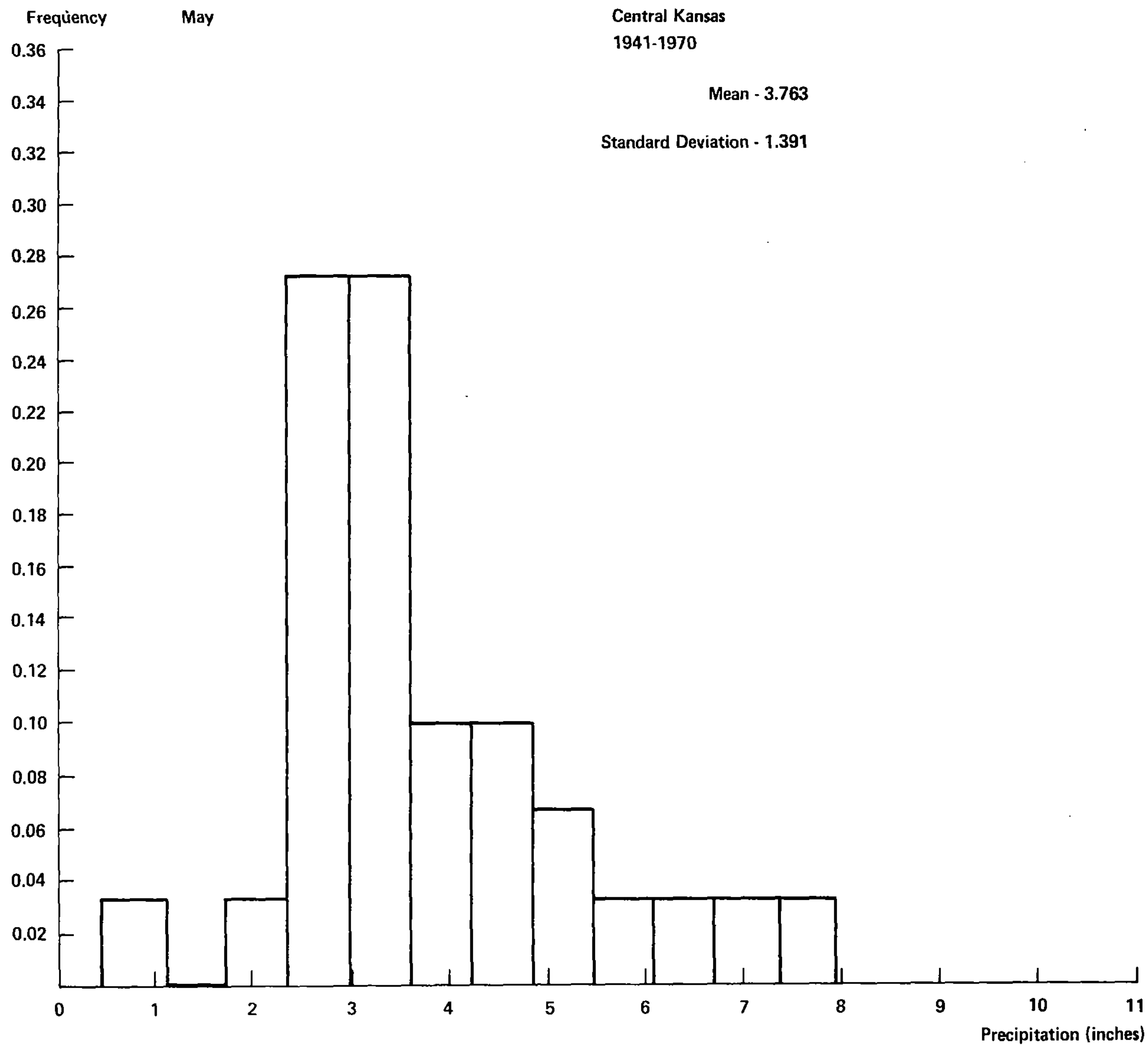
HISTOGRAMS FOR AVERAGE MONTHLY PRECIPITATION FOR THE CENTRAL CROP REPORTING DISTRICT, STATE OF KANSAS, 1941-1970


Frequency
0.467
January
Central Kansas
1941-1970
Mean - 0.621
Standard Deviation - 0.597
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

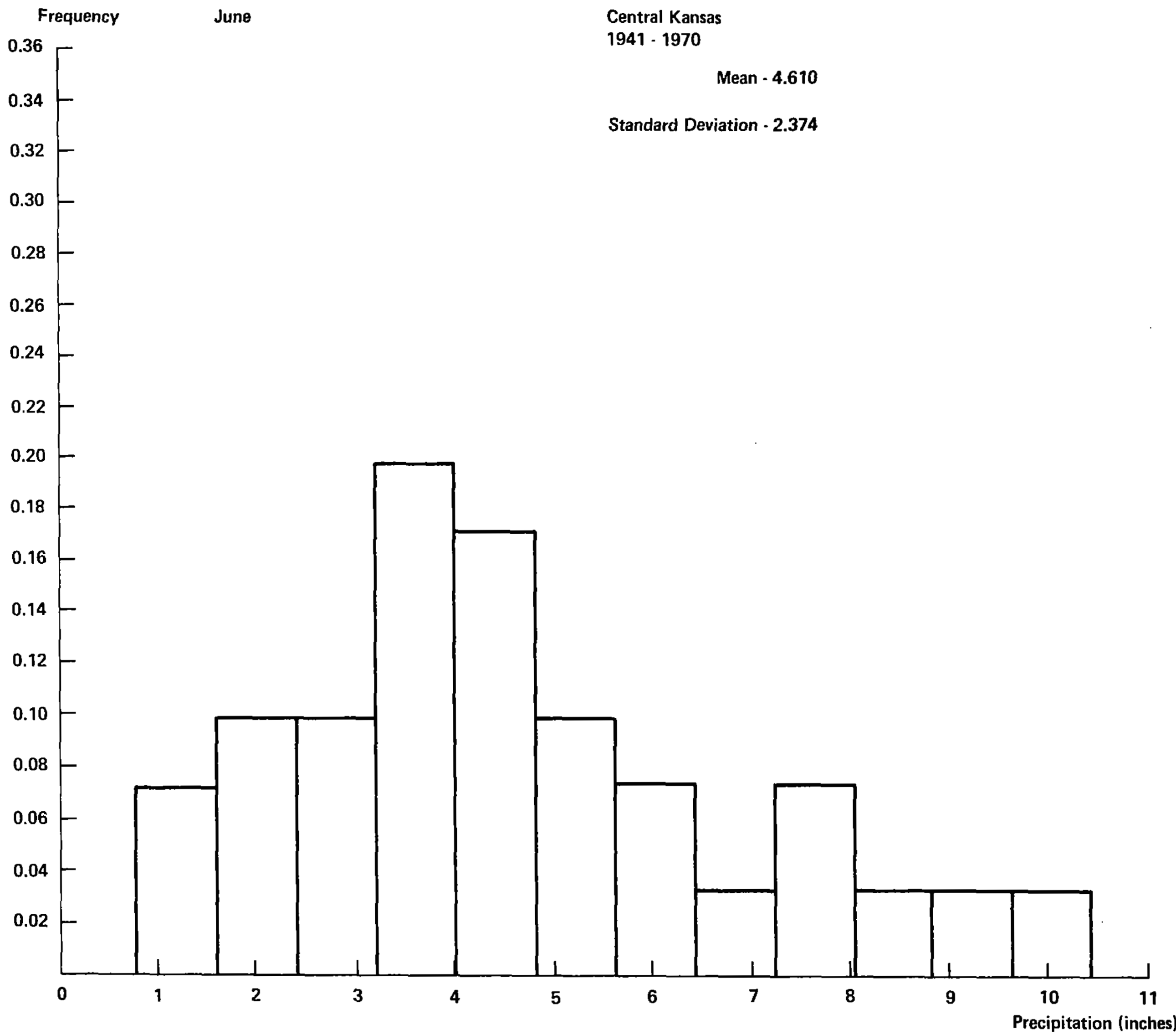

Frequency
February
Central Kansas
1941-1970
Mean - 0.87
Standard Deviation - 0.590
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

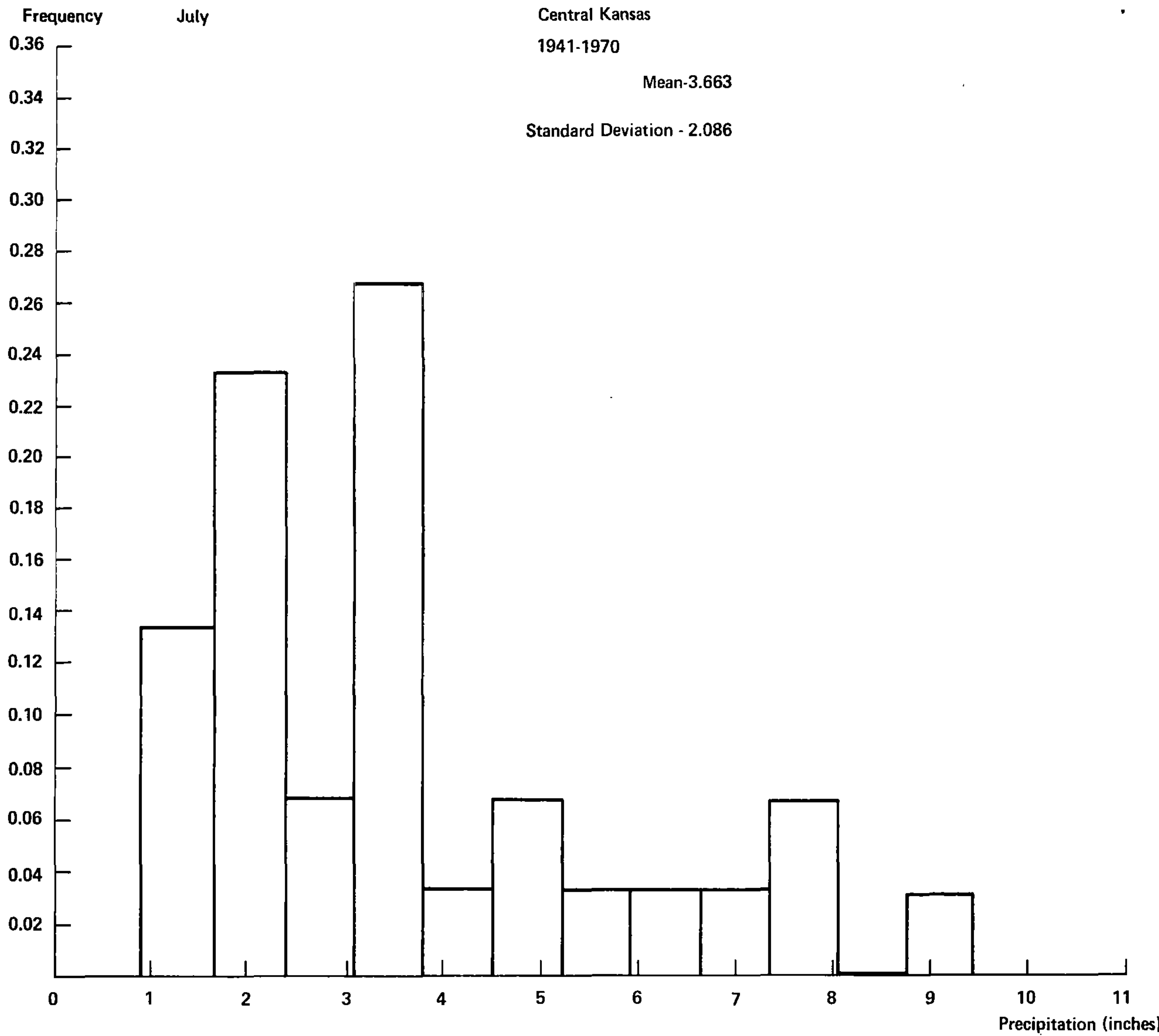

Frequency
March
Central Kansas
1941-1970
Mean - 1.529
Standard Deviation - 0.939
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

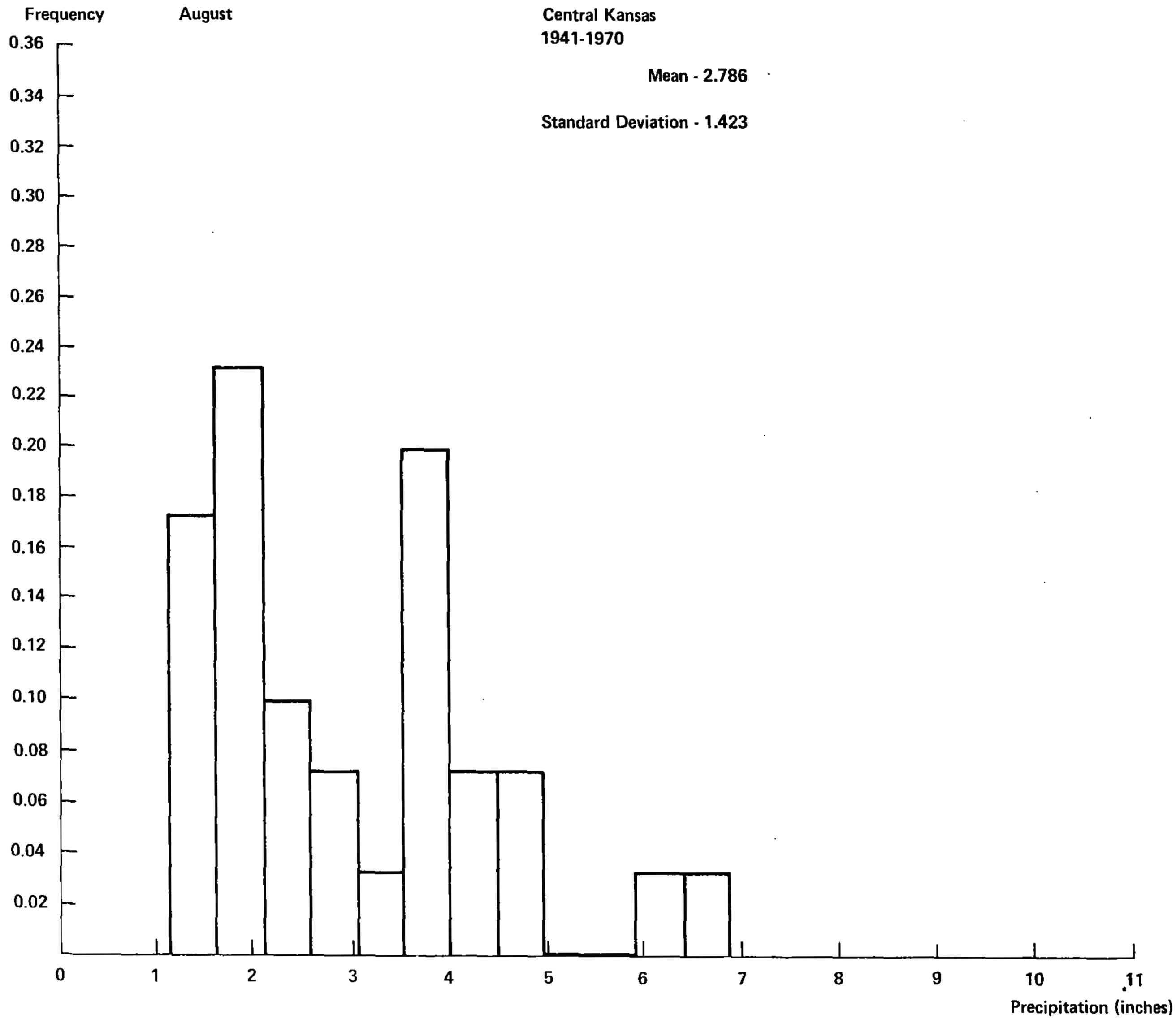

Frequency
April
Central Kansas
1941-1970
Mean - 2.492
Standard Deviation - 1.391
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

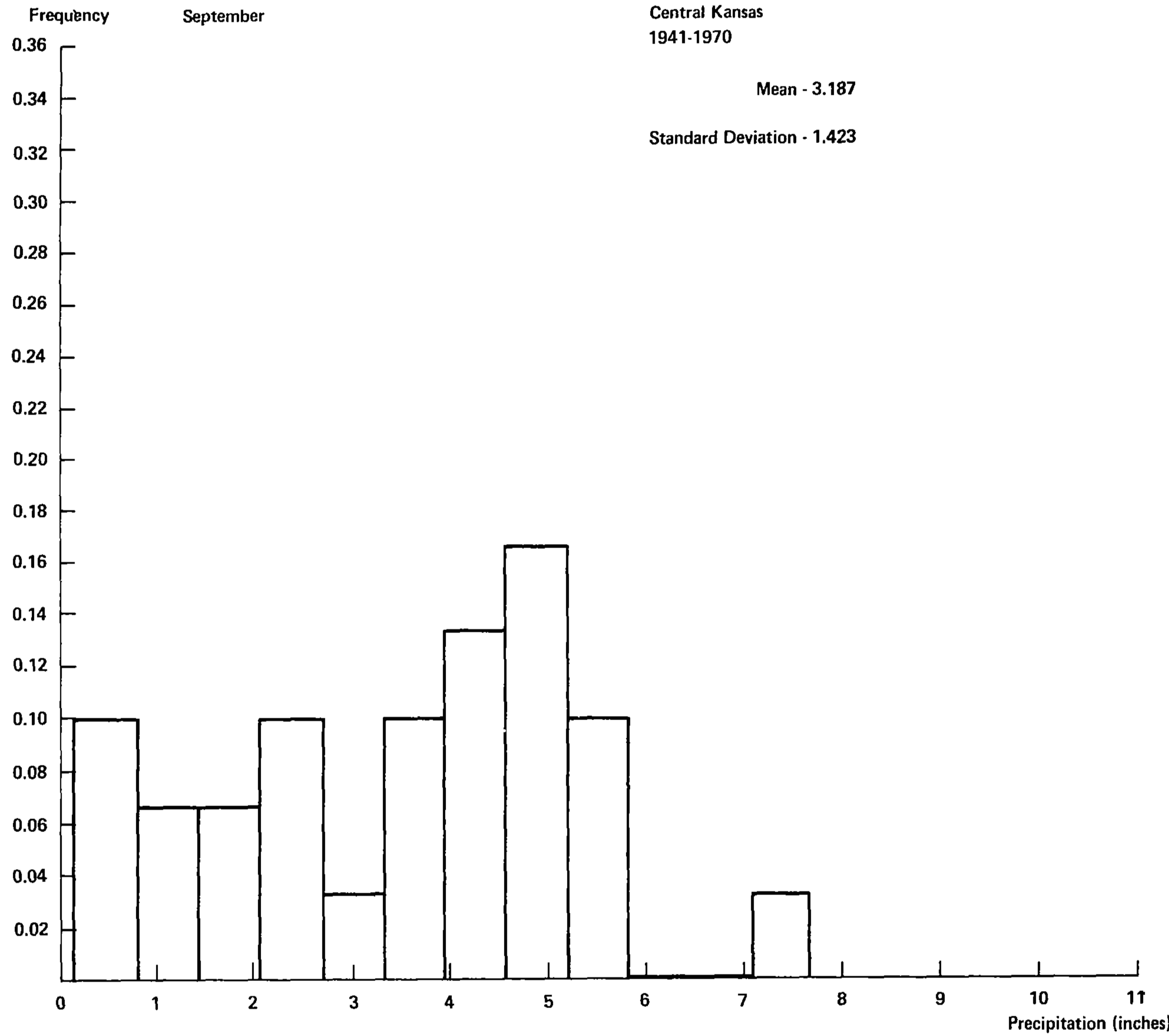


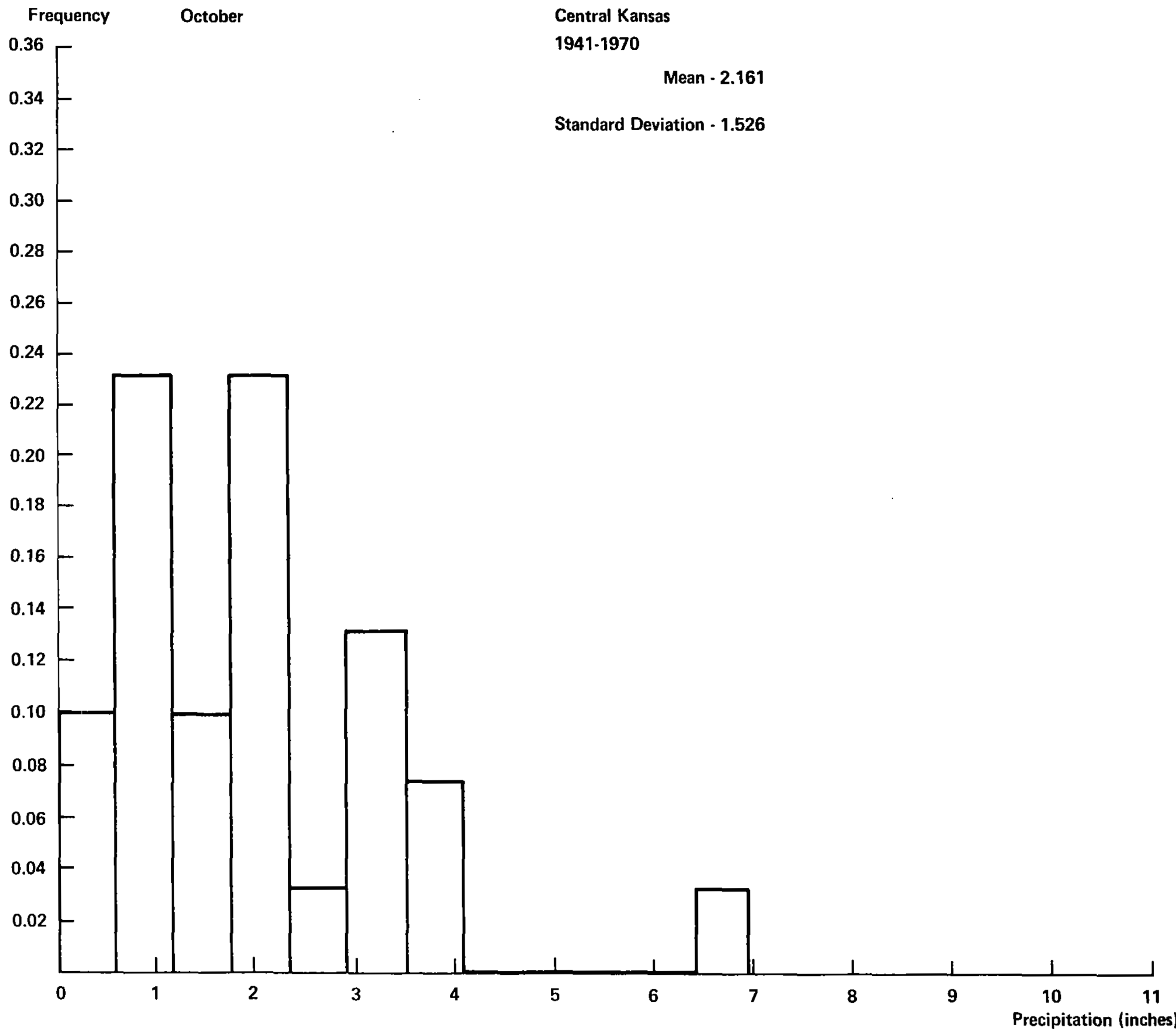
Frequency
May
Central Kansas
1941-1970
Mean - 3.763
Standard Deviation - 1.391
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

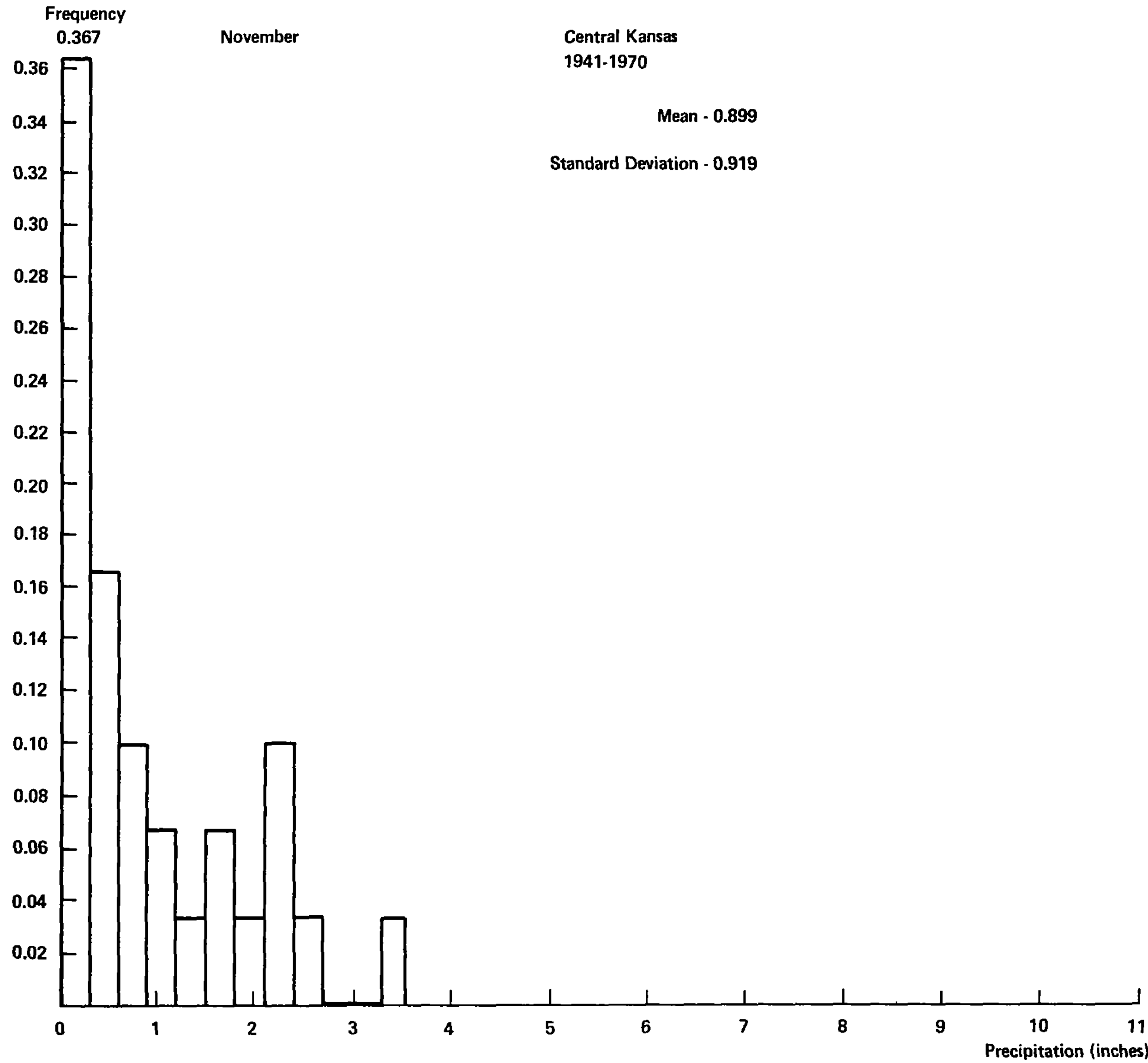

Frequency
June
Central Kansas
1941 - 1970
Mean - 4.610
Standard Deviation - 2.374
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

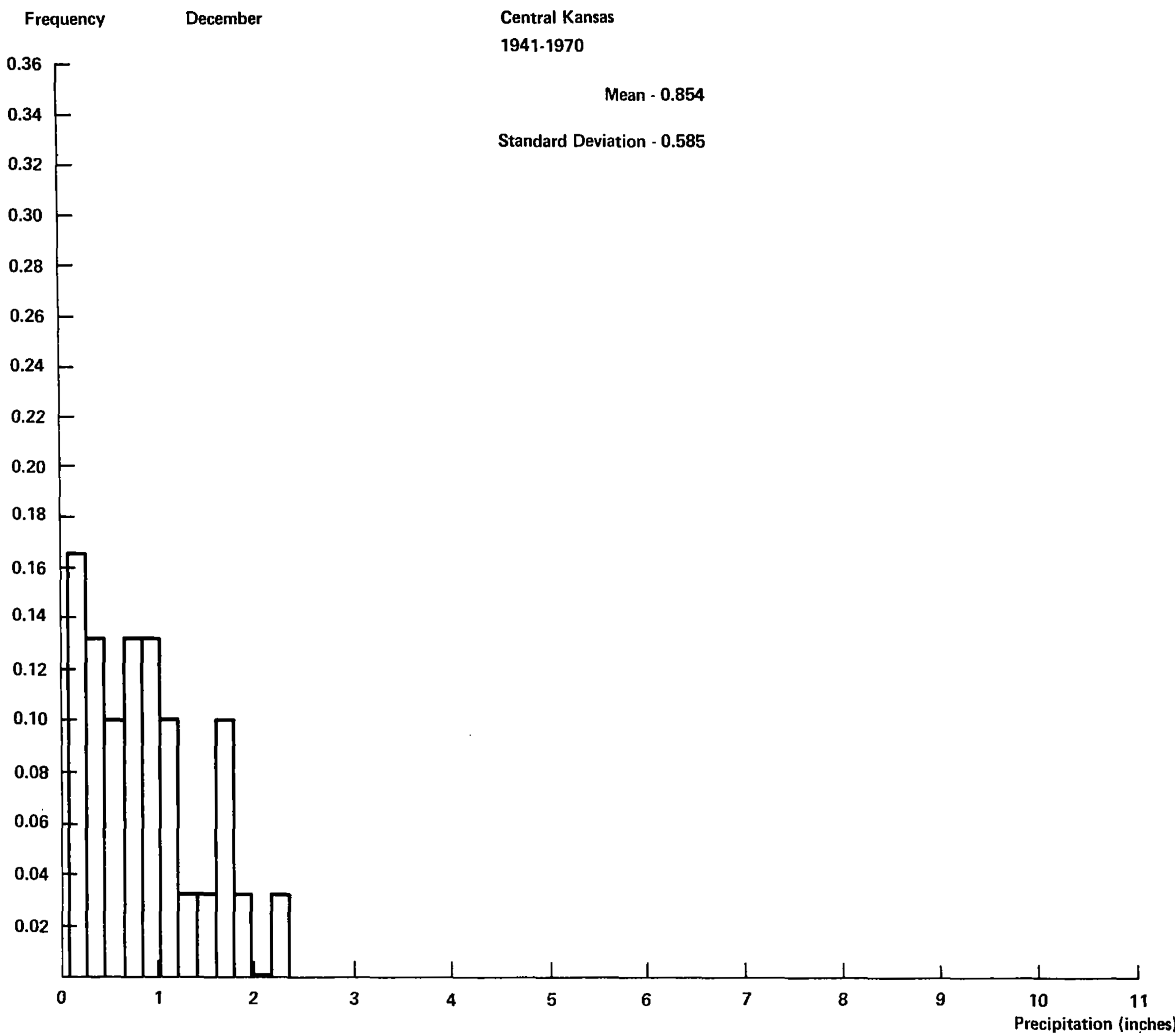

Frequency
July
Central Kansas
1941-1970
Mean-3.663
Standard Deviation - 2.086
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

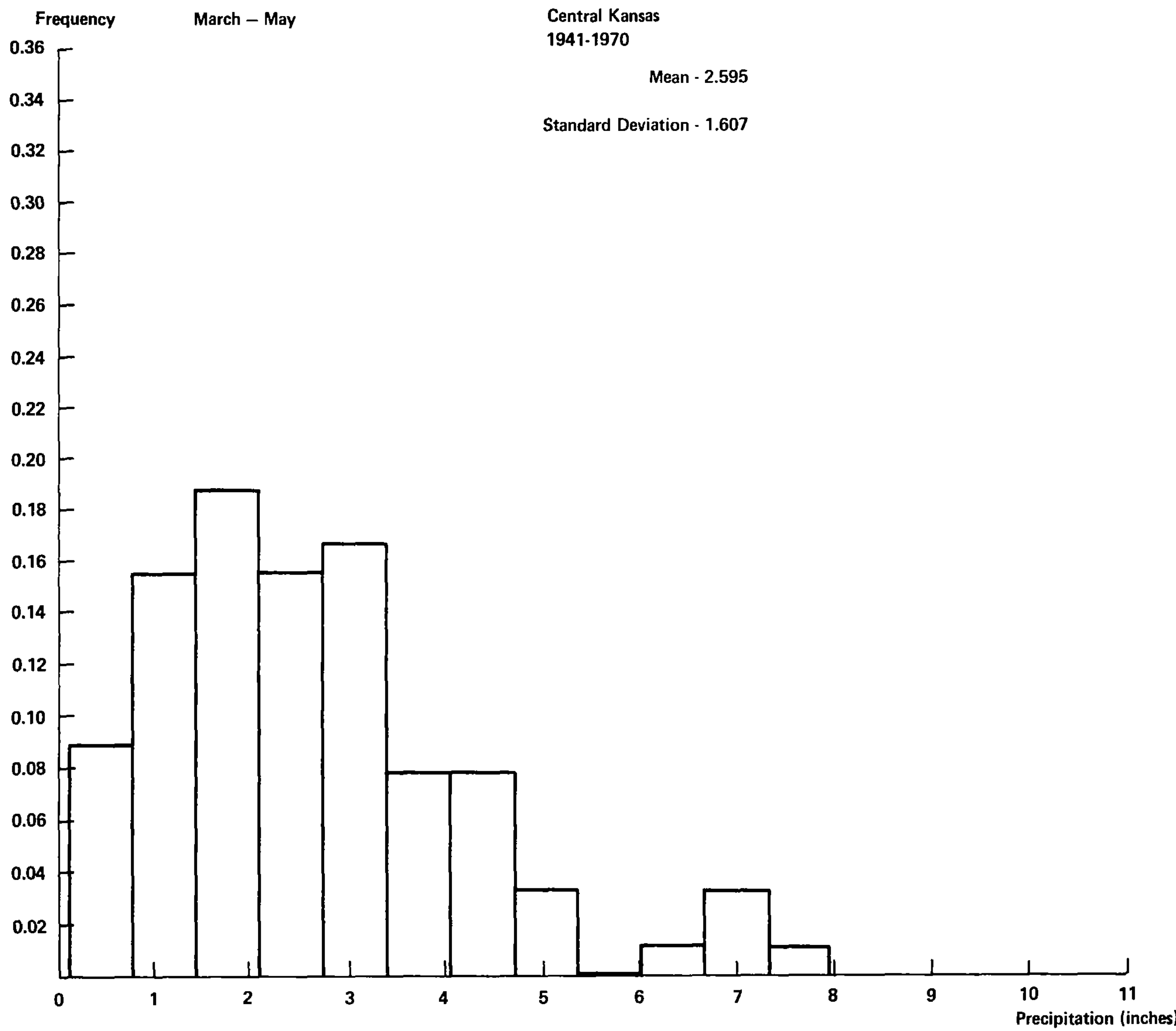

Frequency
August
Central Kansas
1941-1970
Mean - 2.786
Standard Deviation - 1.423
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

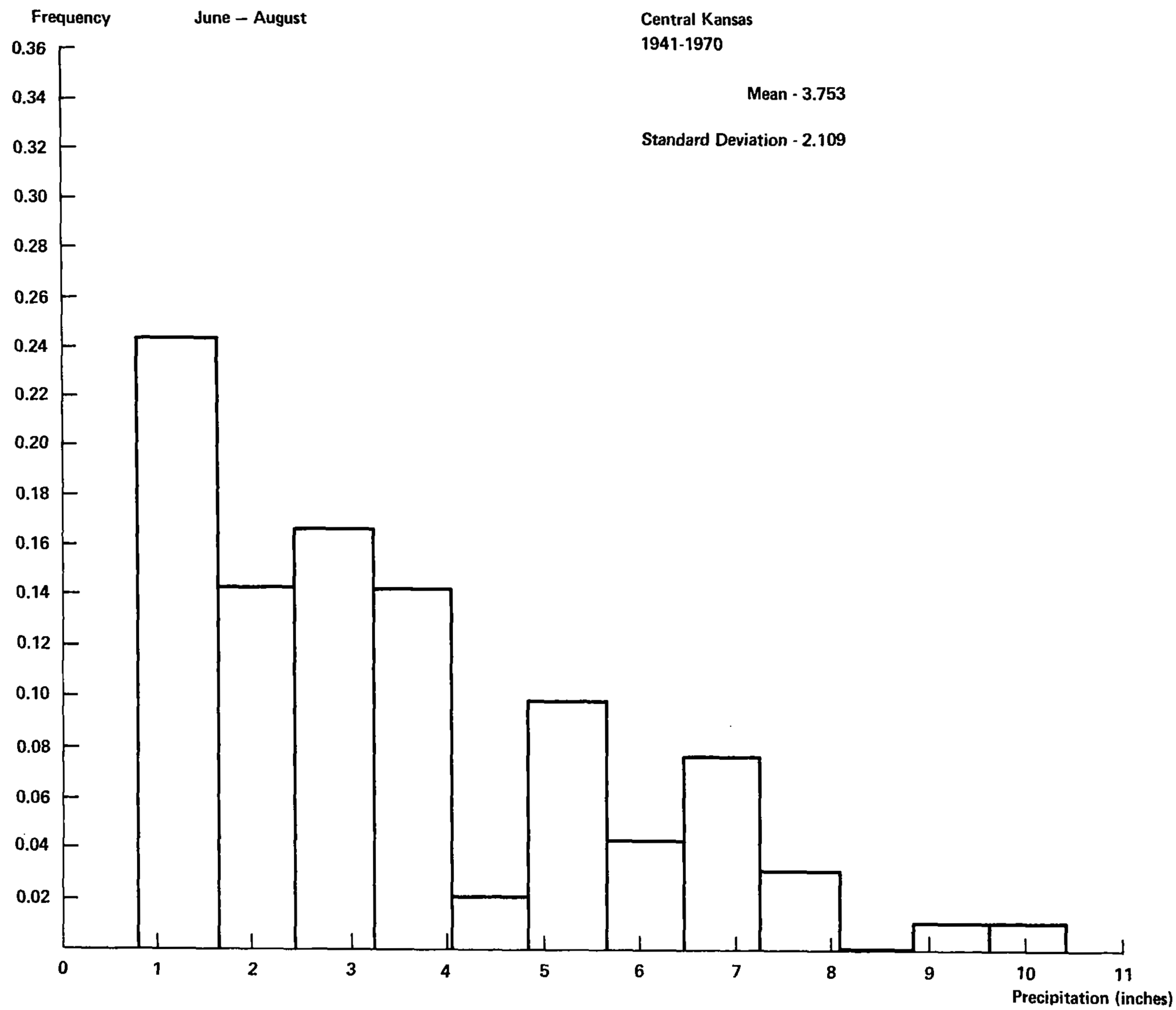

Frequency
September
Central Kansas
1941-1970
Mean - 3.187
Standard Deviation - 1.423
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)


Frequency
October
Central Kansas
1941-1970
Mean - 2.161
Standard Deviation - 1.526
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

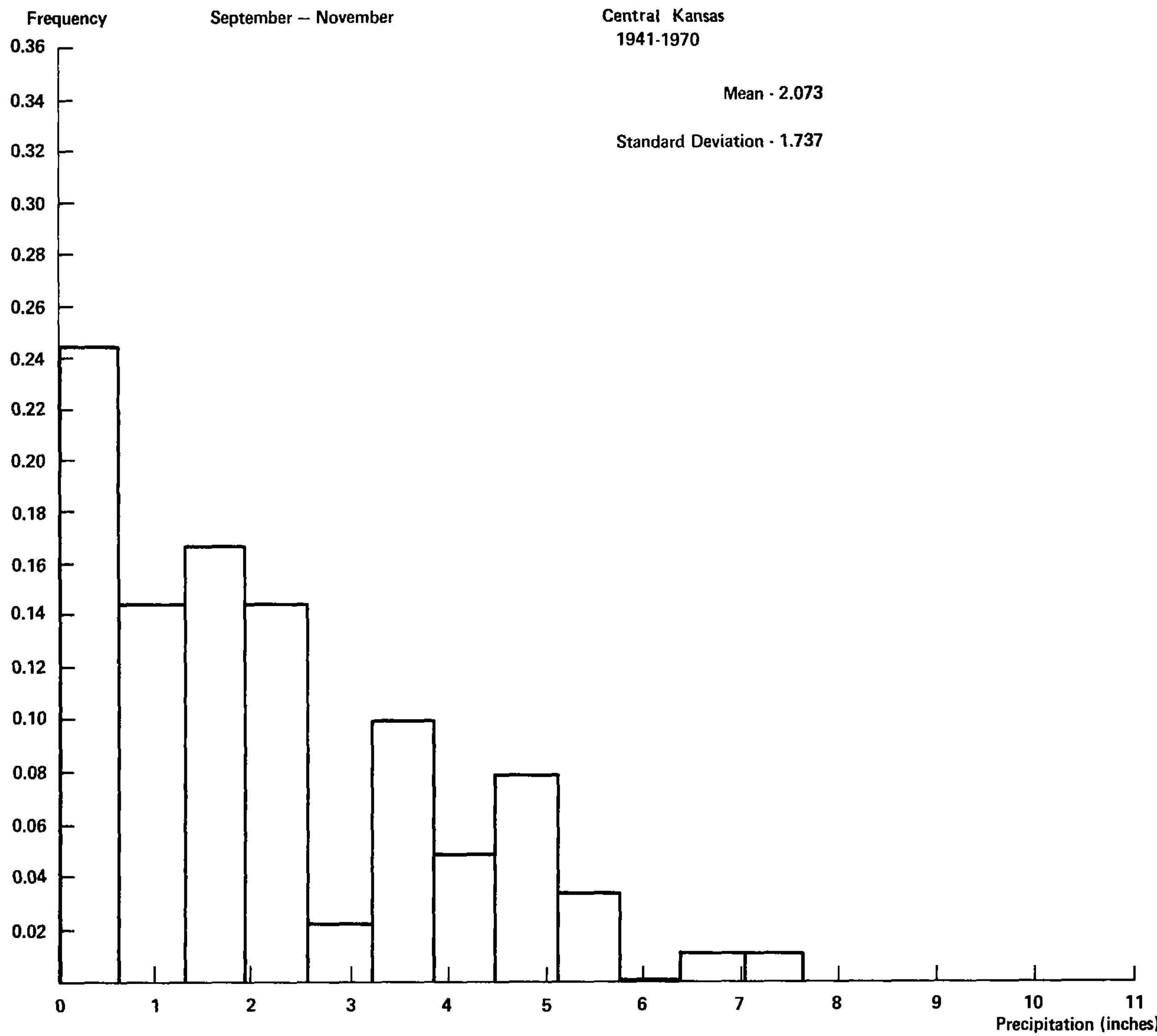

Frequency
0.367
November
Central Kansas
1941-1970
Mean - 0.899
Standard Deviation - 0.919
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

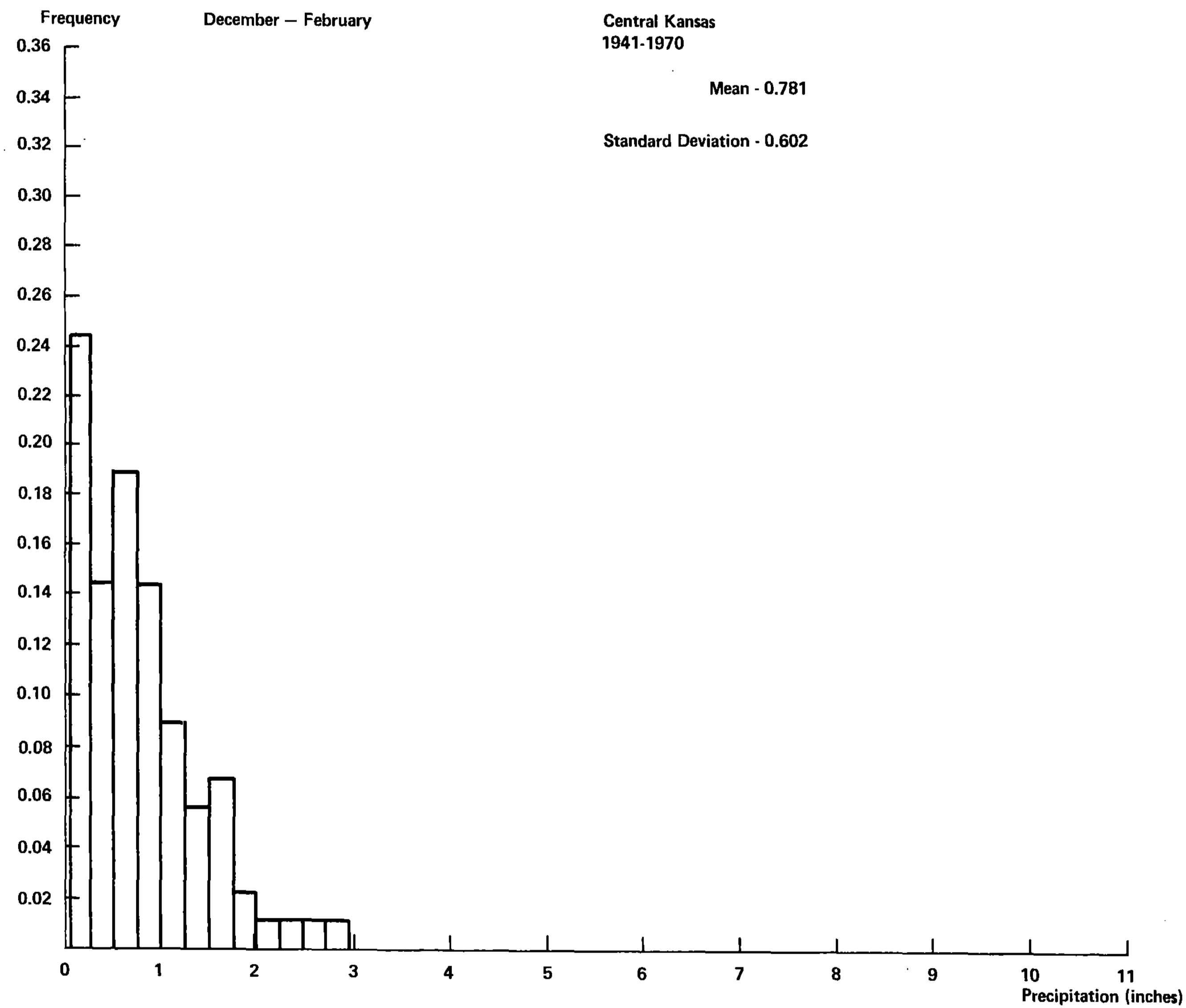

Frequency
December
Central Kansas
1941-1970
Mean - 0.854
Standard Deviation - 0.585
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)


Frequency
March – May
Central Kansas
1941-1970
Mean - 2.595
Standard Deviation - 1.607
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)



Frequency
June – August
Central Kansas
1941-1970
Mean - 3.753
Standard Deviation - 2.109
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0 1 2 3 4 5 6 7 8 9 10 11
Precipitation (inches)


Frequency
September – November
Central Kansas
1941-1970
Mean - 2.073
Standard Deviation - 1.737
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)


Frequency
December — February
Central Kansas
1941-1970
Mean - 0.781
Standard Deviation - 0.602
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
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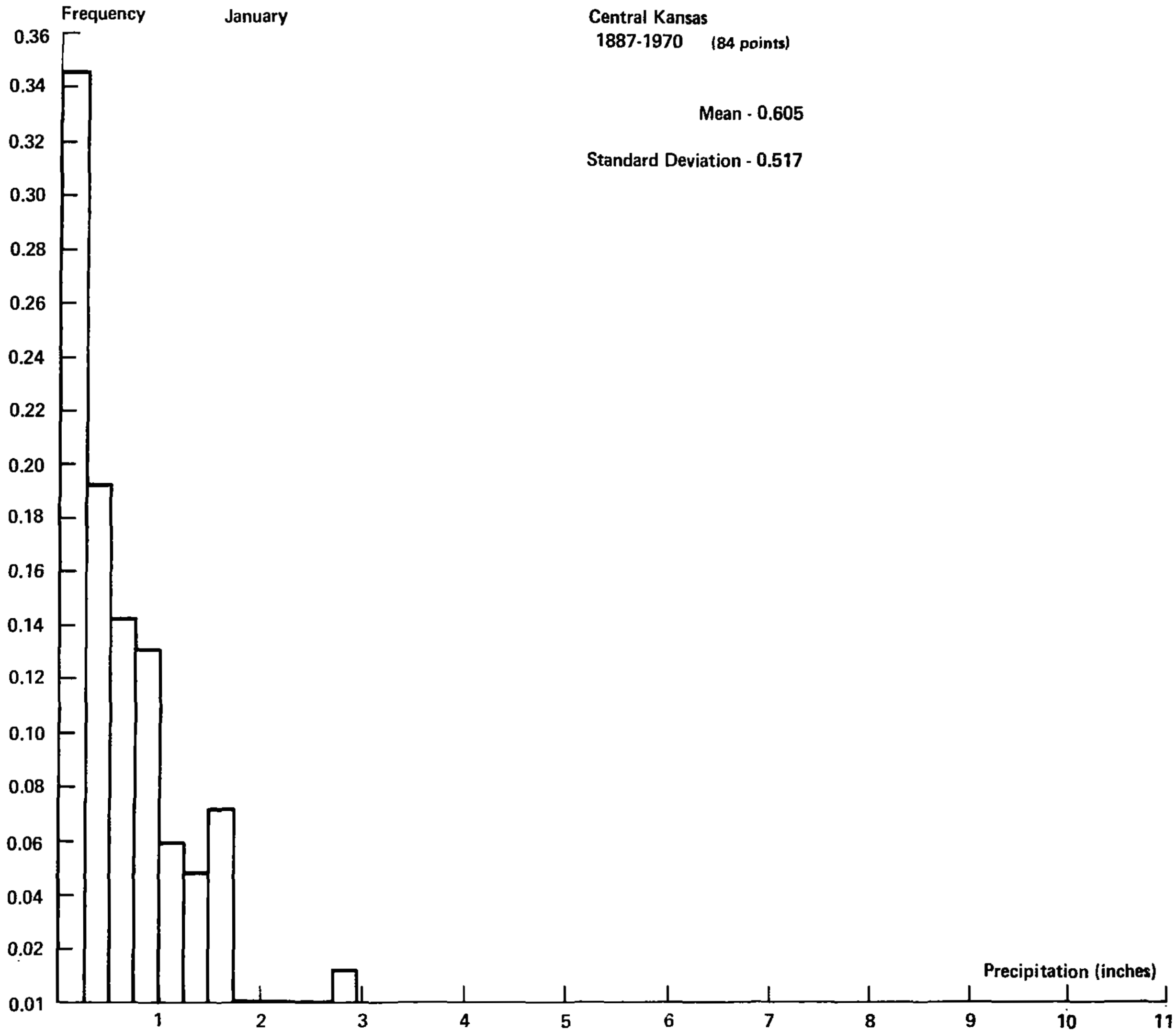
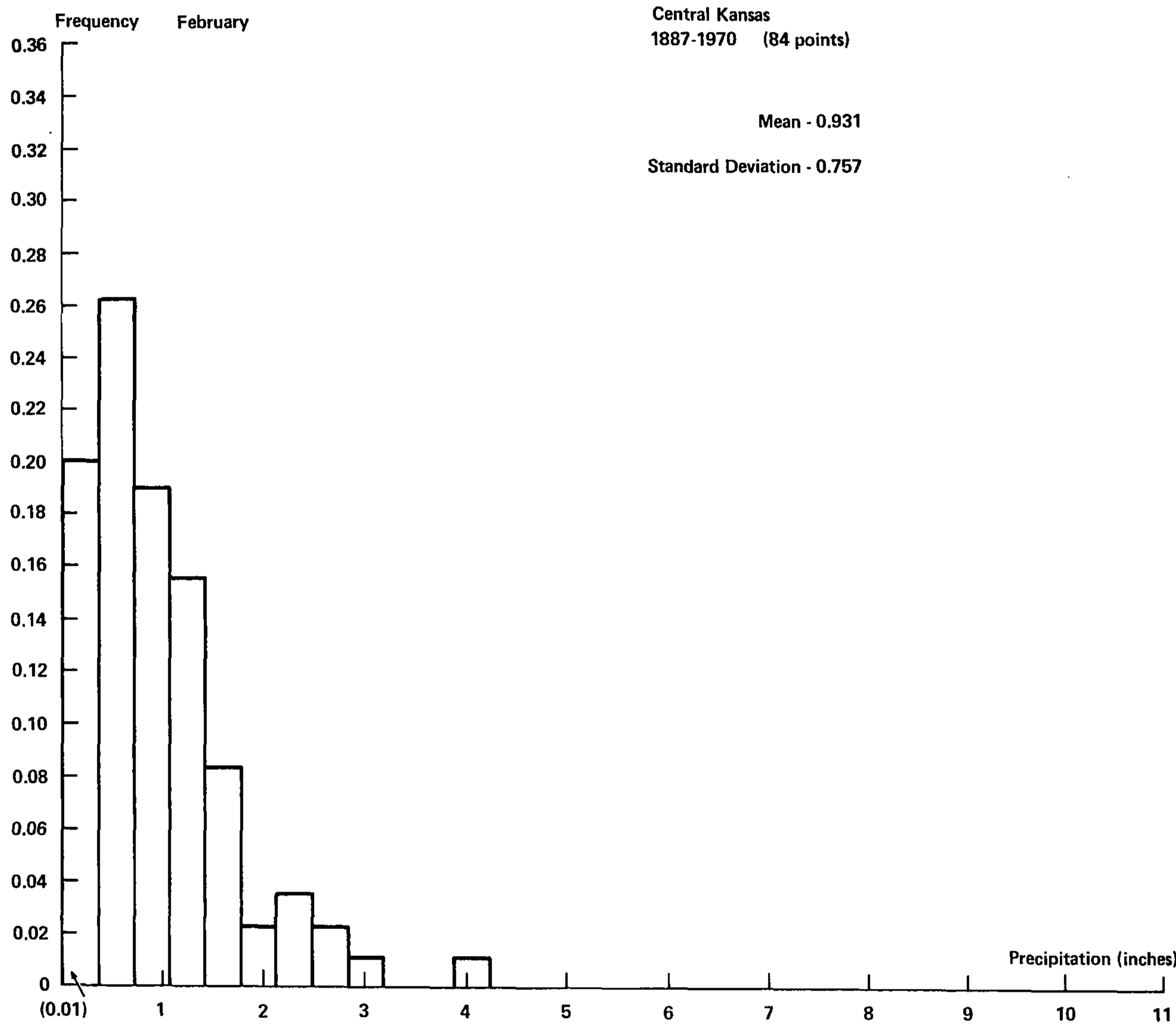
5
6
7
8
9
10
11
Precipitation (inches)

APPENDIX B

HISTOGRAMS FOR AVERAGE MONTHLY PRECIPITATION FOR THE CENTRAL CROP REPORTING DISTRICT, STATE OF KANSAS, 1887-1970


Frequency
January
Central Kansas
1887-1970 (84 points)
Mean - 0.605
Standard Deviation - 0.517
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0.01
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)



Frequency
February
Central Kansas
1887-1970 (84 points)
Mean - 0.931
Standard Deviation - 0.757
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.01)
1
2
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5
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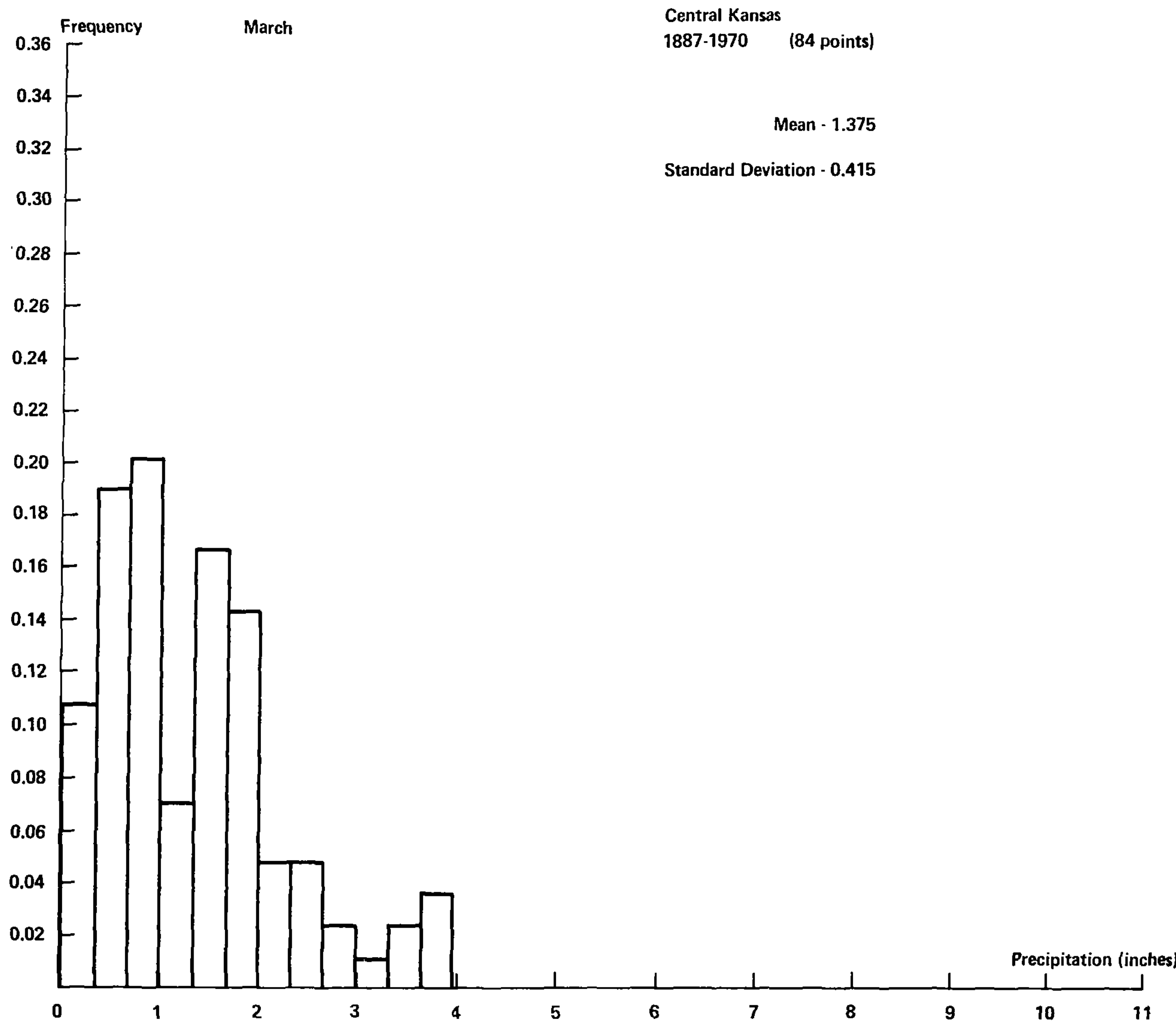
7
8
9
10
11
Precipitation (inches)


Frequency
March
Central Kansas
1887-1970 (84 points)
Mean - 1.375
Standard Deviation - 0.415
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Precipitation (inches)
0
1
2
3
4
5
6
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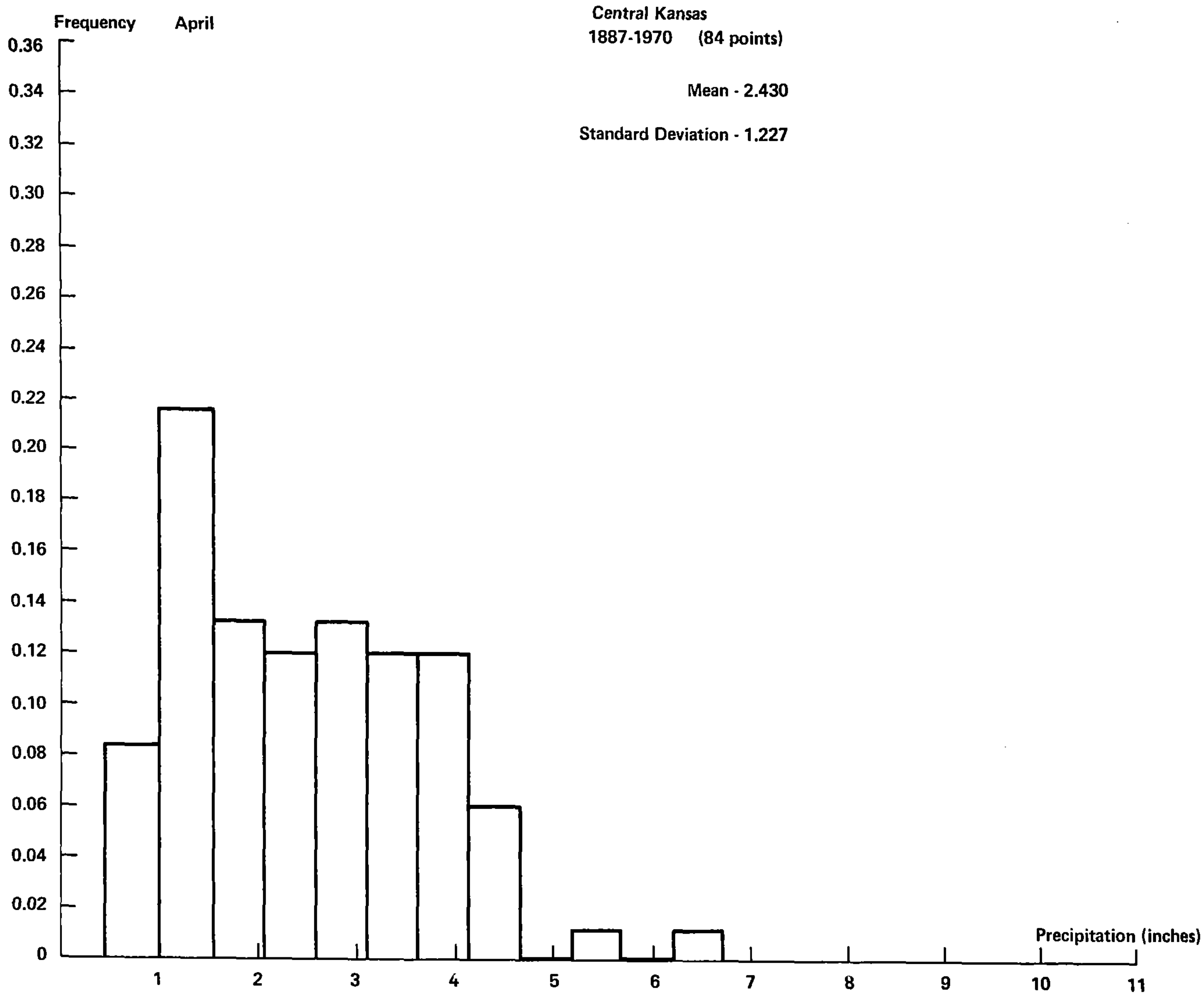
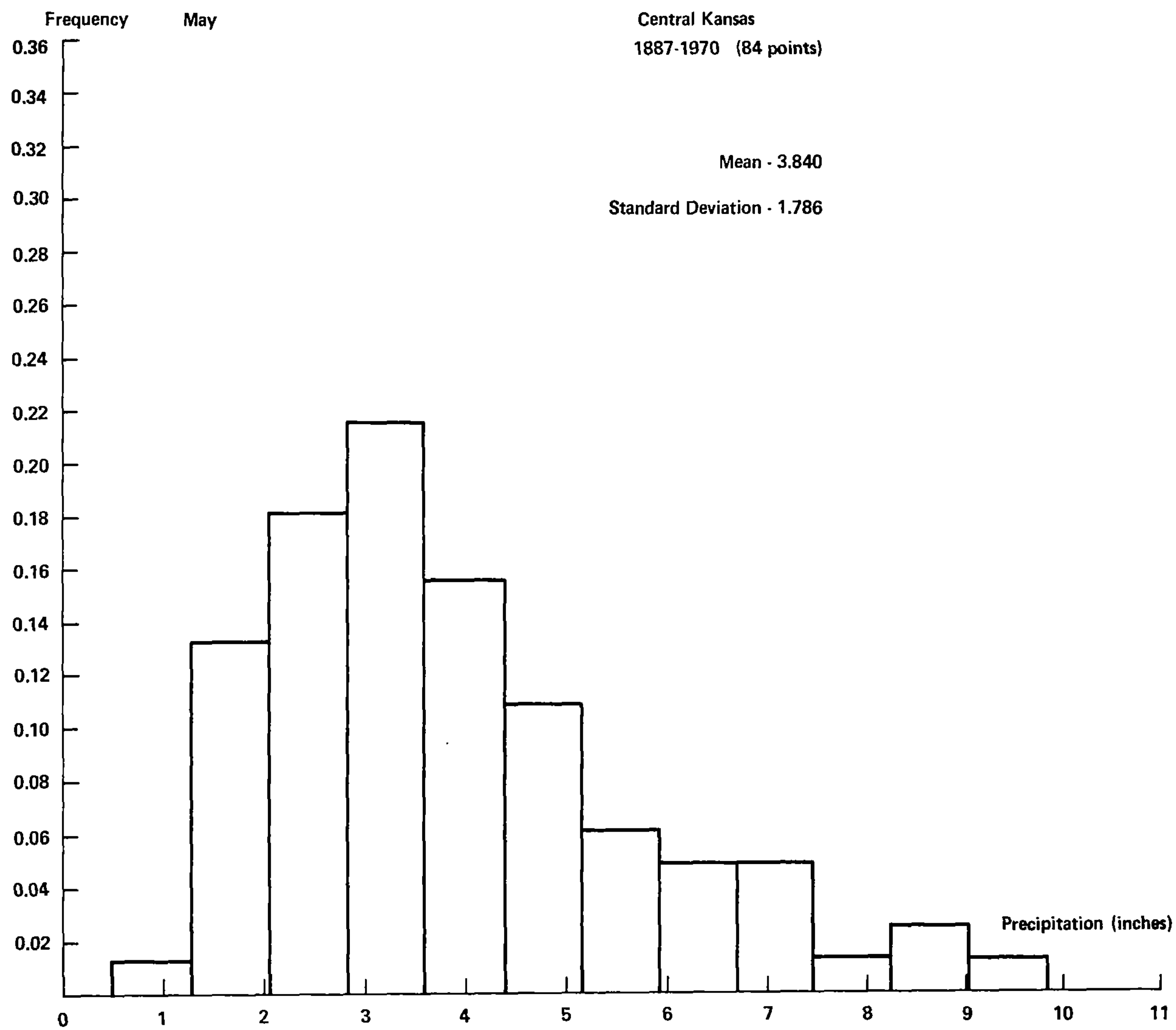
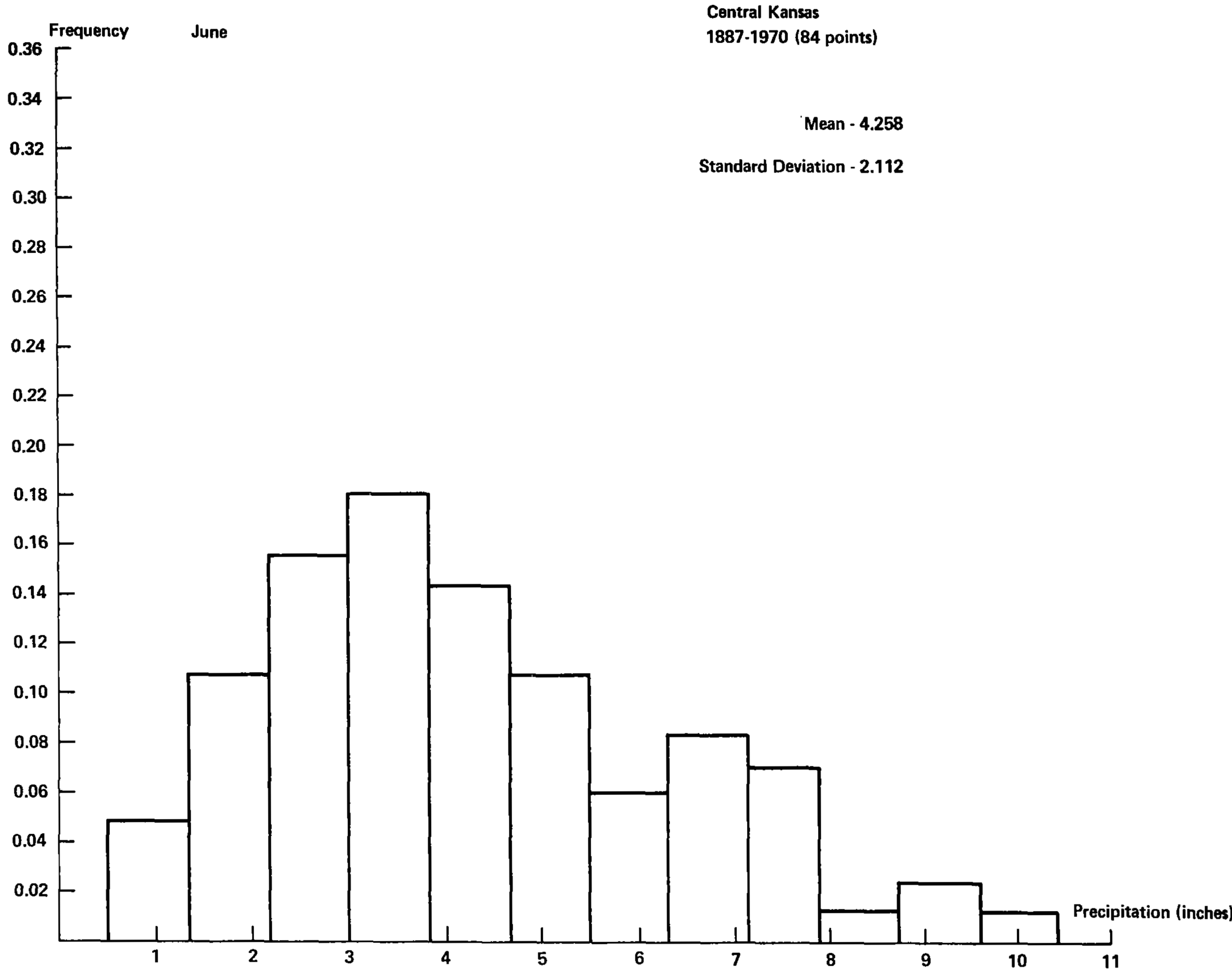
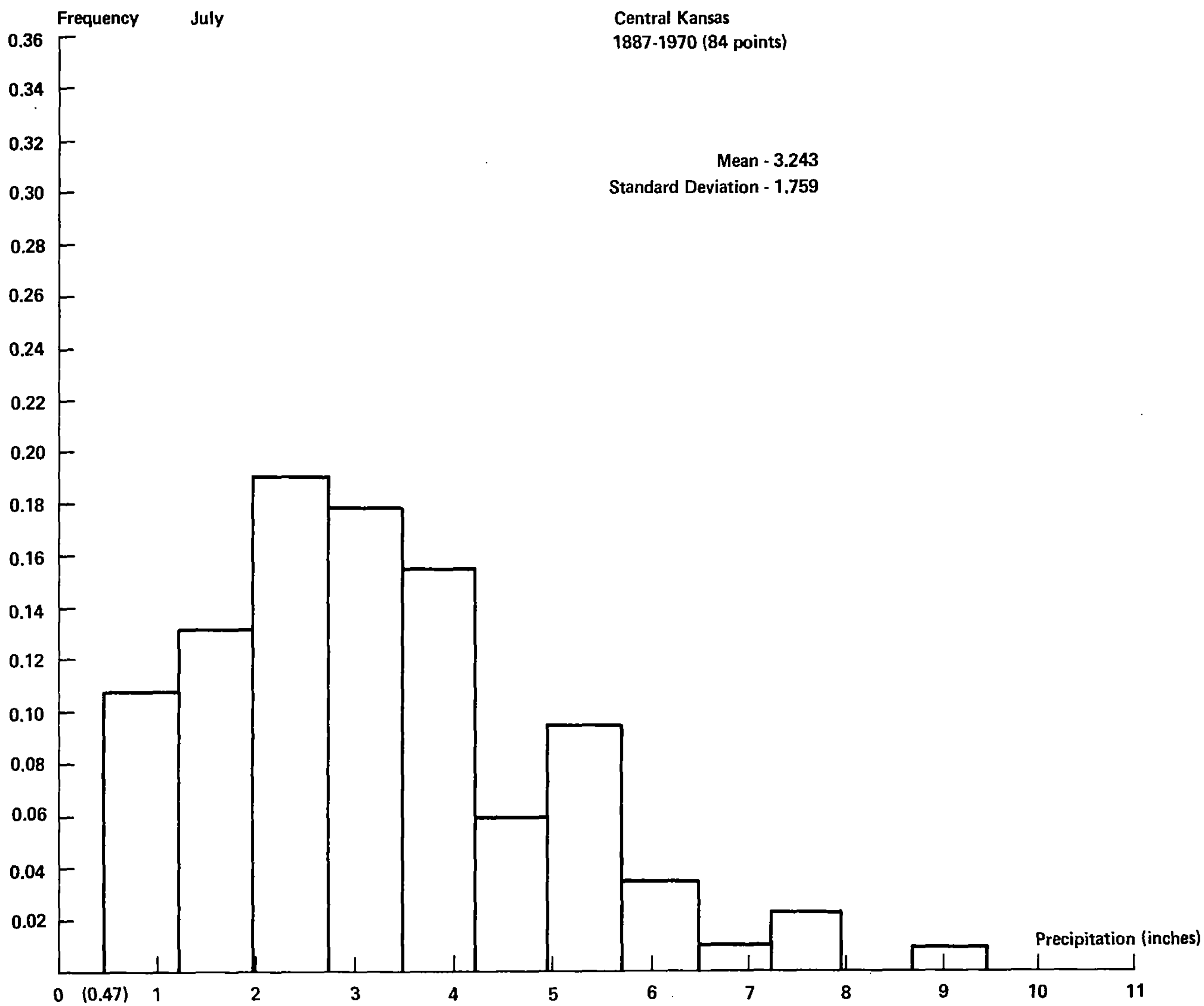
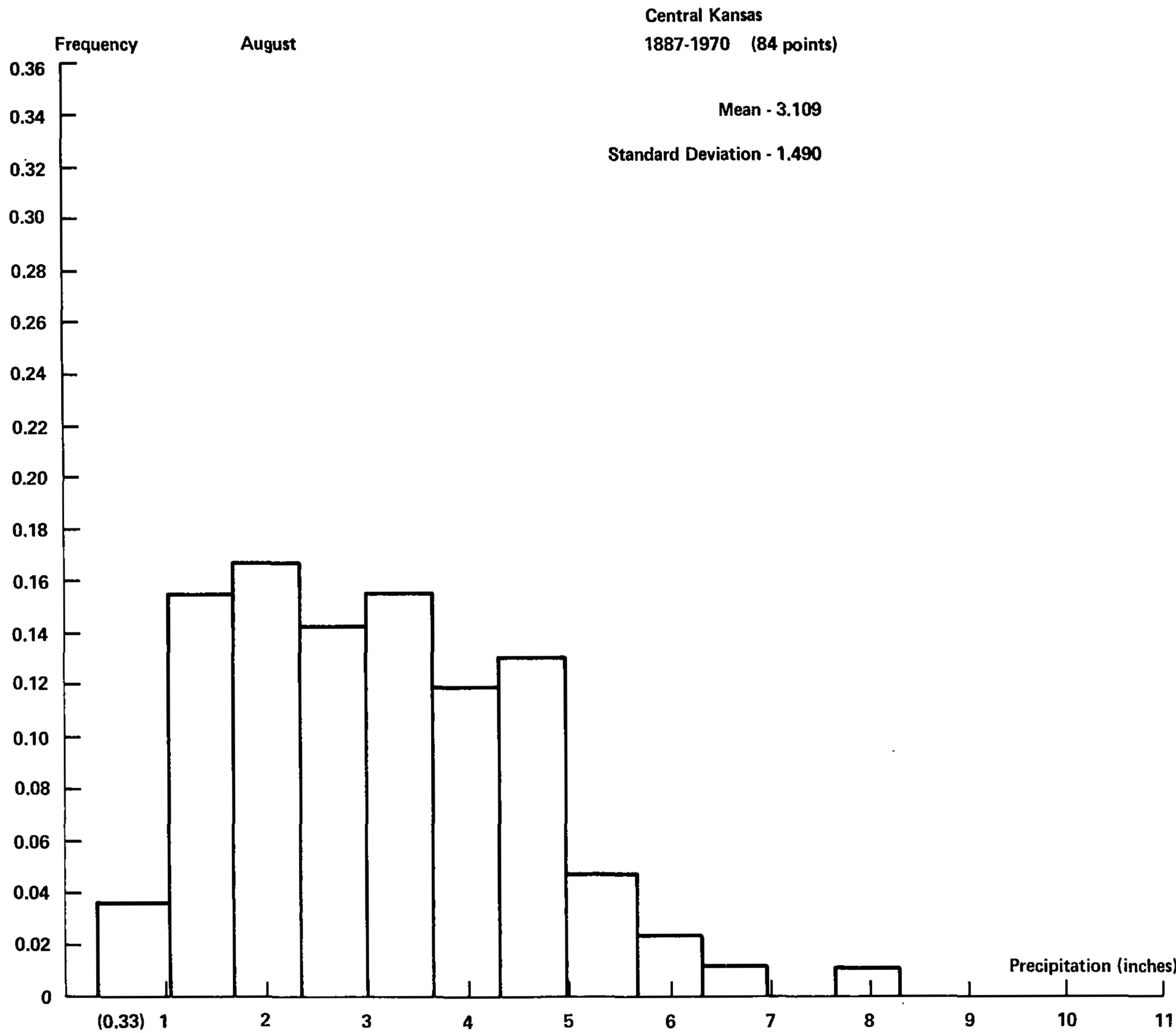
8
9
10
11

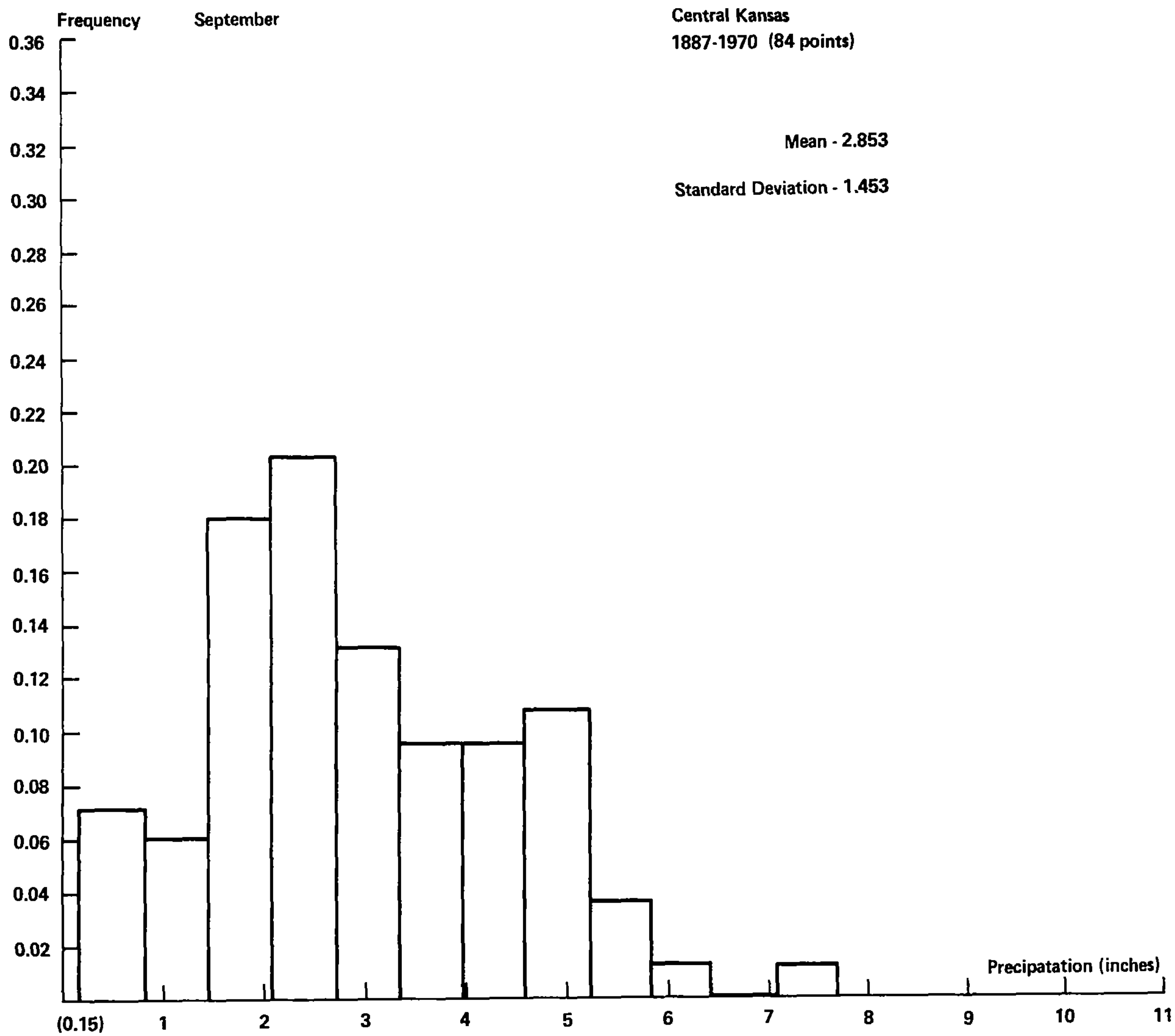

Frequency
April
Central Kansas
1887-1970 (84 points)
Mean - 2.430
Standard Deviation - 1.227
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

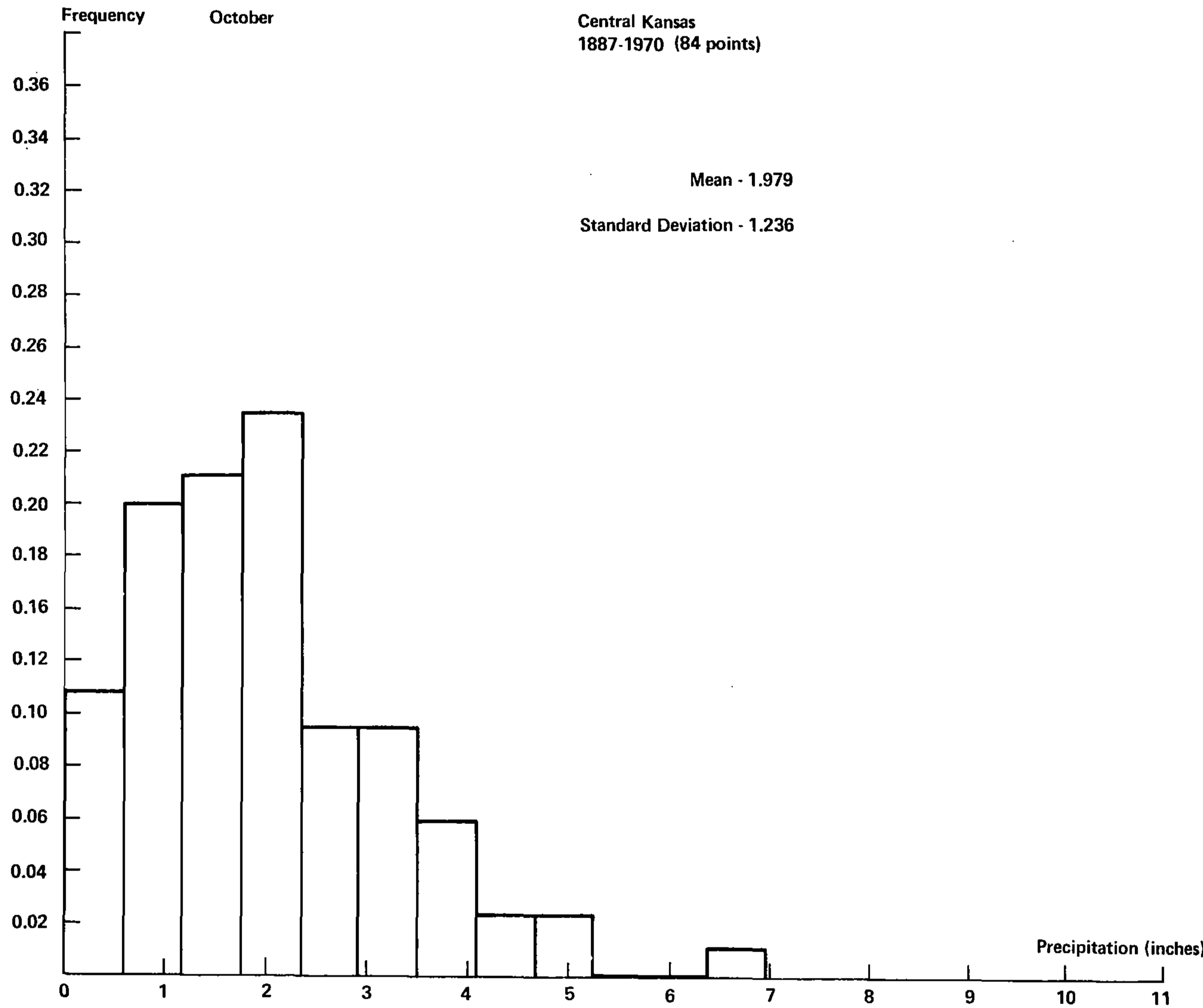

Frequency
May
Central Kansas
1887-1970 (84 points)
Mean - 3.840
Standard Deviation - 1.786
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Precipitation (inches)
0
1
2
3
4
5
6
7
8
9
10
11

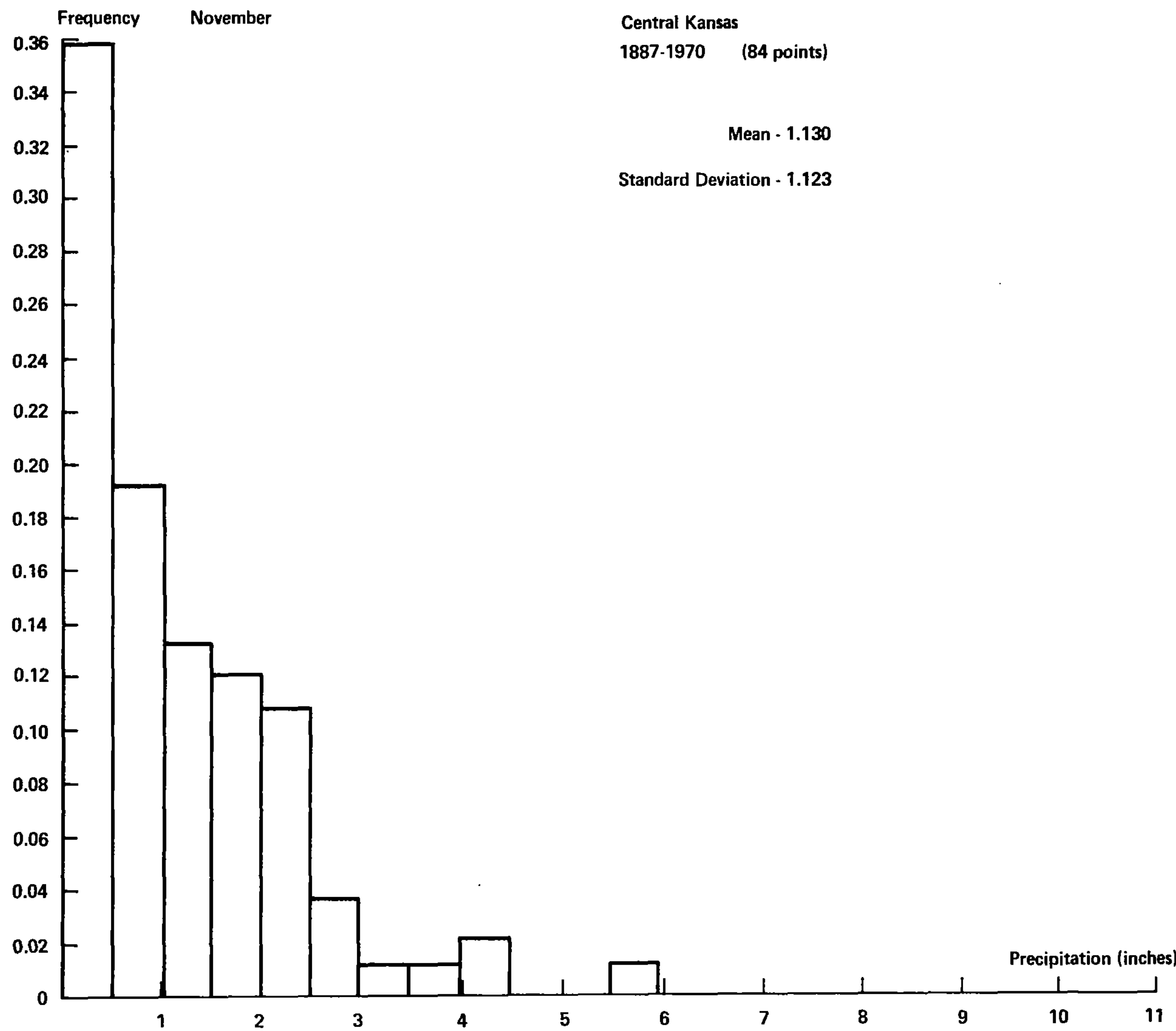

Frequency
June
Central Kansas
1887-1970 (84 points)
Mean - 4.258
Standard Deviation - 2.112
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Precipitation (inches)
1
2
3
4
5
6
7
8
9
10
11

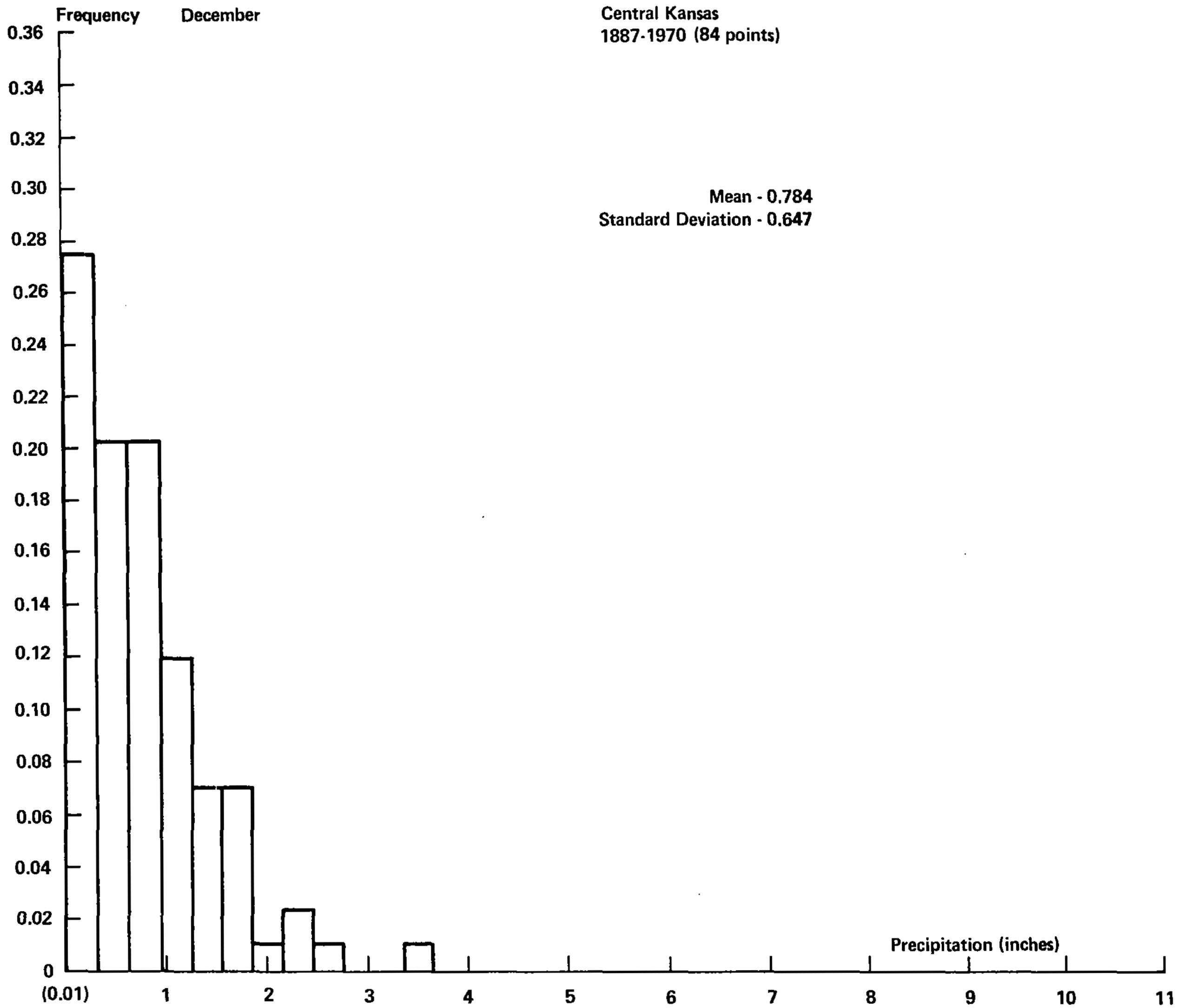

Frequency
July
Central Kansas
1887-1970 (84 points)
Mean - 3.243
Standard Deviation - 1.759
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Precipitation (inches)
0
(0.47)
1
2
3
4
5
6
7
8
9
10
11


Frequency
August
Central Kansas
1887-1970 (84 points)
Mean - 3.109
Standard Deviation - 1.490
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
Precipitation (inches)
(0.33) 1
2
3
4
5
6
7
8
9
10
11


Frequency
September
Central Kansas
1887-1970 (84 points)
Mean - 2.853
Standard Deviation - 1.453
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
Precipatation (inches)
(0.15)
1
2
3
4
5
6
7
8
9
10
11


Frequency
October
Central Kansas
1887-1970 (84 points)
Mean - 1.979
Standard Deviation - 1.236
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

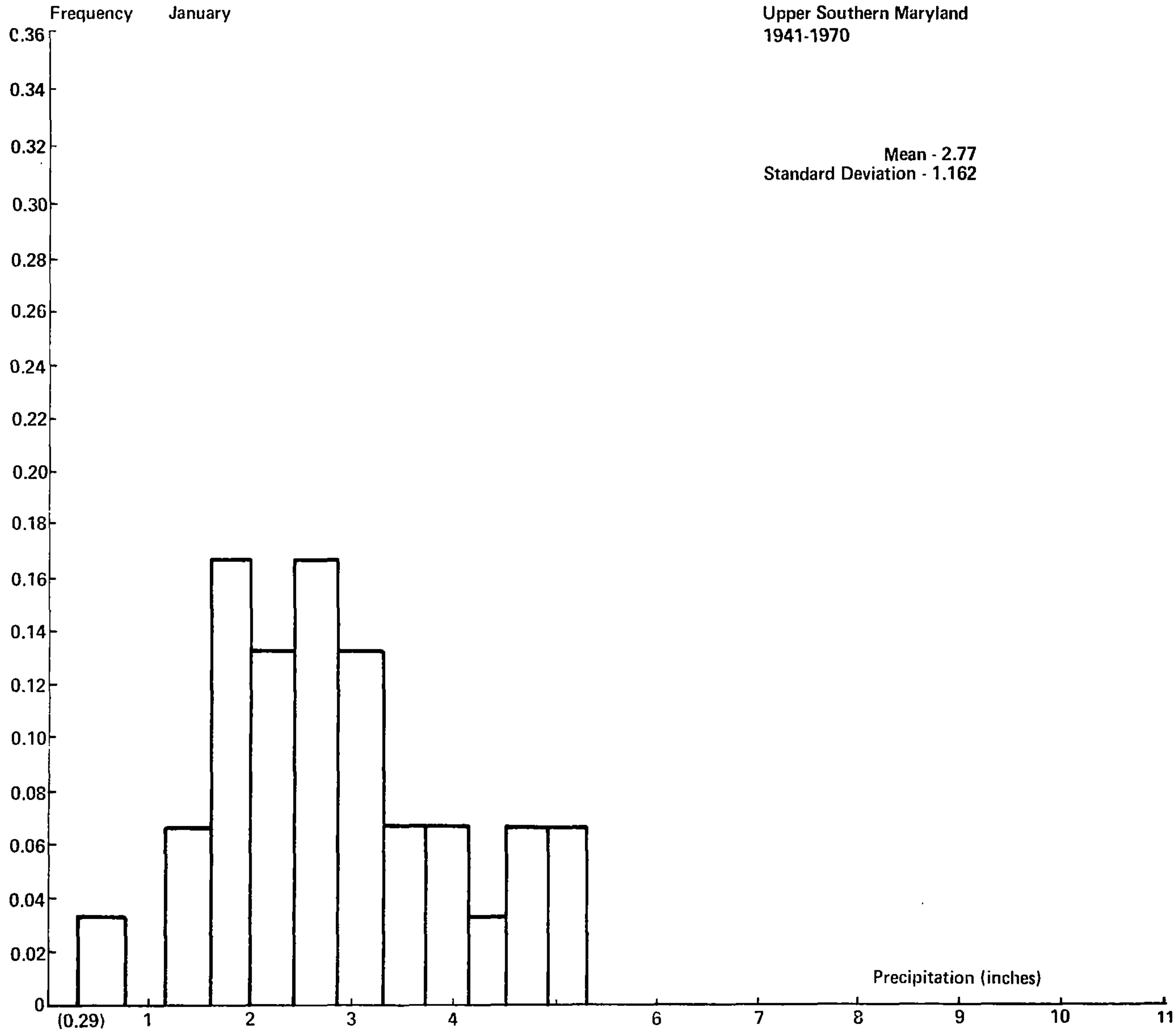

Frequency
November
Central Kansas
1887-1970 (84 points)
Mean - 1.130
Standard Deviation - 1.123
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

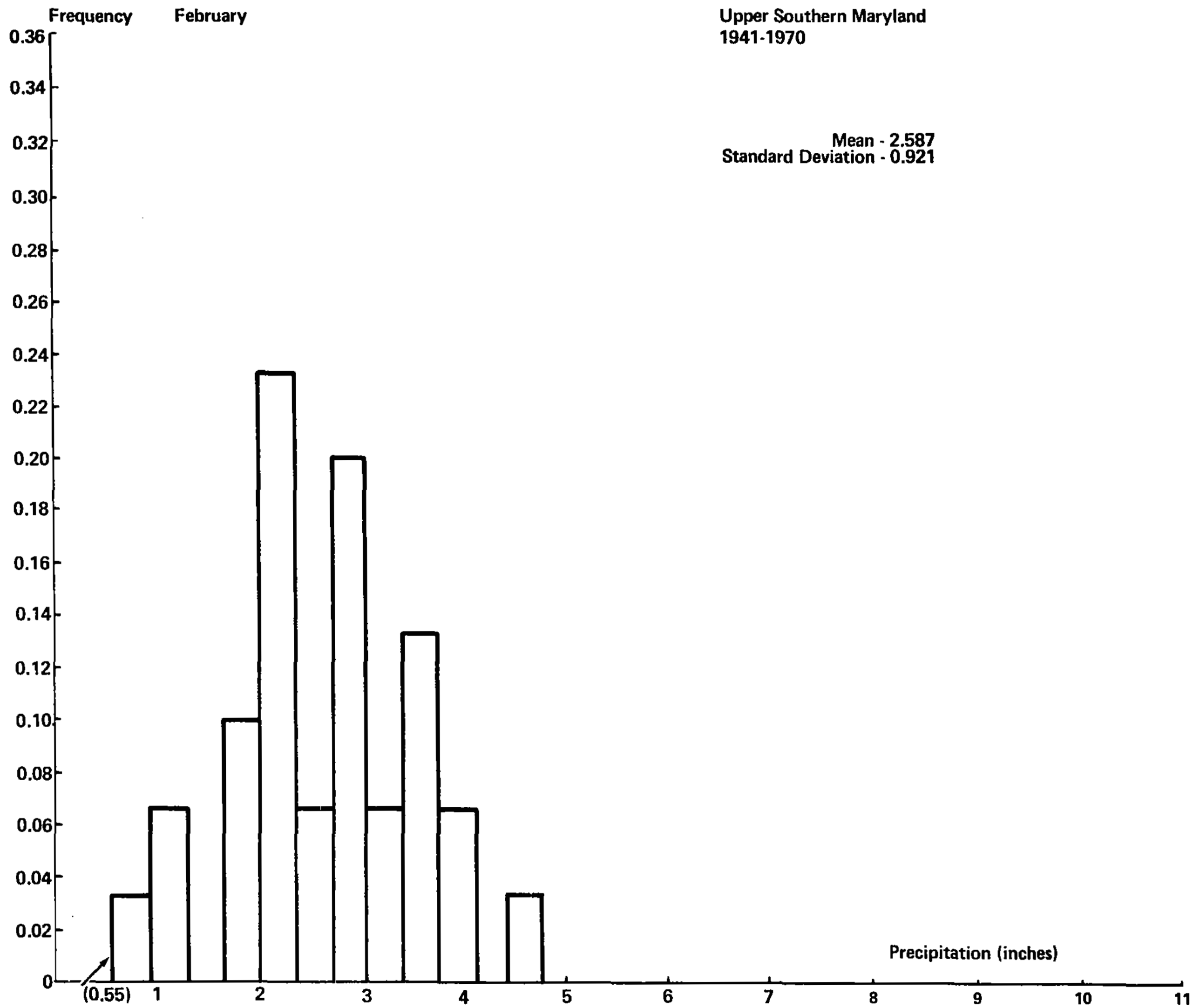

Frequency
December
Central Kansas
1887-1970 (84 points)
Mean - 0.784
Standard Deviation - 0.647
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.01)
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

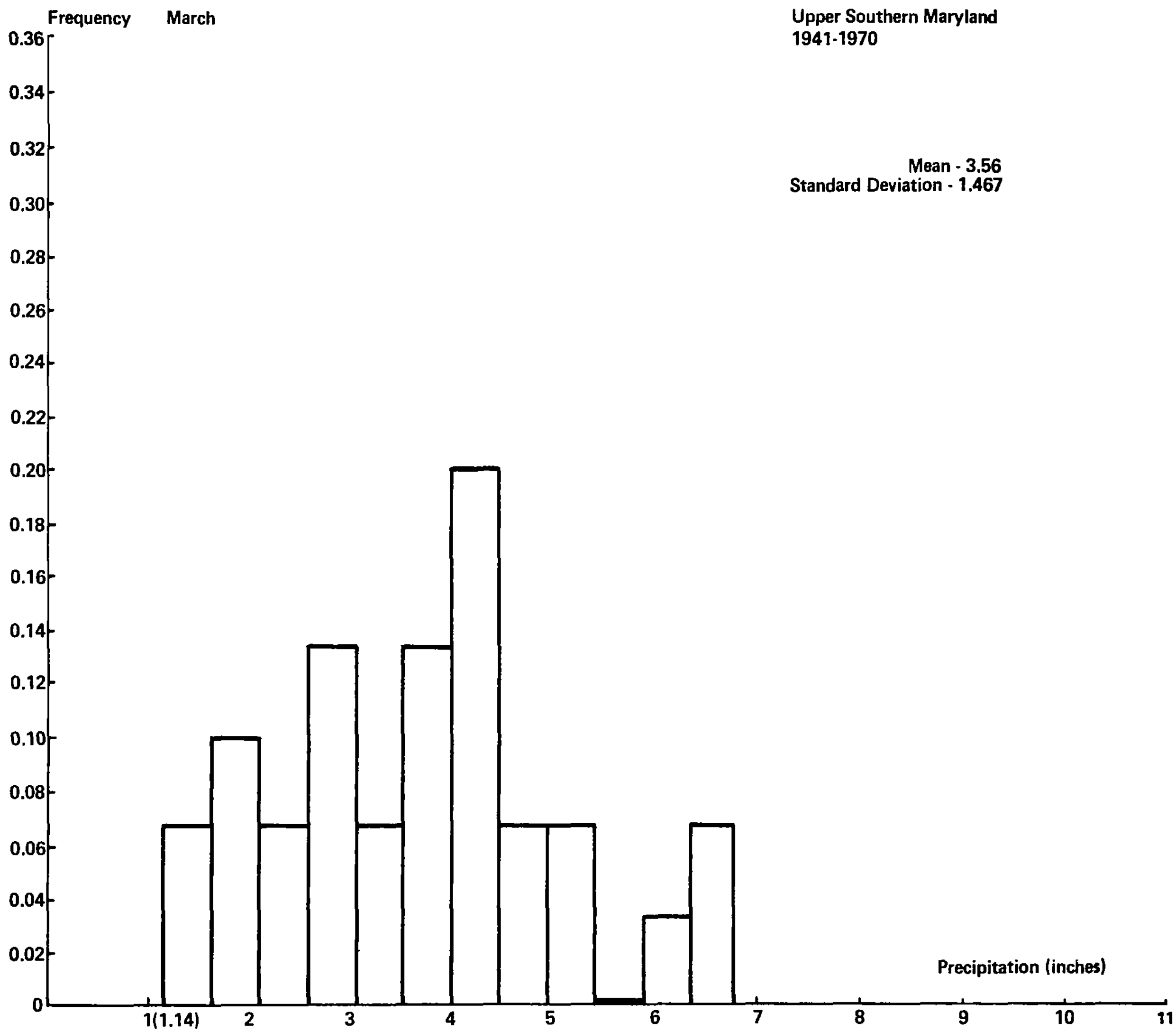
APPENDIX C

HISTOGRAMS FOR AVERAGE MONTHLY PRECIPITATION

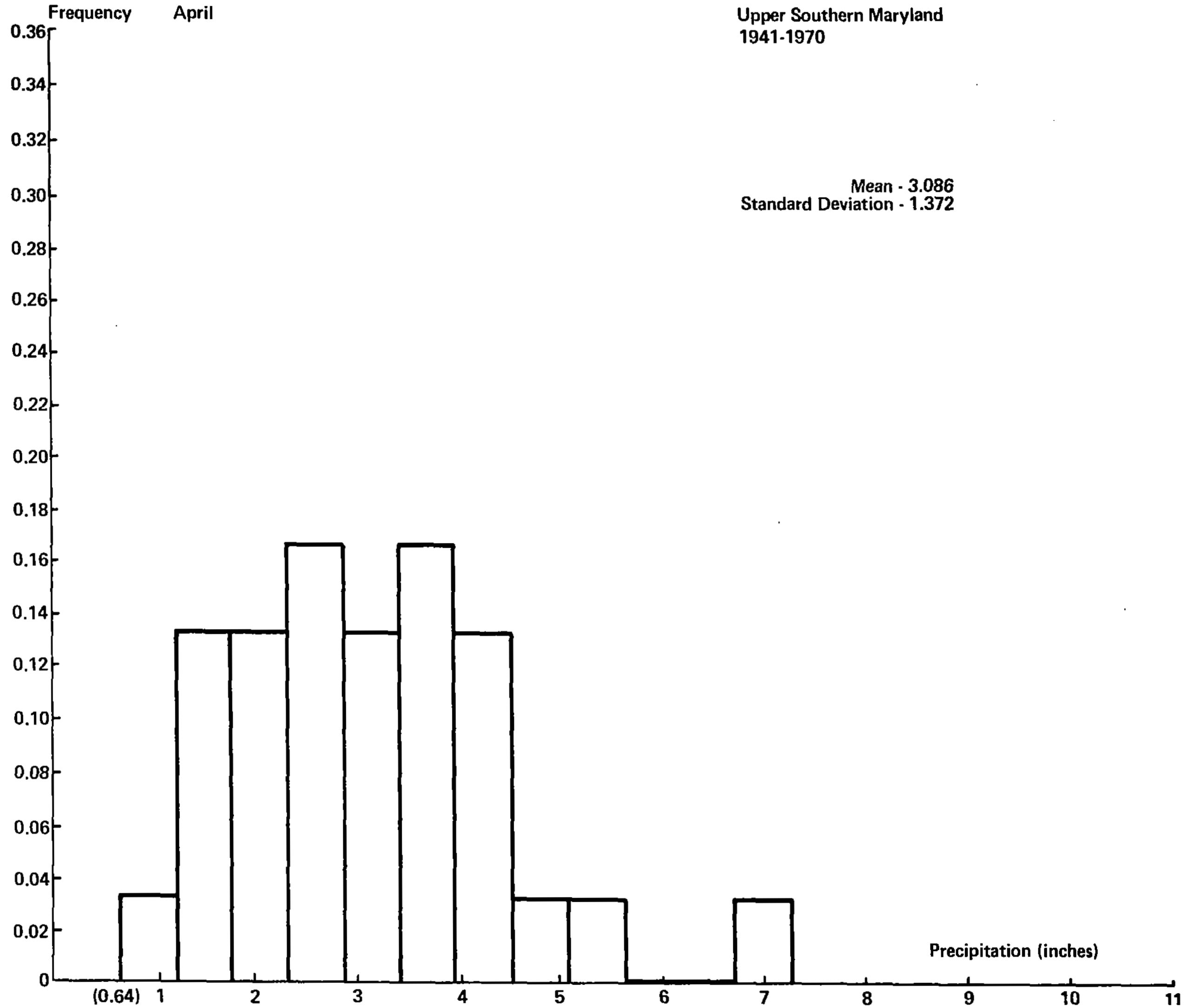
FOR UPPER SOUTHERN MARYLAND, 1941-1970

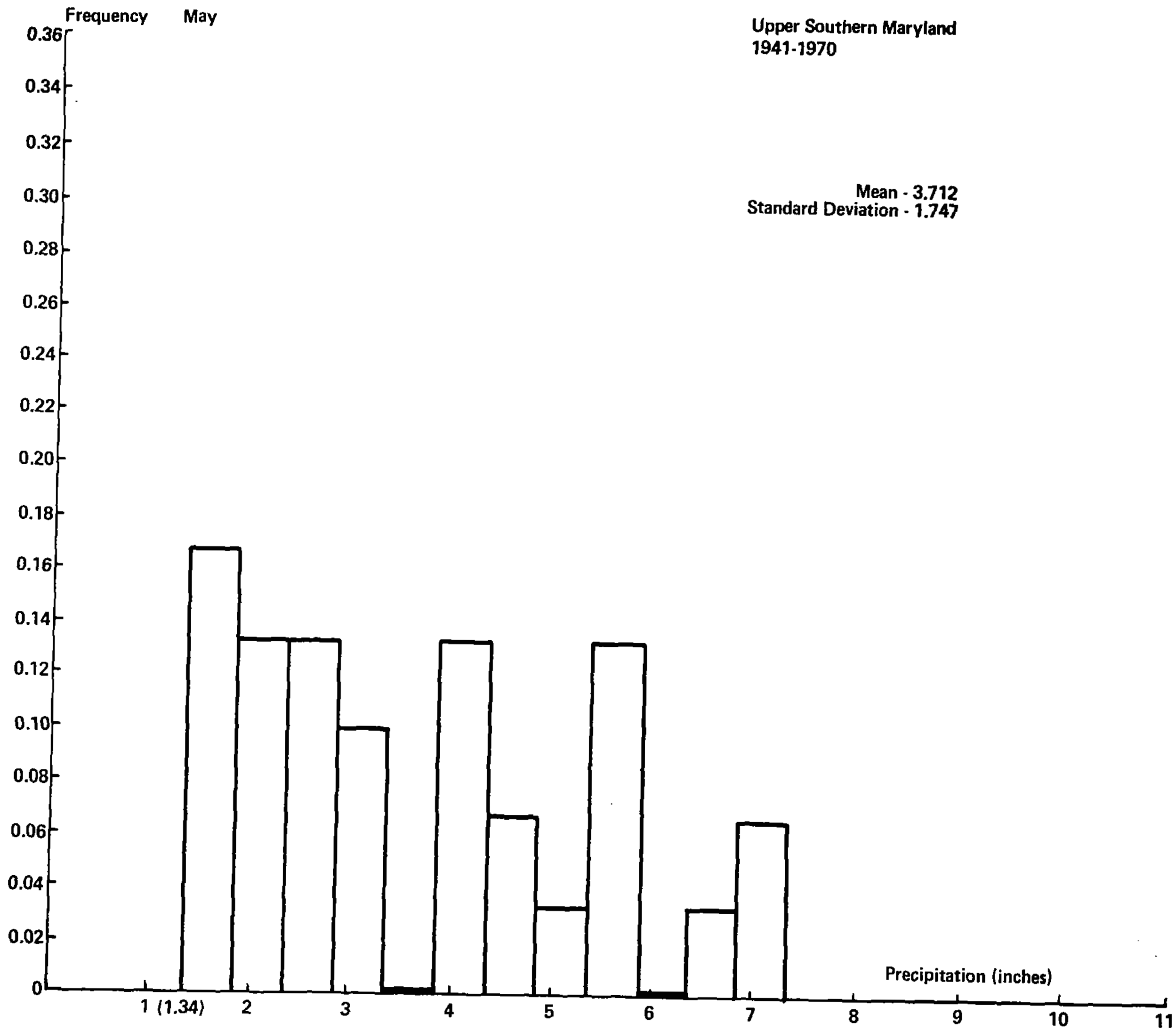

Frequency
January
Upper Southern Maryland
1941-1970
Mean - 2.77
Standard Deviation - 1.162
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.29)
1
2
3
4
6
7
8
9
10
11
Precipitation (inches)


Frequency
February
Upper Southern Maryland
1941-1970
Mean - 2.587
Standard Deviation - 0.921
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.55)
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

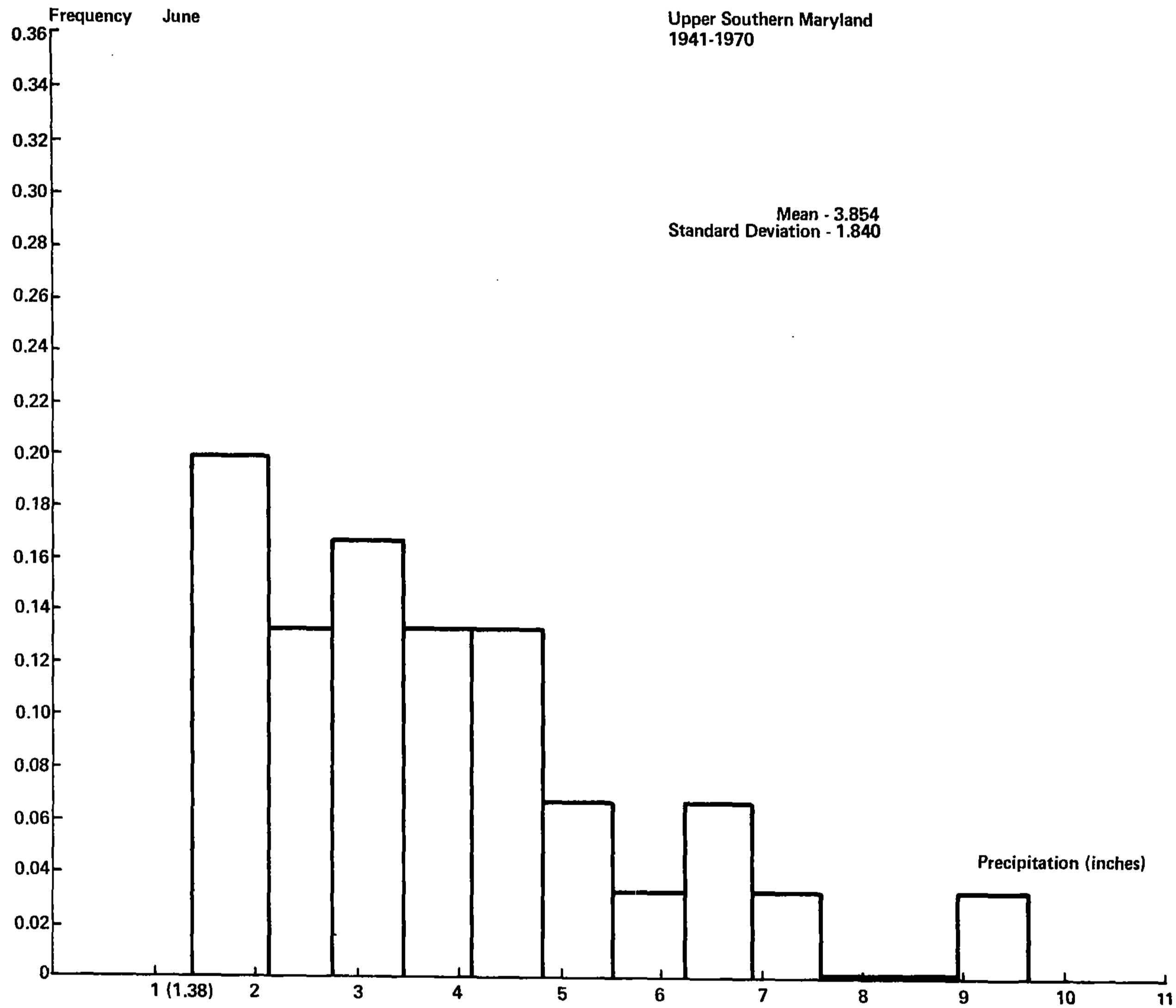


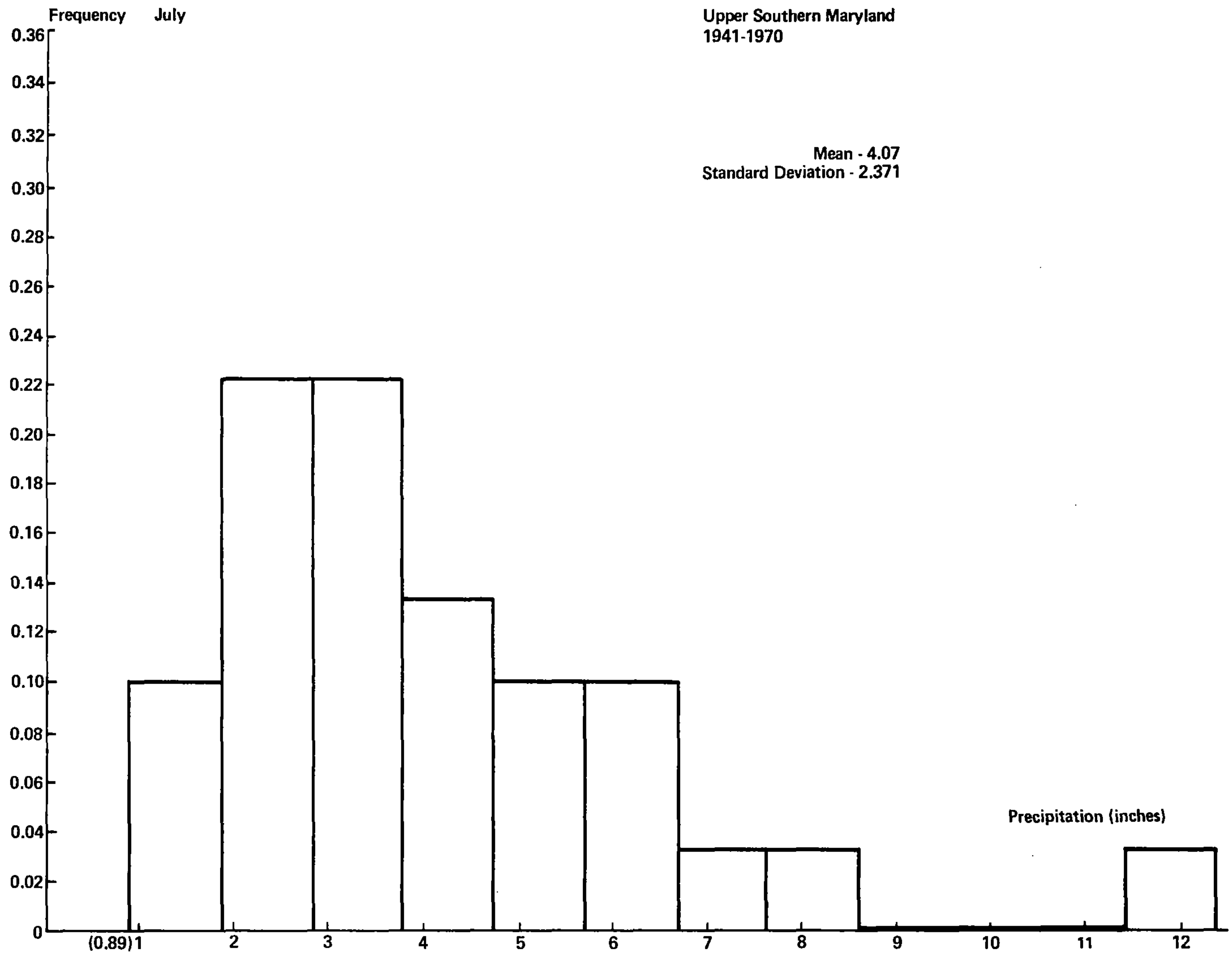
Frequency
March
Upper Southern Maryland
1941-1970
Mean - 3.56
Standard Deviation - 1.467
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
Precipitation (inches)
1(1.14)
2
3
4
5
6
7
8
9
10
11


Frequency
April
Upper Southern Maryland
1941-1970
Mean - 3.086
Standard Deviation - 1.372
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.64)
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

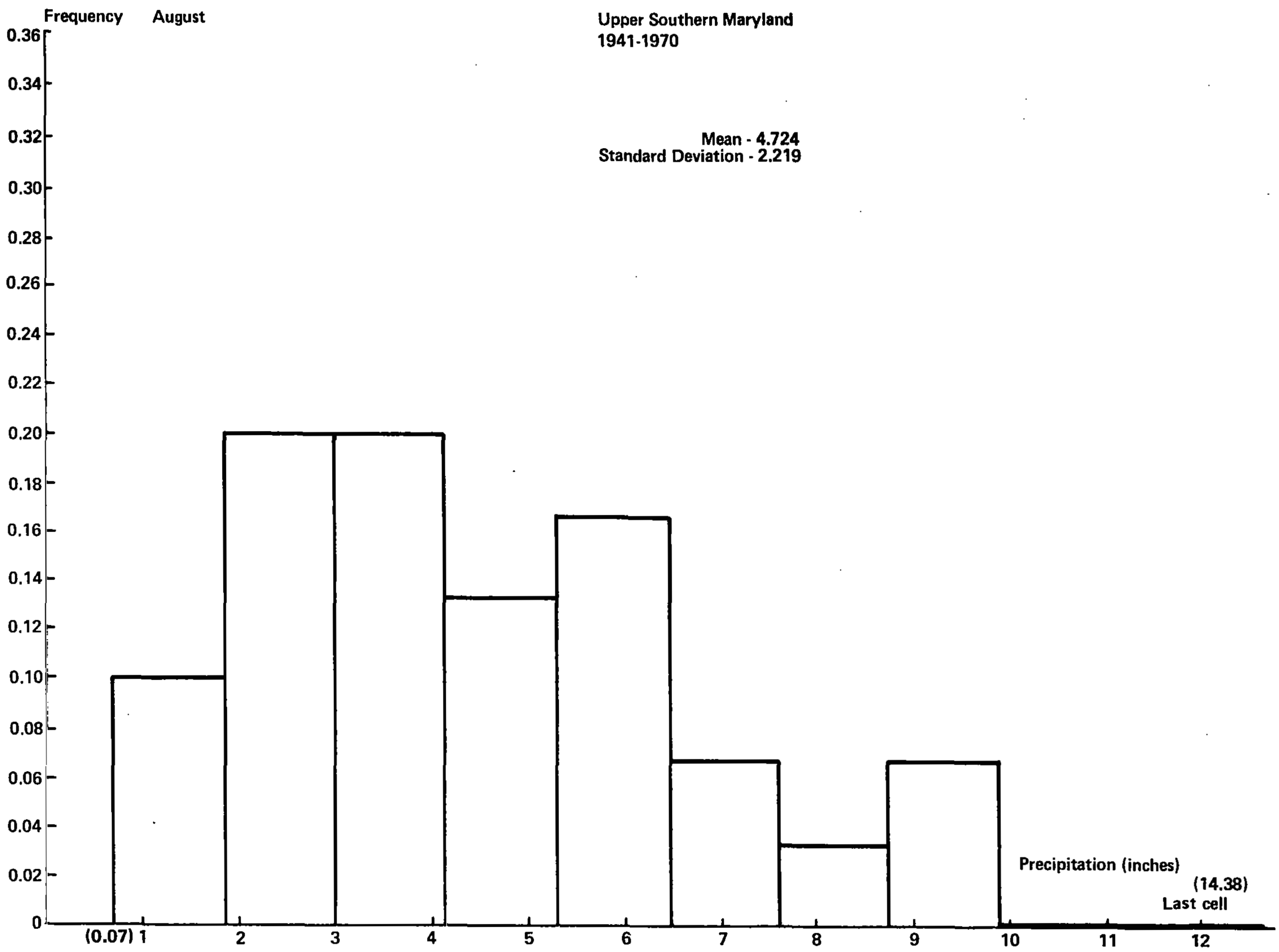


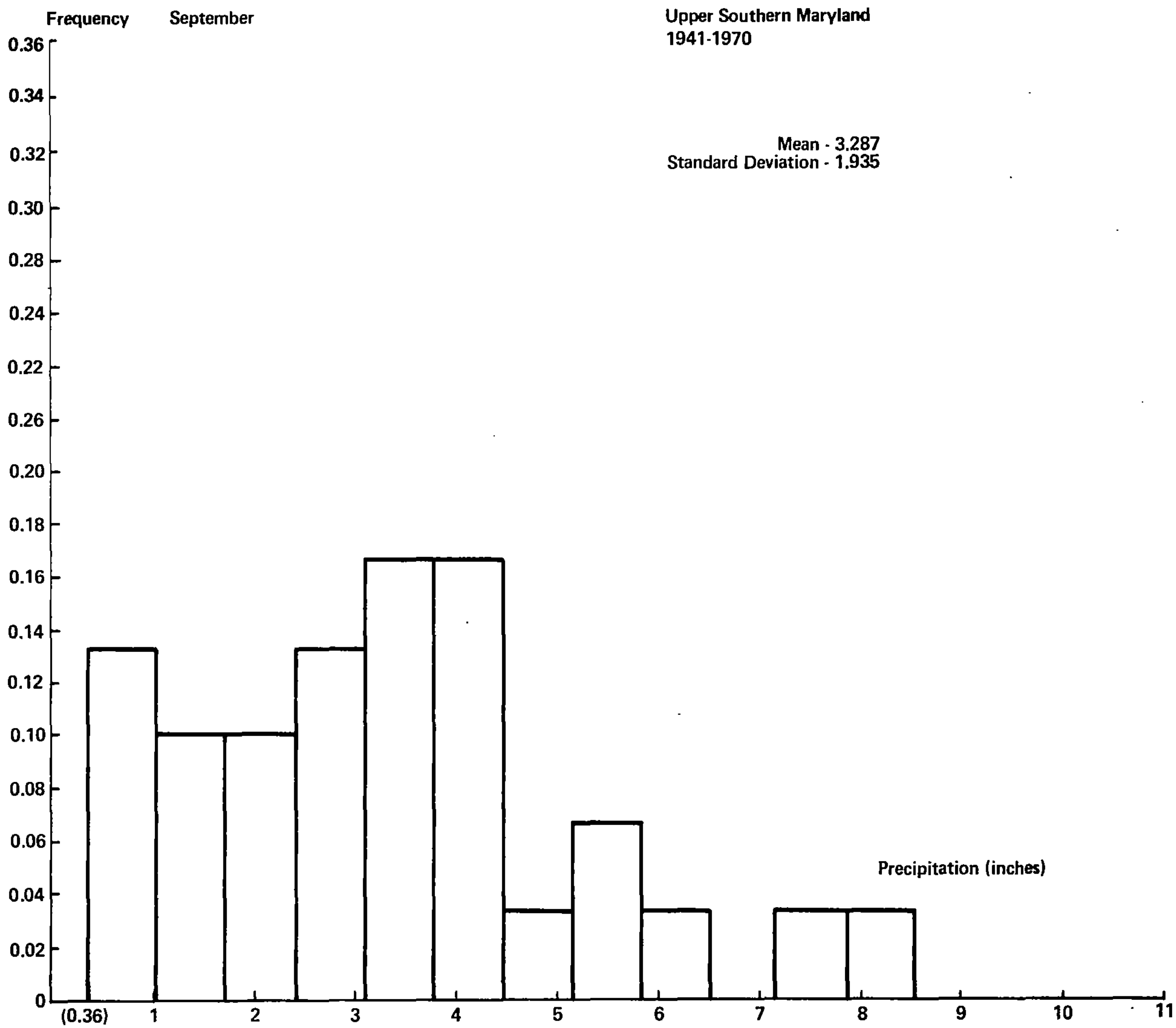
Frequency
May
Upper Southern Maryland
1941-1970
Mean - 3.712
Standard Deviation - 1.747
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1 (1.34)
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

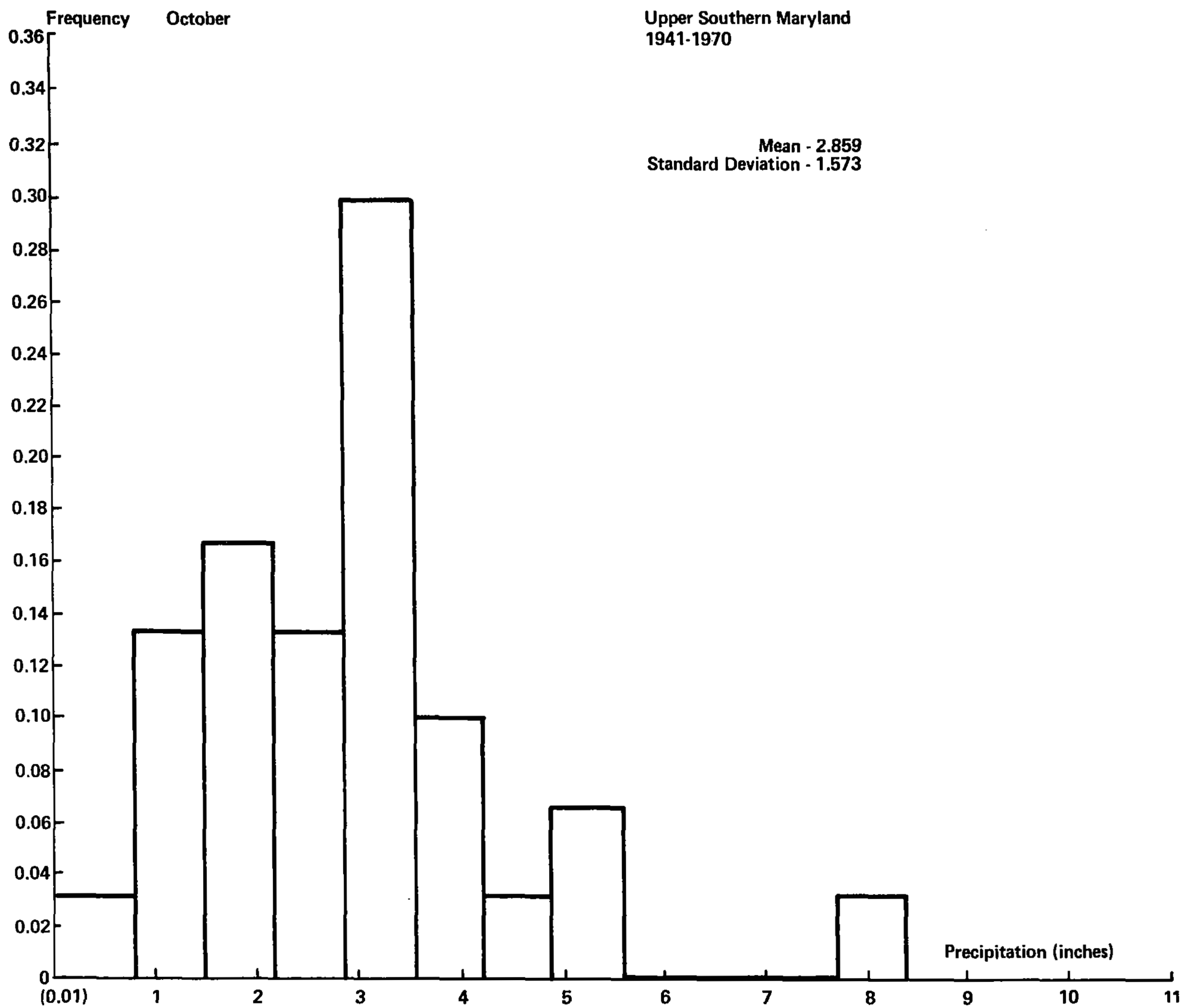

Frequency
June
Upper Southern Maryland
1941-1970
Mean - 3.854
Standard Deviation - 1.840
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
1 (1.38)
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

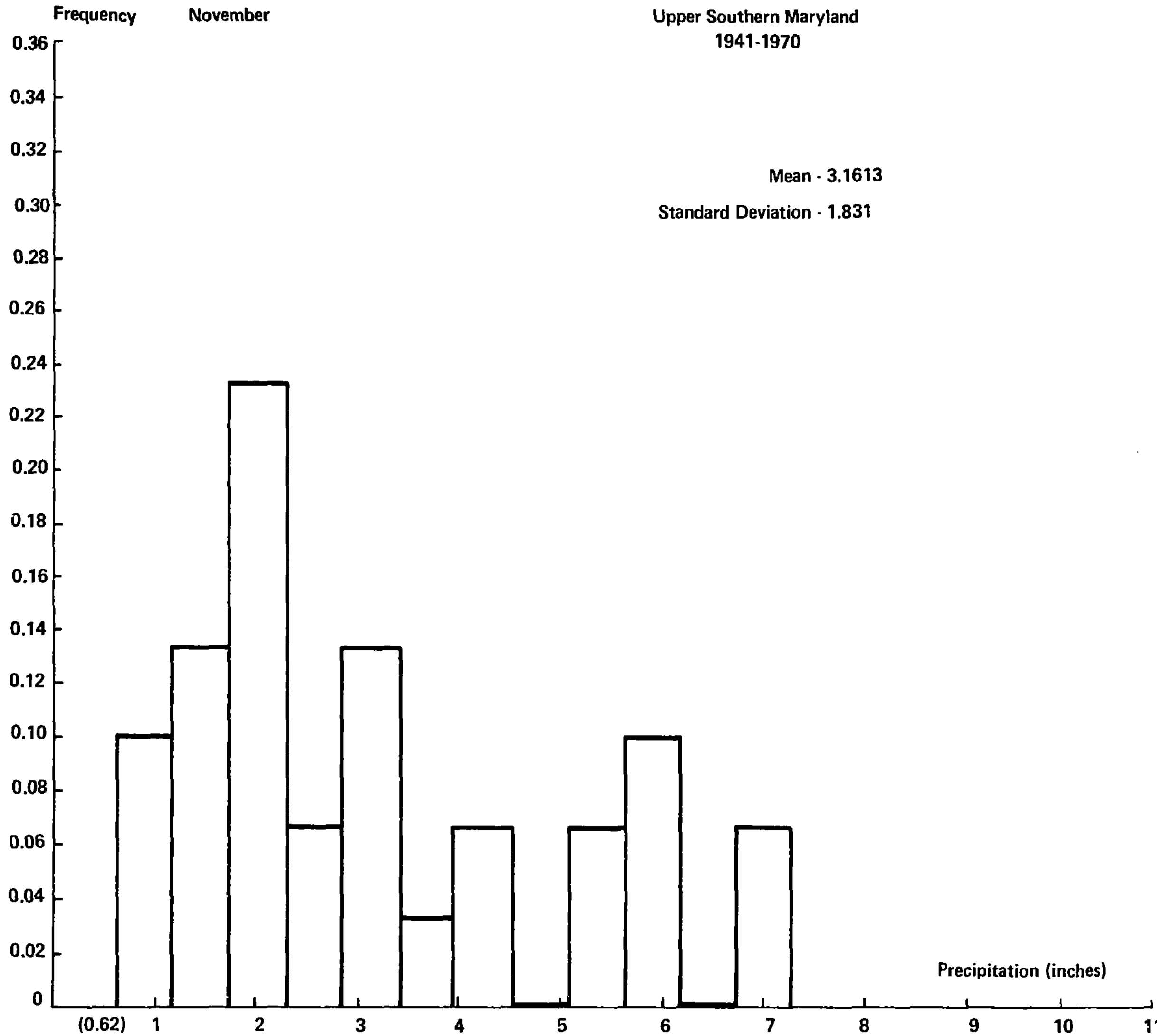


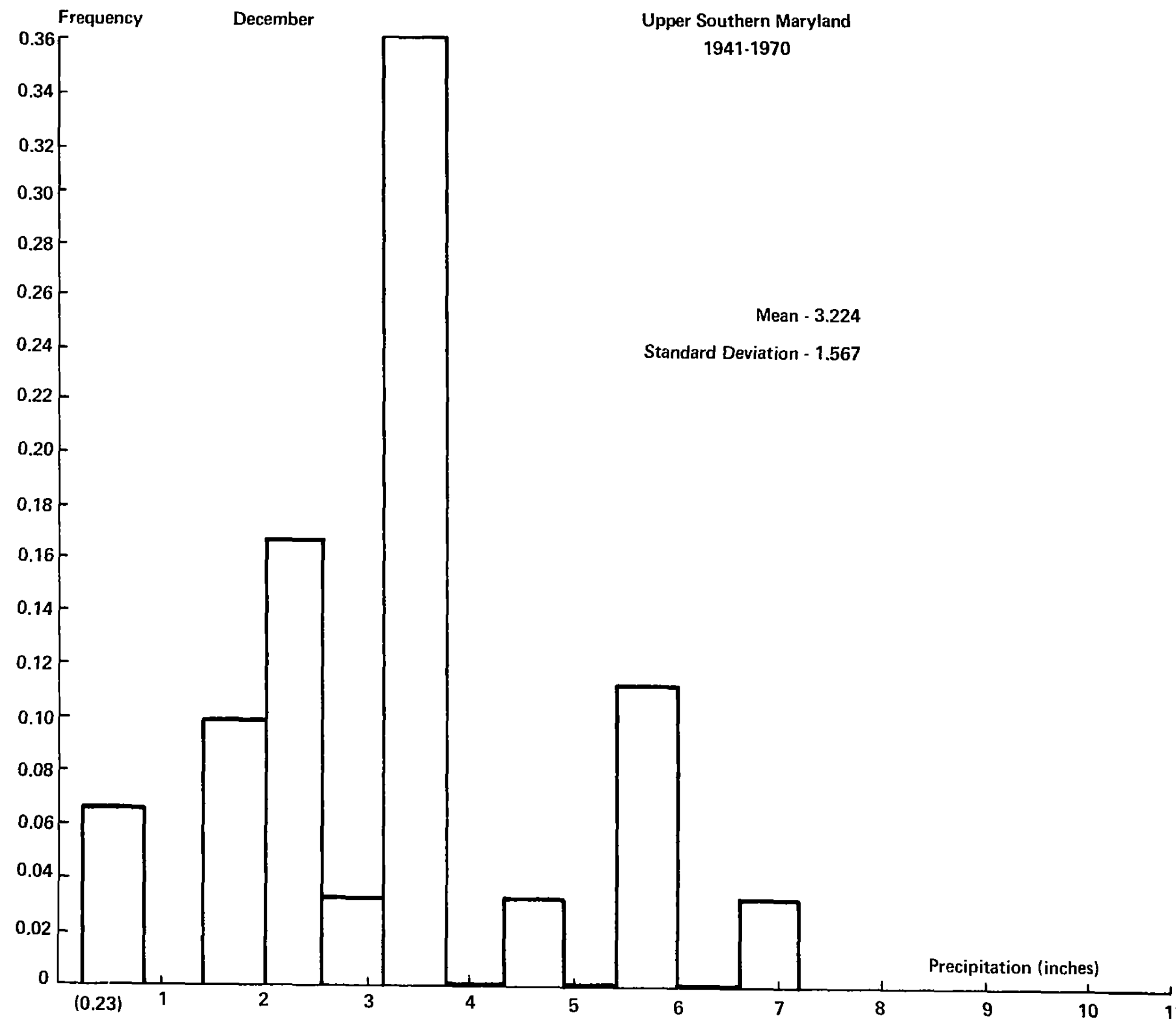
Frequency
July
Upper Southern Maryland
1941-1970
Mean - 4.07
Standard Deviation - 2.371
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.89) 1
2
3
4
5
6
7
8
9
10
11
12
Precipitation (inches)


Frequency
August
Upper Southern Maryland
1941-1970
Mean - 4.724
Standard Deviation - 2.219
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.07) 1
2
3
4
5
6
7
8
9
10
11
12
Precipitation (inches)
(14.38)
Last cell

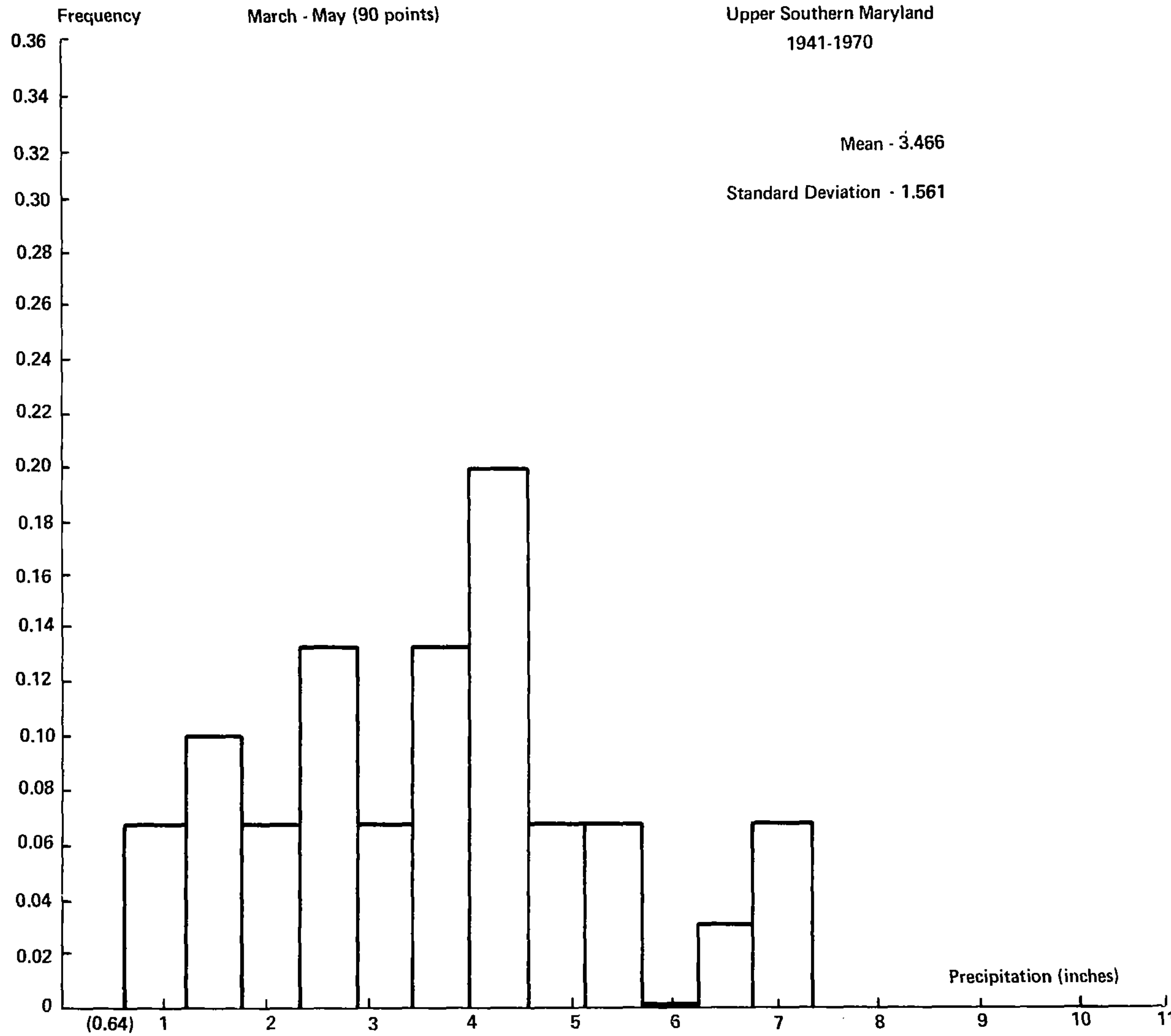

Frequency
September
Upper Southern Maryland
1941-1970
Mean - 3.287
Standard Deviation - 1.935
0.36
0.34
0.32
0.30
0.28
0.24
0.22
0.26
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.36)
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

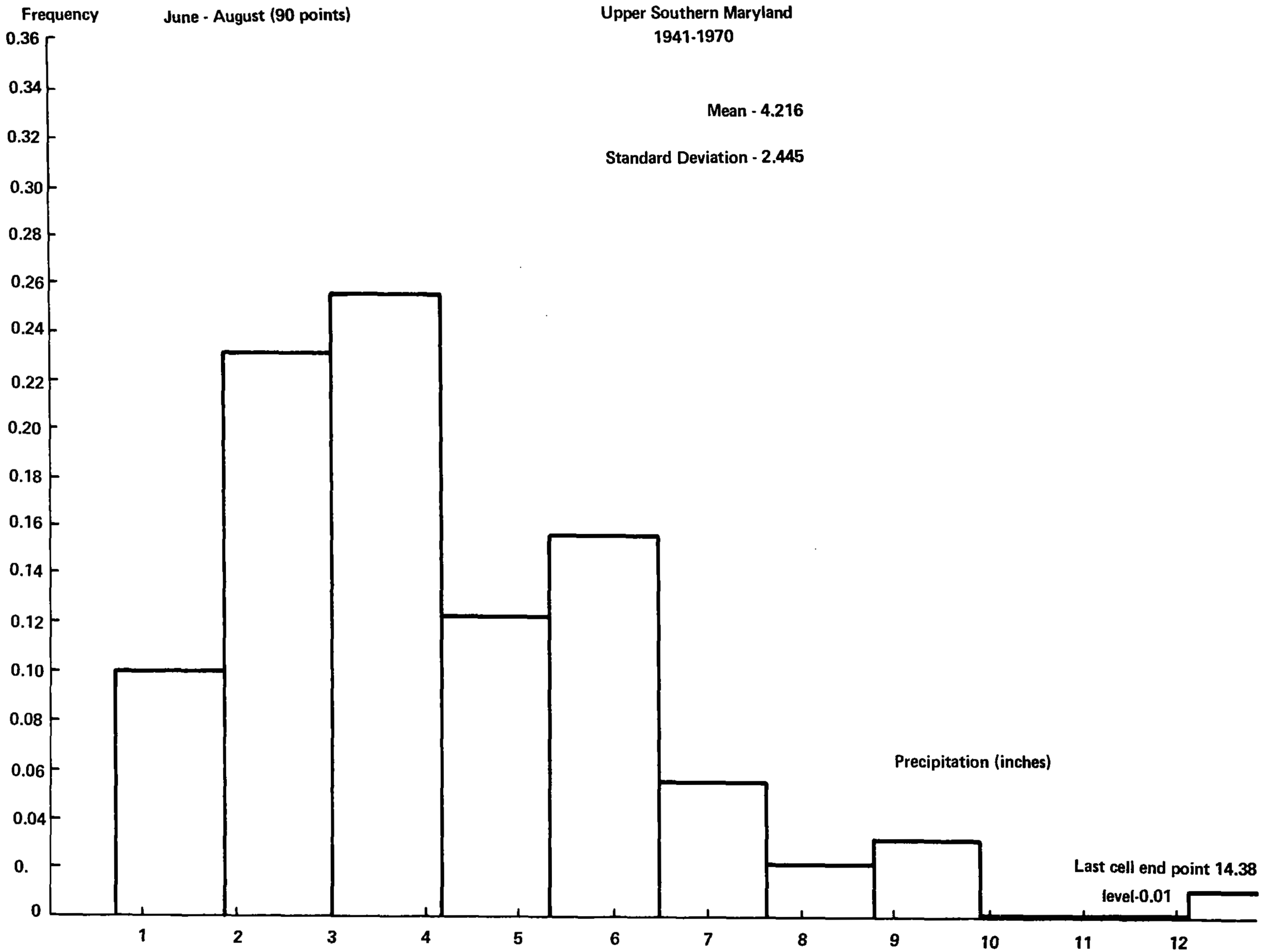

Frequency
October
Upper Southern Maryland
1941-1970
Mean - 2.859
Standard Deviation - 1.573
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.01)
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)


Frequency
November
Upper Southern Maryland
1941-1970
Mean - 3.1613
Standard Deviation - 1.831
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
Precipitation (inches)
(0.62) 1 2 3 4 5 6 7 8 9 10 11

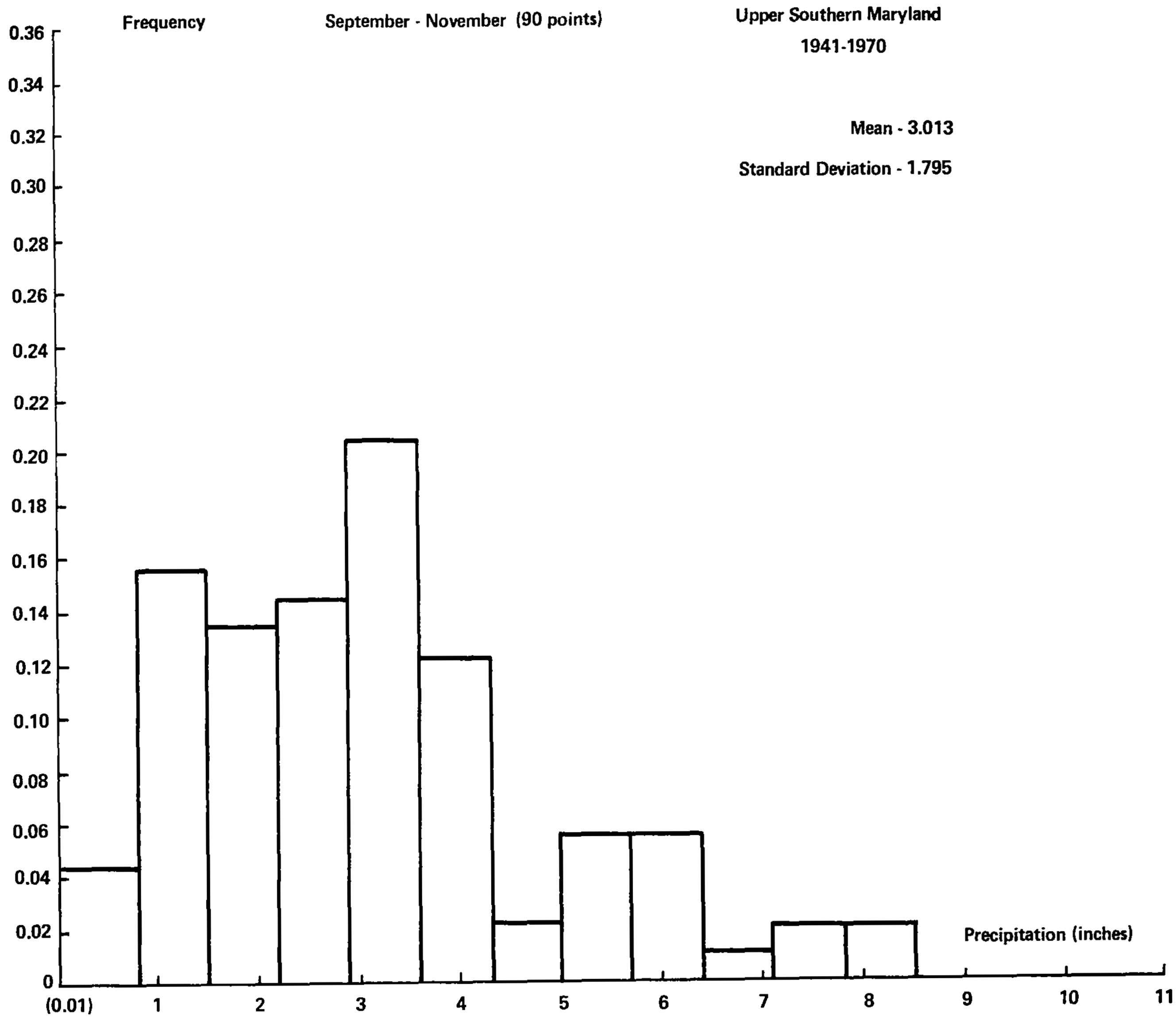


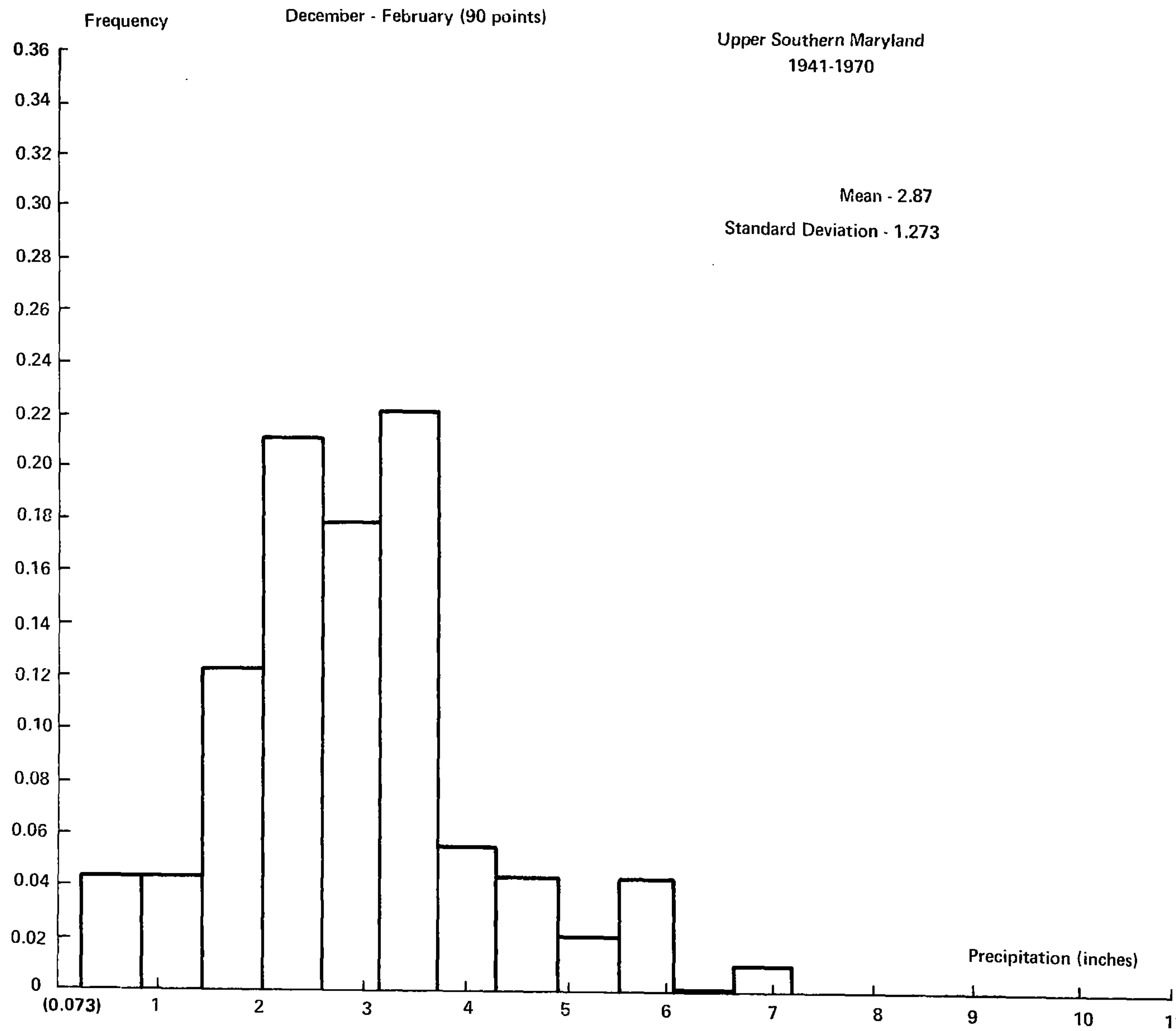
Frequency
December
Upper Southern Maryland
1941-1970
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
Mean - 3.224
Standard Deviation - 1.567
Precipitation (inches)
(0.23)
1
2
3
4
5
6
7
8
9
10
11


Frequency
March - May (90 points)
Upper Southern Maryland
1941-1970
Mean - 3.466
Standard Deviation - 1.561
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
Precipitation (inches)
(0.64)
1
2
3
4
5
6
7
8
9
10
11



Frequency
June - August (90 points)
Upper Southern Maryland
1941-1970
Mean - 4.216
Standard Deviation - 2.445
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.
0
1
2
3
4
5
6
7
8
9
10
11
12
Precipitation (inches)
Last cell end point 14.38
level-0.01


Frequency
September - November (90 points)
Upper Southern Maryland
1941-1970
Mean - 3.013
Standard Deviation - 1.795
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.01)
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)


Frequency
December - February (90 points)
Upper Southern Maryland
1941-1970
Mean - 2.87
Standard Deviation - 1.273
0.36
0.34
0.32
0.30
0.28
0.26
0.24
0.22
0.20
0.18
0.16
0.14
0.12
0.10
0.08
0.06
0.04
0.02
0
(0.073)
1
2
3
4
5
6
7
8
9
10
11
Precipitation (inches)

APPENDIX D

STATISTICAL ANALYSES FOR THE SEASONS OF FALL, SPRING, AND EARLY WINTER

PERIOD 1941--1970

I. ORTHOGONAL FACTOR ANALYSIS

II. OBLIQUE FACTOR ANALYSIS

III. STEPWISE MULTIPLE LINEAR REGRESSION

I. ORTHOGONAL FACTOR ANALYSIS

FALL SEASON, 9 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES - VAR 2-JUL AVERAGE MONTHLY PRECIPITATION

VAR 3-AUG AVERAGE MONTHLY PRECIPITATION

VAR 4-SEP AVERAGE MONTHLY PRECIPITATION

VAR 5-OCT AVERAGE MONTHLY PRECIPITATION

VAR 6-JUL AVERAGE MONTHLY TEMPERATURE

VAR 7-AUG AVERAGE MONTHLY TEMPERATURE

VAR 8-SEP AVERAGE MONTHLY TEMPERATURE

VAR 9-OCT AVERAGE MONTHLY TEMPERATURE

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	20.6100	6.2974	30
AR2	3.6633	2.1217	30
AR3	2.9560	1.4478	30
AR4	3.1867	1.8683	30
AR5	2.1613	1.5520	30
AR6	80.1767	4.1347	30
AR7	78.9920	2.9175	30
AR8	69.4800	3.1183	30
AR9	58.5533	3.4222	30

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

CORRELATION COEFFICIENTS..

	VAR1	VAR2	VAR3	VAR4	VAR5	VAR6	VAR7	VAR8	VAR9
VAR1	1.00000	-.13440	-.14863	.40645	.44437	-.11543	.06214	-.25048	-.35147
VAR2	-.13440	1.00000	.27544	.11565	.19237	-.56669	-.45662	-.31770	.05402
VAR3	-.14863	.27544	1.00000	-.14615	.08306	-.17102	-.41474	-.13177	-.04914
VAR4	.40645	.11565	-.14615	1.00000	.26510	-.22228	-.15167	-.51414	-.36236
VAR5	.44437	-.19237	.08306	.26510	1.00000	-.04823	.16696	-.03633	-.13817
VAR6	-.11543	-.56669	-.17102	-.22228	-.04823	1.00000	.34864	.41429	-.03061
VAR7	.06214	-.45662	-.41474	-.15167	.16696	.34864	1.00000	.53944	.05882
VAR8	-.25048	-.31770	-.13177	-.51414	-.03633	.41429	.53944	.00000	.38005
VAR9	-.35147	.05402	-.04914	-.36236	-.13817	-.03061	.05882	.38005	1.00000

DETERMINANT OF CORRELATION MATRIX = .0676745(.67674467 -01)

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	-.24639	.64899	.09837	.11624
AR2	-.56498	-.42228	-.15125	.19214
AR3	-.36197	-.43546	.71050	-.07653
AR4	-.49259	.45770	-.13795	-.03818
AR5	-.08928	.53462	.42474	.32509
VAR6	.65709	.16711	.15429	-.48080
AR7	.63514	.33240	-.03167	.19933
AR8	.81484	-.17567	.13410	.27232
VAR9	.29606	-.40936	-.08980	.29433

VARIABLE	COMMUNALITY	FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
VAR1	.58358	1	2.34834	43.6	43.6
VAR2	.55732	2	1.65950	30.8	74.4
VAR3	.83131	3	.78615	14.6	89.0
VAR4	.51084	4	.59512	11.0	100.0
VAR5	.57987				
VAR6	.71467				
VAR7	.55463				
VAR8	.78696				
VAR9	.34992				

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FILE KAN (CREATION DATE = 21 APR 78) FCIP STUDY

VARIMAX ROTATED FACTOR MATRIX

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	.00974	.54993	-.42034	-.15614
AR2	-.69331	-.20075	-.04713	.18471
AR3	-.15973	.03942	.04370	.89573
AR4	-.19789	.26692	-.61055	-.16631
AR5	.06411	.74849	-.10084	.06686
AR6	.82976	-.13738	.07874	-.03314
AR7	.44616	.27609	.33438	-.40931
AR8	.40764	.05617	.77534	-.12837
AR9	-.11646	-.15855	.55486	-.05786

I. ORTHOGONAL FACTOR ANALYSIS

FALL SEASON, 5 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES-VAR 2-JUL AVERAGE MONTHLY PRECIPITATION

VAR 3-AUG AVERAGE MONTHLY PRECIPITATION

VAR 4-SEP AVERAGE MONTHLY PRECIPITATION

VAR 5-OCT AVERAGE MONTHLY PRECIPITATION

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	20.6100	6.0974	30
AR2	3.6633	2.1217	30
AR3	2.9860	1.4478	30
AR4	3.1967	1.8653	30
AR5	2.1613	1.5520	30

WELKER
21 APR 78 PAGE 4

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

CORRELATION COEFFICIENTS..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.00000	-.13440	-.14863	.40645	.44437
R2	-.13440	1.00000	.27544	.11565	-.19237
R3	-.14863	.27544	1.00000	-.14615	.08306
R4	.40645	.11565	-.14615	1.00000	.26510
R5	.44437	-.19237	.08306	.26510	1.00000

DETERMINANT OF CORRELATION MATRIX = .5104134(.51041337 +00)

WELKER
21 APR 78 PAGE 5

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

INVERSE OF CORRELATION MATRIX..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.44792	.09942	.16765	-.43684	-.52260
VAR2	.09942	1.21776	-.39313	-.31994	.30800
AR3	.16765	-.39313	1.19329	.23426	-.31134
VAR4	-.43684	-.31994	.23426	1.31093	-.23441
R5	-.52260	.30800	-.31134	-.23441	1.37948

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2	FACTOR 3
VAR1	.68103	.06672	-.04331
ARR2	-.27662	.60621	-.29885
VAR3	-.24494	.53325	.39921
VAR4	.54903	.25650	-.37390
VAR5	.65943	.17175	.37896

```
 VARIABLE       COMMUNALITY                              FACTOR         EIGENVALUE
T OF VAR   CUM PCT

 VAR1               .47013                                 1             1.33660
 50.9          50.9
 VAR2               .53331                                 2              .75694
 28.8          79.7
 VAR3               .50907                                 3              .53396
 20.3         100.0
 VAR4               .50703
 VAR5               .60796
```

WELKER
21 APR 78 PAGE 8

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

VARIMAX ROTATED FACTOR MATRIX

	FACTOR 1	FACTOR 2	FACTOR 3
VAR1	.47047	.47322	-.15766
ARR2	-.36302	.26767	.57463
VAR3	.13183	-.22270	.66490
VAR4	.16198	.69313	-.01906
VAR5	.75034	.20735	.04432

TRANSFORMATION MATRIX

	FACTOR 1	FACTOR 2	FACTOR 3
FACTOR 1	.72741	.61367	-.30706
ACTOR 2	.66963	.37917	.92270
FACTOR 3	.62266	-.69256	.23308

II. OBLIQUE FACTOR ANALYSIS

FALL SEASON, 9 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES - VAR 2-JUL AVERAGE MONTHLY PRECIPITATION
VAR 3-AUG AVERAGE MONTHLY PRECIPITATION
VAR 4-SEP AVERAGE MONTHLY PRECIPITATION
VAR 5-OCT AVERAGE MONTHLY PRECIPITATION
VAR 6-JUL AVERAGE MONTHLY TEMPERATURE
VAR 7-AUG AVERAGE MONTHLY TEMPERATURE
VAR 8-SEP AVERAGE MONTHLY TEMPERATURE
VAR 9-OCT AVERAGE MONTHLY TEMPERATURE

WELKER
26 APR 78 PAGE 3

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	20.6100	6.0574	30
VAR2	3.6633	2.1217	30
VAR3	2.9660	1.4478	30
VAR4	3.1967	1.8583	30
VAR5	2.1613	1.5520	30
VAR6	80.1767	4.1347	30
VAR7	72.9800	2.9175	30
VAR8	65.4800	3.1163	30
VAR9	58.5533	3.4228	30

WELKER
26 APR 78 PAGE 4

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

CORRELATION COEFFICIENTS..

	VAR1	VAR2	VAR3	VAR4	VAR5	VAR6	VAR7	VAR8	VAR9
VAR1	1.00000	-.13440	-.14863	.40645	.44437	-.11543	.06214	-.25048	-.35147
VAR2	-.13440	1.00000	.27544	.11565	-.19237	-.56669	-.45662	-.31770	.05402
VAR3	-.14863	.27544	1.00000	-.14615	.08306	-.17102	-.41474	-.13177	-.04914
VAR4	.40645	.11565	-.14615	1.00000	.26510	-.22228	-.15167	-.51414	-.36236
VAR5	.44437	-.19237	.08306	.26510	1.00000	-.04823	.16696	-.03638	-.13817
VAR6	-.11543	-.56669	-.17102	-.22228	-.04823	1.00000	.34864	.41429	-.03061
VAR7	.06214	-.45662	-.41474	-.15167	.16696	.34864	1.00000	.53944	.05882
VAR8	-.25048	-.31770	-.13177	-.51414	-.03638	.41429	.53944	1.00000	.38005
VAR9	-.35147	.05402	-.04914	-.36236	-.13817	-.03061	.05882	.38005	1.00000

DETERMINANT OF CORRELATION MATRIX = .06767450 .67674467 -01)

WELKER
26 APR 78 PAGE 5

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	-.24639	.64995	.09037	.11654
VAR2	-.56495	-.42228	-.15125	.19214
VAR3	-.36197	-.43546	.71850	-.07653
VAR4	-.49259	.49778	-.13793	-.20818
VAR5	-.08928	.53462	.42474	.32508
VAR6	.65709	.16711	.15429	-.48089
VAR7	.63514	.33240	-.23167	.19933
VAR8	.81484	-.17567	.13410	.27232
VAR9	.29606	-.42936	-.06990	.29433

VARIABLE / PCT OF VAR	COMMUNALITY / CUM PCT	FACTOR	EIGENVALUE
VAR1	.50358	1	2.34834
43.6	43.6		
VAR2	.55732	2	1.65950
30.8	74.4		
VAR3	.83131	3	.78615
14.6	89.0		
VAR4	.51084	4	.59512
11.0	100.0		
VAR5	.57987		
VAR6	.71467		
VAR7	.55463		
VAR8	.78696		
VAR9	.34592		

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FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

DELTA = .00

WELKER
26 APR 78 PAGE 9

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY
ROTATION FOR DIRECT OBLIMIN LOADINGS

ITERATION	DIROBL CRITERION
0	4.444706
1	3.927131

[illegible]	4.444725
1	3.927131
2	3.247185
[illegible]	3.022260
[illegible]	2.716891
5	2.685840
6	2.539499
7	2.376746
8	2.073933
9	1.898787
10	1.847353
11	1.836270
12	1.834155
13	1.833764
14	1.833688
15	1.833672

WELKER

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FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

AFTER ROTATION WITH KAISER NORMALIZATION

FACTOR PATTERN

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	-.03004	.50489	-.14281	-.34519
VAR2	-.64964	-.17455	.11894	-.02037
VAR3	-.02111	.14569	.92770	.02697
VAR4	-.16714	.18368	-.20395	-.57291
VAR5	-.02416	.78292	.13106	.06779
VAR6	.66890	-.16906	.02462	-.02547
VAR7	.28564	.28323	-.34966	.37442
VAR8	.25002	.14511	-.05109	.79491
VAR9	-.20885	-.03727	-.04936	.57619

FACTOR CORRELATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
FACTOR 1	1.00000	.16300	-.25522	.25083
FACTOR 2	.16300	1.00000	-.21104	-.23718
FACTOR 3	-.25522	-.21104	1.00000	-.03005

FACTOR PATTERN:

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	-.03004	.50489	-.14281	-.34519
VAR2	-.64964	-.17455	.11894	-.02037
VAR3	-.02111	.14549	.92770	.02697
VAR4	-.16714	.16368	-.20395	-.57291
VAR5	-.02416	.70292	.13106	.00779
VAR6	.86890	-.16996	.02462	-.02547
VAR7	.22564	.22323	-.34966	.37442
VAR8	.25002	.14511	-.05109	.79491
VAR9	-.20885	-.02727	-.04936	.57610

FACTOR CORRELATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
FACTOR 1	1.00000	.16300	-.25522	.25083
FACTOR 2	.16300	1.00000	-.21104	-.23718
FACTOR 3	-.25522	-.21104	1.00000	-.03005
FACTOR 4	.25083	-.23718	-.03005	1.00000

FACTOR STRUCTURE

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	.02212	.61200	-.23133	-.46818
VAR2	-.71355	-.30071	.32219	-.14549
VAR3	-.22737	-.05593	.90153	-.04076
VAR4	-.22085	.33536	-.18284	-.65227
VAR5	.07196	.74947	-.02224	-.19750
VAR6	.82868	-.02658	-.16670	.23183
VAR7	.51497	.31478	-.49359	.38939
VAR8	.48610	.00811	-.16942	.82474
VAR9	-.06608	-.24814	.00517	.54604

WELKER 26 APR 78 PAGE 11

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

FACTOR SCORE COEFFICIENTS

II. OBLIQUE FACTOR ANALYSIS

PERIOD 1941-1970

FALL SEASON, 5 VARIABLES

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES - VAR 2-JUL AVERAGE MONTHLY PRECIPITATION

VAR 3-AUG AVERAGE MONTHLY PRECIPITATION

VAR 4-SEP AVERAGE MONTHLY PRECIPITATION

VAR 5-OCT AVERAGE MONTHLY PRECIPITATION

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	20.6100	6.0974	30
VAR2	3.2633	2.1217	30
VAR3	2.[illegible]60	1.4478	30
VAR4	3.1667	1.8683	30
VAR5	2.1613	1.5520	30

WELKER
26 APR 78 PAGE 4

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

CORRELATION COEFFICIENTS..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.00000	-.13440	-.14863	.40645	.44437
VAR2	-.13440	1.00000	.27544	.11565	-.19237
VAR3	-.14863	.27544	1.00000	-.14615	.08306
VAR4	.40645	.11565	-.14615	1.00000	.26510
VAR5	.44437	-.19237	.08306	.26510	1.00000

DETERMINANT OF CORRELATION MATRIX = .5104134(.51041337 +00)

WELKER
26 APR 78 PAGE 5

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

INVERSE OF CORRELATION MATRIX..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.44792	.09842	.16765	-.43684	-.52260
VAR2	.09842	1.21776	-.39313	-.31994	.30800
VAR3	.16765	-.39313	1.19329	.23426	-.31134
VAR4	-.43684	-.31994	.23426	1.31093	-.23441
VAR5	-.52260	.30800	-.31134	-.23441	1.37948

WELKER
26 APR 78 PAGE 6

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2
VAR1	.75714	.32137
VAR2	-.53711	.81028
VAR3	-.22182	.15205
VAR4	.40264	.37588
VAR5	.50251	.14774

VARIABLE	COMMUNALITY	FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
VAR1	.67654	1	1.32558	58.4	58.4
VAR2	.94503	2	.94685	41.6	100.0
VAR3	.07223				
VAR4	.30341				
VAR5	.27434				

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FILE KAN (CREATION DATE = 26 APR 78) FCIP STUDY

DELTA = .00

WELKER 26 APR 78 PAGE 9

FILE KAN (CREATION DATE = 26 APR 78) FCIP STUDY

ROTATION FOR DIRECT OBLIMIN LOADINGS

ITERATION	DIROBL CRITERION
0	1.762191
1	1.343382
2	.498330
3	.384172
4	.382539
5	.382523

FACTOR PATTERN

	FACTOR 1	FACTOR 2
VAR1	.73779	-.09352
VAR2	.13762	.99165
VAR3	-.06674	.24671
VAR4	.56317	.13295
VAR5	.48507	-.12049

FACTOR CORRELATIONS

	FACTOR 1	FACTOR 2
FACTOR 1	1.00000	-.20986
FACTOR 2	-.20986	1.00000

FACTOR STRUCTURE

	FACTOR 1	FACTOR 2
VAR1	.81742	-.26095
VAR2	-.07049	.96277
VAR3	-.11852	.26072
VAR4	.53527	.01476
VAR5	.51036	-.22229

WELKER
26 APR 78 PAGE 11

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

FACTOR SCORE COEFFICIENTS

	FACTOR 1	FACTOR 2
VAR1	.65622	-.12965
VAR2	.02714	.97106
VAR3	-.01017	-.[illegible]

III. STEPWISE MULTIPLE LINEAR REGRESSION

FALL SEASON, 9 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES- VAR 2-JUL AVERAGE MONTHLY PRECIPITATION

VAR 3-AUG AVERAGE MONTHLY PRECIPITATION

VAR 4-SEP AVERAGE MONTHLY PRECIPITATION

VAR 5-OCT AVERAGE MONTHLY PRECIPITATION

VAR 6-JUL AVERAGE MONTHLY TEMPERATURE

VAR 7-AUG AVERAGE MONTHLY TEMPERATURE

VAR 8-SEP AVERAGE MONTHLY TEMPERATURE

VAR 9-OCT AVERAGE MONTHLY TEMPERATURE

EPENDENT VARIABLE..   VAR1   REGRESSION LIST 1

WELKER
19 APR 78   PAGE   6

FILE   KAN   (CREATION DATE = 19 APR 78)   PCIP STUDY
ONS

* M U L T I P L E   R E
S S I O N * * * * * * * * * * * * * *   VARIABLE LIST 1

REGRESSION LIST 1

EPENDENT VARIABLE..   VAR1

SUMMARY TABL

VARIABLE	MULTIPLE R	R SQUARE	SQ CHANGE	SIMPLE R	B	BETA
VAR5	.44437	.19746	.19746	.44437	1.38348	.35214
VAR4	.53579	.28708	.08961	.40645	.49110	.15048
VAR9	.57294	.32826	.04119	-.35148	-.39709	-.22291
AR3	.59439	.35330	.02504	-.14863	-.69583	-.16523
AR6	.60175	.36210	.00880	-.11543	-.20899	-.14171
AR2	.60940	.37137	.00927	-.13440	-.38071	-.13248
VAR8	.61232	.37493	.00357	-.25048	-.15783	-.08074
(CONSTANT)					70.50394	

III. STEPWISE MULTIPLE LINEAR REGRESSION

FALL SEASON, 5 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES -VAR 2-JUL AVERAGE MONTHLY PRECIPITATION
VAR 3-AUG AVERAGE MONTHLY PRECIPITATION
VAR 4-SEP AVERAGE MONTHLY PRECIPITATION
VAR 5-OCT AVERAGE MONTHLY PRECIPITATION

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 WELKER
                19 APR 78           PAGE    4

 FILE   KAN        (CREATION DATE = 19 APR 78)    PCIP STUDY YRS BYU 4MOS S
ONS

 * * * * * * * * * * * * * * * * * * * * * * * *  M U L T I P L E   R E G
 S S I O N  * * * * * * * * * * * * * *    VARIABLE LIST  1

                                                 REGRESSION LIST  1
EPENDENT VARIABLE..     VAR1

                                                                SUMMARY TABL


 VARIABLE                                                MULTIPLE R   R SQUARE
SQ CHANGE    SIMPLE R                B                  BETA

 VAR5                                                        .44437      .19746
    .19746        .44437                1.41800             .36093
VAR4                                                        .53579      .28708
  .08961       .40645               .98465               .30170
AR3                                                          .55276     .30554
  .01846     -.14863              -.48763               .11579
 VAR2                                                         .55620     .30936
  .00381     -.13440              -.19533              -.06797
(CONSTANT)
                                        16.57915


 WELKER
                19 APR 78           PAGE    5

FINISH

                DATA TRANSFORMATION DONE UP TO THIS POINT..
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I. ORTHOGONAL FACTOR ANALYSIS

SPRING SEASON, 9 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES - VAR 2-MAR AVERAGE MONTHLY PRECIPITATION
VAR 3-APR AVERAGE MONTHLY PRECIPITATION
VAR 4-MAY AVERAGE MONTHLY PRECIPITATION
VAR 5-JUN AVERAGE MONTHLY PRECIPITATION
VAR 6-MAR AVERAGE MONTHLY TEMPERATURE
VAR 7-APR AVERAGE MONTHLY TEMPERATURE
VAR 8-MAY AVERAGE MONTHLY TEMPERATURE
VAR 9-JUN AVERAGE MONTHLY TEMPERATURE

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	19.9500	5.5928	30
AR2	1.5290	.9548	30
AR3	2.4923	1.4147	30
AR4	3.7627	1.5821	30
AR5	4.5097	2.2614	30
VAR6	41.[illegible]333	5.3071	30
AR7	54.	3.4866	30
AR8	64.	3.2704	30
AR9	74.	3.3329	30

WELKER
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FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

CORRELATION COEFFICIENTS..

	VAR1	VAR2	VAR3	VAR4	VAR5	VAR6	VAR7	VAR8	VAR9
VAR1	1.00000	.17637	.00672	-.07927	.10220	-.37899	-.02486	.14492	-.16802
VAR2	.17637	1.00000	.26295	.45546	.01824	-.30901	-.30771	-.02573	-.00523
VAR3	.00672	.26295	1.00000	.09560	.07670	-.01409	-.28108	-.21367	-.33932
VAR4	-.07927	.45546	.09560	1.00000	.12376	-.06919	-.27040	-.19557	-.27605
VAR5	.10220	.01824	.07670	.12376	1.00000	-.23632	.27583	.07978	-.58742
VAR6	-.37899	-.30901	-.01409	-.06919	-.23632	1.00000	-.01062	-.26851	.18910
VAR7	-.02486	-.30771	-.28108	-.27040	.27583	-.01062	1.00000	-.08133	-.07947
VAR8	.14492	-.02573	-.21367	-.19557	.07978	-.26851	-.08133	1.00000	.01514
VAR9	-.16802	-.00523	-.33932	-.27605	-.58742	.18910	-.07947	.01514	1.00000

DETERMINANT OF CORRELATION MATRIX = .1300868(.13008684 +00)

WELKER
21 APR 78 PAGE 5

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

INVERSE OF CORRELATION MATRIX

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
VAR1	.21516	-.16913	.38895	-.09966	.05115
R2	.51660	.37110	.28620	.07851	.27129
R3	.47474	.18356	-.26241	-.56100	.23466
R4	.66075	.38630	-.20212	.56919	-.06729
VAR5	.40978	-.52334	-.06909	.07689	-.02425
R6	-.39423	.23204	-.60350	-.02529	-.12317
R7	-.26915	-.67015	-.16656	.28744	.39026
R8	-.04024	-.17030	.44915	-.03668	-.28290
R9	-.71720	.52845	.29250	.13171	.22735

VARIABLE	COMMUNALITY	FACTOR	EIGENVALUE
T OF VAR	CUM PCT		
VAR1	.23873	1	1.88692
34.0	34.0		
VAR2	.56626	2	1.43434
25.9	59.9		
VAR3	.69773	3	1.02692
18.5	78.4		
VAR4	.95518	4	.76267
13.8	92.1		
VAR5	.45308	5	.43559
7.9	100.0		
VAR6	.58929		
VAR7	.78422		
VAR8	.31374		
VAR9	.94822		

WELKER 21 APR 78 PAGE 8

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

VARIMAX ROTATED FACTOR MATRIX

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4	FACTOR 5
VAR1	[illegible]	-.03955	.47846	.02071	-.01746
R2	[illegible]	.54496	.38756	.29239	-.13272
R3	.16699	.04259	.00323	.78754	-.20179
R4	.21823	.93404	-.11593	-.00932	-.14693
R5	.60411	.05420	.19229	-.00465	.21953
R6	-.13400	-.12624	-.74344	.02961	-.04262
R7	.16797	-.20071	-.24469	-.16814	.82792
R8	.03925	-.19339	.37195	-.31961	-.18515
VAR9	-.94586	-.07614	-.09169	-.19644	.02805

I. ORTHOGONAL FACTOR ANALYSIS

SPRING SEASON, 5 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES - VAR 2-MAR AVERAGE MONTHLY PRECIPITATION
VAR 3-APR AVERAGE MONTHLY PRECIPITATION
VAR 4-MAY AVERAGE MONTHLY PRECIPITATION
VAR 5-JUN AVERAGE MONTHLY PRECIPITATION

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	19.9500	5.5928	30
AR2	1.5290	.9548	30
AR3	2.4923	1.4147	30
AR4	3.7627	1.5821	30
VAR5	4.5097	2.2614	30

WELKER

21 APR 78 PAGE 4

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

CORRELATION COEFFICIENTS..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.00000	.17637	.00672	-.07927	.10220
AR2	.17637	1.00000	.26295	.45546	.01824
R3	.00672	.26295	1.00000	.09560	.07670
R4	-.07927	.45546	.09560	1.00000	.12376
VAR5	.10220	.01824	.07670	.12376	1.00000

DETERMINANT OF CORRELATION MATRIX = .6612742(.66127417 +00)

WELKER

21 APR 78 PAGE 5

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

INVERSE OF CORRELATION MATRIX..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.08884	-.31623	.06350	.24164	-.14029
R2	-.31623	1.44108	-.32194	-.66462	.11299
VAR3	.06350	-.32194	1.08557	.05917	-.09121
R4	.24164	-.66462	.05917	1.33883	-.18281
R5	-.14029	.11299	-.09121	-.18281	1.04190

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	.12642	.56425	.09843	-.16917
AR2	.83202	.15240	-.21912	-.03474
AR3	.30325	.08262	-.05485	.42621
AR4	.65516	-.36192	.18470	-.14617
AR5	.13612	.10232	.48118	.12348

VARIABLE		COMMUNALITY	FACTOR	EIGENVALUE
T OF VAR	CUM PCT			
VAR1		.37267	1	1.24797
54.0	54.0			
VAR2		.76471	2	.48989
21.2	75.2			
VAR3		.28345	3	.32636
14.1	89.3			
VAR4		.61571	4	.24809
10.7	100.0			
VAR5		.27578		

WELKER

21 APR 78 PAGE 8

FILE KAN (CREATION DATE = 21 APR 78) PCIP STUDY

VARIMAX ROTATED FACTOR MATRIX

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	-.01534	.60188	.00571	.10075
AR2	.66019	.32841	.41777	-.14021
AR3	.08293	-.00316	.52037	.07599
AR4	.74977	-.14159	.03867	.17890
AR5	.05446	.08363	.06310	.51170

TRANSFORMATION MATRIX

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
FACTOR 1	.87164	.21394	.43274	.08492
ACTOR 2	-.33462	.91695	.20891	.05995
ACTOR 3	.02936	.00473	-.25133	.96744
ACTOR 4	-.35695	-.33677	.84019	.23075

II. OBLIQUE FACTOR ANALYSIS

SPRING SEASON, 9 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES -VAR 2-MAR AVERAGE MONTHLY PRECIPITATION
VAR 3-APR AVERAGE MONTHLY PRECIPITATION
VAR 4-MAY AVERAGE MONTHLY PRECIPITATION
VAR 5-JUN AVERAGE MONTHLY PRECIPITATION
VAR 6-MAR AVERAGE MONTHLY TEMPERATURE
VAR 7-APR AVERAGE MONTHLY TEMPERATURE
VAR 8-MAY AVERAGE MONTHLY TEMPERATURE
VAR 9-JUN AVERAGE MONTHLY TEMPERATURE

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	19.9500	5.5922	30
VAR2	1.5290	.9548	30
VAR3	2.4922	1.4147	30
VAR4	3.7627	1.5821	30
VAR5	4.5097	2.2614	30
VAR6	41.6333	5.3071	30
VAR7	54.8933	3.4866	30
VAR8	64.6733	3.2704	30
VAR9	74.5533	3.3329	30

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

CORRELATION COEFFICIENTS..

VAR6	VAR1 VAR7	VAR2 VAR8	VAR3 VAR9	VAR4	VAR5
VAR1	1.00000	.17637	.00672	-.07927	.10220
-.37899	-.02486	.14492	-.16802		
VAR2	.17637	1.00000	.26295	.45546	.01824
-.30901	-.30771	-.02573	-.00523		
VAR3	.00672	.26295	1.00000	.09560	.07672
-.01409	-.28108	-.21367	-.33932		
VAR4	-.07927	.45546	.09560	1.00000	.12376
-.06919	-.27040	-.19557	-.27605		
VAR5	.10220	.01824	.07670	.12376	1.00000
-.23632	.27583	.07978	-.58742		
VAR6	-.37899	-.30901	-.01409	-.06919	-.23632
1.00000	-.01062	-.26851	.18910		
VAR7	-.02486	-.30771	-.28108	-.27040	.27583
-.01062	1.00000	-.08133	-.07947		
VAR8	.14492	-.02573	-.21367	-.19557	.07978
-.26851	-.08133	1.00000	.01514		
VAR9	-.16802	-.00523	-.33932	-.27605	-.58742
.18910	-.07947	.01514	1.00000		

DETERMINANT OF CORRELATION MATRIX = .1300868(.13008684 +00)

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

INVERSE OF CORRELATION MATRIX..

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2	FACTOR 3
VAR1	.28906	-.04181	.36748
VAR2	.47214	.62269	.13785
VAR3	.32987	.21177	-.27279
VAR4	.40577	.36450	-.24460
VAR5	.53046	-.44019	-.06017
VAR6	-.50715	.02158	-.59726
VAR7	-.10015	-.53433	.03072
VAR8	.03550	-.12742	.42012
VAR9	-.77894	.39053	.34006

VARIABLE	COMMUNALITY	FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
VAR1	.22035	1	1.73657	44.6	44.6
VAR2	.62965	2	1.21568	31.2	75.8
VAR3	.22807	3	.94171	24.2	100.0
VAR4	.35734				
VAR5	.47878				
VAR6	.61439				
VAR7	.29648				
VAR8	.19400				
VAR9	.87491				

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FILE KAN (CREATION DATE = 26 APR 78) PCIF STUDY

DELTA = .00

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FILE KAN (CREATION DATE = 26 APR 78) PCIF STUDY
ROTATION FOR DIRECT OBLIMIN LOADINGS

ITERATION	DIROBL CRITERION
0	3.910030
1	3.107087
2	2.408284

ITERATION	DIROBL CRITERION
0	3.910030
1	3.307087
2	2.408284
3	1.992813
4	1.852807
5	1.808320
6	1.794732
7	1.790698
8	1.789495
9	1.789131
10	1.789019
11	1.788984

WELKER

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FILE   KAN   (CREATION DATE = 26 APR 78)   PCIP STUDY

AFTER ROTATION WITH KAISER NORMALIZATION

FACTOR PATTERN

	FACTOR 1	FACTOR 2	FACTOR 3
VAR1	.08161	.26133	.45375
VAR2	-.08853	.75863	.29258
VAR3	.21967	.37857	-.13030
VAR4	.17185	.54580	-.07928
VAR5	.66214	-.11819	.16412
VAR6	-.13176	-.15845	-.75061
VAR7	.23257	-.51949	.00553
VAR8	-.86936	-.14366	.40630
VAR9	-.92274	-.07978	-.00045

FACTOR CORRELATIONS

	FACTOR 1	FACTOR 2	FACTOR 3
FACTOR 1	1.00000	.11571	.27273
FACTOR 2	.11571	1.00000	-.64504
FACTOR 3	.27273	-.64504	1.00000

FACTOR STRUCTURE

FACTOR PATTERN

	FACTOR 1	FACTOR 2	FACTOR 3
VAR1	.08161	.06133	.45375
VAR2	-.08853	.75863	.29258
VAR3	.21967	.37857	-.13030
VAR4	.17185	.54580	-.07928
VAR5	.66214	-.11819	.16412
VAR6	-.13176	-.15845	-.75061
VAR7	.23257	-.51949	.00553
VAR8	-.06936	-.14366	.40630
VAR9	-.92274	-.07972	-.00045

FACTOR CORRELATIONS

	FACTOR 1	FACTOR 2	FACTOR 3
FACTOR 1	1.00000	.11571	.07273
FACTOR 2	.11571	1.00000	-.04504
FACTOR 3	.07273	-.04504	1.00000

FACTOR STRUCTURE

	FACTOR 1	FACTOR 2	FACTOR 3
VAR1	.12170	.05034	.45692
VAR2	.02053	.73521	.25198
VAR3	.25400	.40986	-.13138
VAR4	.22924	.56925	-.09136
VAR5	.66040	-.04896	.21760
VAR6	-.20468	-.13990	-.75306
VAR7	.17286	-.49223	.04584
VAR8	-.05644	-.16999	.40773
VAR9	-.93201	-.16653	-.06397

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FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

FACTOR SCORE COEFFICIENTS

II. OBLIQUE FACTOR ANALYSIS

SPRING SEASON, 5 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES - VAR 2-MAR AVERAGE MONTHLY PRECIPITATION

VAR 3-APR AVERAGE MONTHLY PRECIPITATION

VAR 4-MAY AVERAGE MONTHLY PRECIPITATION

VAR 5-JUN AVERAGE MONTHLY PRECIPITATION

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	19.9500	5.5928	30
VAR2	1.5290	.9548	30
VAR3	2.4923	1.4147	30
VAR4	3.7627	1.5821	30
VAR5	4.5097	2.2614	30

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

CORRELATION COEFFICIENTS..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.00000	.17637	.00672	-.07927	.10220
VAR2	.17637	1.00000	.26295	.45546	.01824
VAR3	.00672	.26295	1.00000	.09560	.07670
VAR4	-.07927	.45546	.09560	1.00000	.12376
VAR5	.10220	.01824	.07670	.12376	1.00000

DETERMINANT OF CORRELATION MATRIX = .6612742(.66127417 +00)

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

INVERSE OF CORRELATION MATRIX..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.08884	-.31623	.06350	.24164	-.14029
VAR2	-.31623	1.44108	-.32194	-.66462	.11299
VAR3	.06350	-.32194	1.08557	.05917	-.09121
VAR4	.24164	-.66462	.05917	1.33883	-.18281
VAR5	-.14029	.11299	-.09121	-.18281	1.04190

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

FACTOR MATRIX USING PRINCIPAL FACTOR WITH ITERATIONS

	FACTOR 1	FACTOR 2
VAR1	.17139	.63388
VAR2	.86561	.02624
VAR3	.26886	-.01895
VAR4	.52874	-.25309
VAR5	.10606	.07129

VARIABLE	COMMUNALITY	FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
VAR1	.43118	1	1.14176	70.8	70.8
VAR2	.74997	2	.47199	29.2	100.0
VAR3	.07265				
VAR4	.34362				
VAR5	.01633				

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FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY

DELTA = .00

WELKER 26 APR 78 PAGE 9

FILE KAN (CREATION DATE = 26 APR 78) PCIP STUDY
ROTATION FOR DIRECT OBLIMIN LOADINGS

ITERATION	DIROBL CRITERION
0	.870671
1	.723171
2	.625843
3	.614556
4	.613543
5	.613457
6	.613449

AFTER ROTATION WITH KAISER NORMALIZATION

FACTOR PATTERN

	FACTOR 1	FACTOR 2
VAR1	-.07010	.66795
VAR2	.81668	.16282
VAR3	.26366	.02317
VAR4	.59807	-.17268
VAR5	.07497	.08879

FACTOR CORRELATIONS

	FACTOR 1	FACTOR 2
FACTOR 1	1.00000	.21247
FACTOR 2	.21247	1.00000

FACTOR STRUCTURE

	FACTOR 1	FACTOR 2
VAR1	.07183	.65306
VAR2	.85127	.33634
VAR3	.26858	.07919
VAR4	.56138	-.04560
VAR5	.09383	.10472

FACTOR SCORE COEFFICIENTS

	FACTOR 1	FACTOR 2
VAR1	-.05145	.58404
VAR2	.75506	.29482
VAR3	.04673	.00690

III. STEPWISE MULTIPLE LINEAR REGRESSION

SPRING SEASON, 9 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES - VAR 2-MAR AVERAGE MONTHLY PRECIPITATION

VAR 3-APR AVERAGE MONTHLY PRECIPITATION

VAR 4-MAY AVERAGE MONTHLY PRECIPITATION

VAR 5-JUN AVERAGE MONTHLY PRECIPITATION

VAR 6-MAR AVERAGE MONTHLY TEMPERATURE

VAR 7-APR AVERAGE MONTHLY TEMPERATURE

VAR 8-MAY AVERAGE MONTHLY TEMPERATURE

VAR 9-JUN AVERAGE MONTHLY TEMPERATURE

FILE KAN (CREATION DATE = 18 APR 78) PCIP STUDY YRS BYU 4MOS S
ONS

* M U L T I P L E R E G
S S I O N * * * * * * * * * * * * * * VARIABLE LIST 1

REGRESSION LIST 1

EPENDENT VARIABLE.. VAR1

SUMMARY TABL

VARIABLE	MULTIPLE R	R SQUARE	RSQ CHANGE	SIMPLE R	B	BETA
VAR6	.37899	.14363	.14363	-.37899	-.31002	-.29419
VAR4	.39347	.15482	.01118	-.07927	-.98974	-.27998
VAR9	.41481	.17207	.01725	-.16803	-.47971	-.28587
AR2	.44300	.19625	.02418	.17637	1.32874	.22684
AR3	.45315	.20535	.00910	.00672	-.56677	-.14337
AR7	.46068	.21222	.00688	-.02486	-.12338	-.07691
VAR5	.46397	.21527	.00304	.10220	-.17938	-.07253
(CONSTANT)					79.30794	

III. STEPWISE MULTIPLE LINEAR REGRESSION

SPRING SEASON, 5 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES -VAR 2-MAR AVERAGE MONTHLY PRECIPITATION
VAR 3-APR AVERAGE MONTHLY PRECIPITATION
VAR 4-MAY AVERAGE MONTHLY PRECIPITATION
VAR 5-JUN AVERAGE MONTHLY PRECIPITATION

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* * * * * * * * * * * * * * * * * * * * * * * * * * * * * M U L T I P L E   R E G
S S I O N  * * * * * * * * * * * * *      VARIABLE LIST  1

                                               REGRESSION LIST  1
EPENDENT VARIABLE..     VAR1

                                                                   SUMMARY TABL

VARIABLE                                                      MULTIPLE R   R SQUARE
SQ CHANGE    SIMPLE R                     B                   BETA

VAR2                                                              .17637      .03111
  .03111       .17637                 1.70124                 .29043
AR4                                                                .25149     .06325
  .03214      -.07927                 -.78451                -.22192
VAR5                                                                .28009      .07845
  .01520       .10220                  .31864                 .12884
AR3                                                                .28564     .08159
  .00314       .00672                 -.23054                -.05832
 (CONSTANT)
                                        19.43829


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          19 APR 78          PAGE     5

          10.

        DATA TRANSFORMATION DONE UP TO THIS POINT

              NO OF TRANSFORMATIONS                    0
             NO OF RECODE VALUES                      0
             NO OF ARITHM. OR LOG. OPERATIONS         0
       THE AMOUNT OF TRANSPACE REQUIRED IS           0 WORDS
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I. ORTHOGONAL FACTOR ANALYSIS

EARLY WINTER SEASON, 5 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES-VAR 2-NOV AVERAGE MONTHLY PRECIPITATION

VAR 3-DEC AVERAGE MONTHLY PRECIPITATION

VAR 4-NOV AVERAGE MONTHLY TEMPERATURE

VAR 5-DEC AVERAGE MONTHLY TEMPERATURE

FILE KAN (CREATION DATE = 30 MAR 79) PCIP STUDY

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	20.6100	6.0974	30
VAR2	.8970	.9351	30
VAR3	.8533	.5949	30
VAR4	43.2333	2.8175	30
VAR5	32.6300	3.6992	30

FILE KAN (CREATION DATE = 30 MAR 79) PCIP STUDY

CORRELATION COEFFICIENTS..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.00000	-.05540	-.11352	-.27240	.10390
VAR2	-.05540	1.00000	.13476	-.06323	-.07737
VAR3	-.11352	.13476	1.00000	.18920	-.05236
VAR4	-.27240	-.06323	.18920	1.00000	.00080
VAR5	.10390	-.07737	-.05236	.00080	1.00000

DETERMINANT OF CORRELATION MATRIX = .8461569(.84615686 +00)

FILE KAN (CREATION DATE = 30 MAR 79) PCIP STUDY

INVERSE OF CORRELATION MATRIX..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.10086	.06384	.05524	.29354	-.10678
VAR2	.06384	1.03585	-.14995	.11120	.06557
VAR3	.05524	-.14995	1.06560	-.19607	.03861
VAR4	.29354	.11120	-.19607	1.12411	-.03306
VAR5	-.10678	.06557	.03861	-.03306	1.01822

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	-.50778	.00100	.27080	-.06765
VAR2	.09620	.45843	.00621	.12135
VAR3	.37901	.22937	.27019	-.07413
VAR4	.58706	-.26348	.10040	.00857
VAR5	-.12360	-.19539	.19772	.18579

VARIABLE PCT OF VAR	COMMUNALITY CUM PCT	FACTOR	EIGENVALUE
VAR1	.33575	1	.77066
55.2	55.2		
VAR2	.23418	2	.37037
26.5	81.7		
VAR3	.27475	3	.19555
14.0	95.7		
VAR4	.42421	4	.05939
4.3	100.0		
VAR5	.12707		

FILE KAN (CREATION DATE = 30 MAR 79) PCIP STUDY

VARIMAX ROTATED FACTOR MATRIX

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
VAR1	-.04996	-.53954	-.07757	.19010
VAR2	.11272	-.01496	.45591	-.11571
VAR3	.47837	.12309	.16580	-.05720
VAR4	.33149	.52473	-.18392	.07183
VAR5	-.02554	-.05773	-.07925	.34176

TRANSFORMATION MATRIX

	FACTOR 1	FACTOR 2	FACTOR 3	FACTOR 4
FACTOR 1	.53887	.82314	.06217	-.16793
FACTOR 2	.21330	-.28658	.83944	-.40954
FACTOR 3	.73974	-.36652	-.03842	.56300
FACTOR 4	-.34191	.32555	.53852	.69793

II. OBLIQUE FACTOR ANALYSIS

EARLY WINTER SEASON, 5 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES -VAR 2-NOV AVERAGE MONTHLY PRECIPITATION

VAR 3-DEC AVERAGE MONTHLY PRECIPITATION

VAR 4-NOV AVERAGE MONTHLY TEMPERATURE

VAR 5-DEC AVERAGE MONTHLY TEMPERATURE

FILE KANSAS (CREATION DATE = 30 MAR 79) PCIP STUDY

VARIABLE	MEAN	STANDARD DEV	CASES
VAR1	20.6100	6.0974	30
VAR2	.8970	.9351	30
VAR3	.8533	.5949	30
VAR4	43.2333	2.8175	30
VAR5	32.6300	3.6992	30

WELKER
30 MAR 79 PAGE 4

FILE KANSAS (CREATION DATE = 30 MAR 79) PCIP STUDY

CORRELATION COEFFICIENTS..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.00000	-.05540	-.11352	-.27240	.10390
VAR2	-.05540	1.00000	.13476	-.06323	-.07737
VAR3	-.11352	.13476	1.00000	.18920	-.05236
VAR4	-.27240	-.06323	.18920	1.00000	.00080
VAR5	.10390	-.07737	-.05236	.00080	1.00000

DETERMINANT OF CORRELATION MATRIX = .8461569(.84615686 +00)

WELKER
30 MAR 79 PAGE 5

FILE KANSAS (CREATION DATE = 30 MAR 79) PCIP STUDY

INVERSE OF CORRELATION MATRIX..

	VAR1	VAR2	VAR3	VAR4	VAR5
VAR1	1.10086	.06384	.05524	.29354	-.10678
VAR2	.06384	1.03585	-.14995	.11120	.06557
VAR3	.05524	-.14995	1.06560	-.19607	.03861
VAR4	.29354	.11120	-.19607	1.12411	-.03306
VAR5	-.10678	.06557	.03861	-.03306	1.01822

FILE NAME KANSAS PCIP STUDY

	FACTOR 1	FACTOR 2
VAR1	-.39446	-.09303
VAR2	.04266	.49951
VAR3	.29874	.21732
VAR4	.72517	-.18926
VAR5	-.08012	-.17867

VARIABLE	COMMUNALITY	FACTOR	EIGENVALUE	PCT OF VAR	CUM PCT
VAR1	.16425	1	.77895	67.6	67.6
VAR2	.25133	2	.37314	32.4	100.0
VAR3	.13648				
VAR4	.56169				
VAR5	.03834				

WELKER 30 MAR 79 PAGE 8

FILE KANSAS (CREATION DATE = 30 MAR 79) PCIP STUDY

DELTA = .00

WELKER 30 MAR 79 PAGE 9

FILE KANSAS (CREATION DATE = 30 MAR 79) PCIP STUDY
ROTATION FOR DIRECT OBLIMIN LOADINGS

ITERATION	DIROBL CRITERION
0	.964998
1	.753702
2	.682564
3	.673688
4	.672737
5	.672637
6	.672626
7	.672625

FACTOR PATTERN

	FACTOR 1	FACTOR 2
VAR1	-.36724	-.10288
VAR2	-.09422	.51639
VAR3	.23794	.22953
VAR4	.77373	-.18280
VAR5	-.03087	-.18584

FACTOR CORRELATIONS

	FACTOR 1	FACTOR 2
FACTOR 1	1.00000	.24881
FACTOR 2	.24881	1.00000

FACTOR STRUCTURE

	FACTOR 1	FACTOR 2
VAR1	-.39284	-.19425
VAR2	.03427	.49295
VAR3	.29505	.28873
VAR4	.72825	.00971
VAR5	-.07711	-.19352

FACTOR SCORE COEFFICIENTS

	FACTOR 1	FACTOR 2
VAR1	-.19197	-.14291

FACTOR VARIABLES=VAR1 TO VAR5/
TYPE=PA2/
ROTATE=OBLIQUE/
STATISTICS 1,2,3,4,5,6,7
READ INPUT DATA

III. STEPWISE MULTIPLE LINEAR REGRESSION

EARLY WINTER SEASON, 5 VARIABLES

PERIOD 1941-1970

DEPENDENT VARIABLE-VAR 1-ANNUAL YIELD

INDEPENDENT VARIABLES-VAR 2-NOV AVERAGE MONTHLY PRECIPITATION

VAR 3-DEC AVERAGE MONTHLY PRECIPITATION

VAR 4-NOV AVERAGE MONTHLY TEMPERATURE

VAR 5-DEC AVERAGE MONTHLY TEMPERATURE

VAR2	-.37816	-.05799	1.26277	.090
VAR3	-.51426	-.05018	2.01408	.065
(CONSTANT)	41.12001			

MAXIMUM STEP REACHED

WELKER
30 MAR 79 PAGE 4

FILE KAN (CREATION DATE = 30 MAR 79) PCIP STUDY YRS BY 4MO SEA
SONS

* M U L T I P L E R E G
R E S S I O N * * * * * * * * * * * * * VARIABLE LIST 1

REGRESSION LIST 1
DEPENDENT VARIABLE.. VAR1

SUMMARY TABL
E

VARIABLE			MULTIPLE R	R SQUARE
RSQ CHANGE	SIMPLE R	B	BETA	
VAR4			.27240	.07420
.07420	-.27240	-.57707	-.26665	
VAR5			.29162	.08504
.01084	.10390	.15988	.09700	
VAR2			.29875	.08925
.00421	-.05540	-.37816	-.05799	
VAR3			.30269	.09162
.00237	-.11352	-.51426	-.05018	
(CONSTANT)				
		41.12001		

APPENDIX E

ECONOMIC INFLUENCES ON THE KANSAS YIELD TIME SERIES

ECONOMIC INFLUENCES ON THE KANSAS YIELD TIME SERIES

The American agricultural sector and, subsequently, the Kansas yield time series from 1885-1975, as shown in Figure 3, have been affected by a number of economic factors. One of the most important factors is the relative magnitude of the prices paid to the farmer for agricultural produce versus his production costs. Other factors in assessing changes in yield over long periods are the technological and scientific inputs into the American agricultural system, factors which are related to the profit margin realized by the farmer. Both the history of new profits to the farmer and technological inputs to agriculture will be briefly sketched below.

The two decades known as the "Golden Years of American Agriculture" started in 1896, and are so called because of the dramatic improvement in the economic status of the American farmer. From the post-Civil War years to the middle of the 1890's, farm prices had continually declined, even though production had continued to rise. In the 1870's, for example, farm prices declined at nearly 4 percent a year while production grew at 6 percent annually; during the 1880's and 1890's, it grew at only 2 percent per year. These data are reflected in the top of Figure E.1.[49] The principal difference in the economic status of the American farmer between the 20 years after 1896 and the pre-1896 period was due to the growth of the industrial sector of the American economy. A basic requirement for vitalization in American agriculture is an annual rate of increase in industrial growth which is far greater than that of the comparable growth in agriculture. As shown in the bottom of Figure E.1, the industrial growth during the "Golden Agricultural Era" of 1896-1915 increased by 156 percent while agricultural production increased by 50 percent.[50] Because of this 3-to-1 production increase ratio, industrial income was able to absorb the 50 percent increase in farm production, the costs of a normal increase in farm population, and a relative slackening in agricultural exports from the pre-1986 period. As a result of these favorable conditions the number of farms rose from 4.5 million in 1890 to 6.4 million in 1910; by 1920 the number was 6.5 million.

From 1911-1915, income per person employed in agriculture was $370 compared with $595 per person employed in industry. This income ratio, established in 1911-1915 and not achieved again until the World War II years, has been advanced by some as the yardstick from which to compute "parity income" for agriculture. During the period 1915-1921, World War I caused a mild increase in cultivated total grain acreage, from 203 million acres in 1914 to 227 million in 1919, a 12 percent increase. Harvested wheat acreage, however, increased greatly due to World War I, going from 47 million acres average annual area during 1909-1913 to 74 million in 1919. After 1920, American agriculture went into a long and severe economic slump, which certainly affected the inputs into modern farming practices and should be reflected in the yield time series statistically analyzed in this paper.[51]

The top portion of Figure E.2 depicts the long and deep economic slide of the American farmer which began in the middle of 1920.[52] For a year and a half after World War I, the stimulation of farm demand and prices remained artificially high. The World War I years had only been a continuation of the two and a half decades of prosperity in American agriculture which had begun in the mid-1890's. This long period of prosperity ended with a large number of American farmers owing

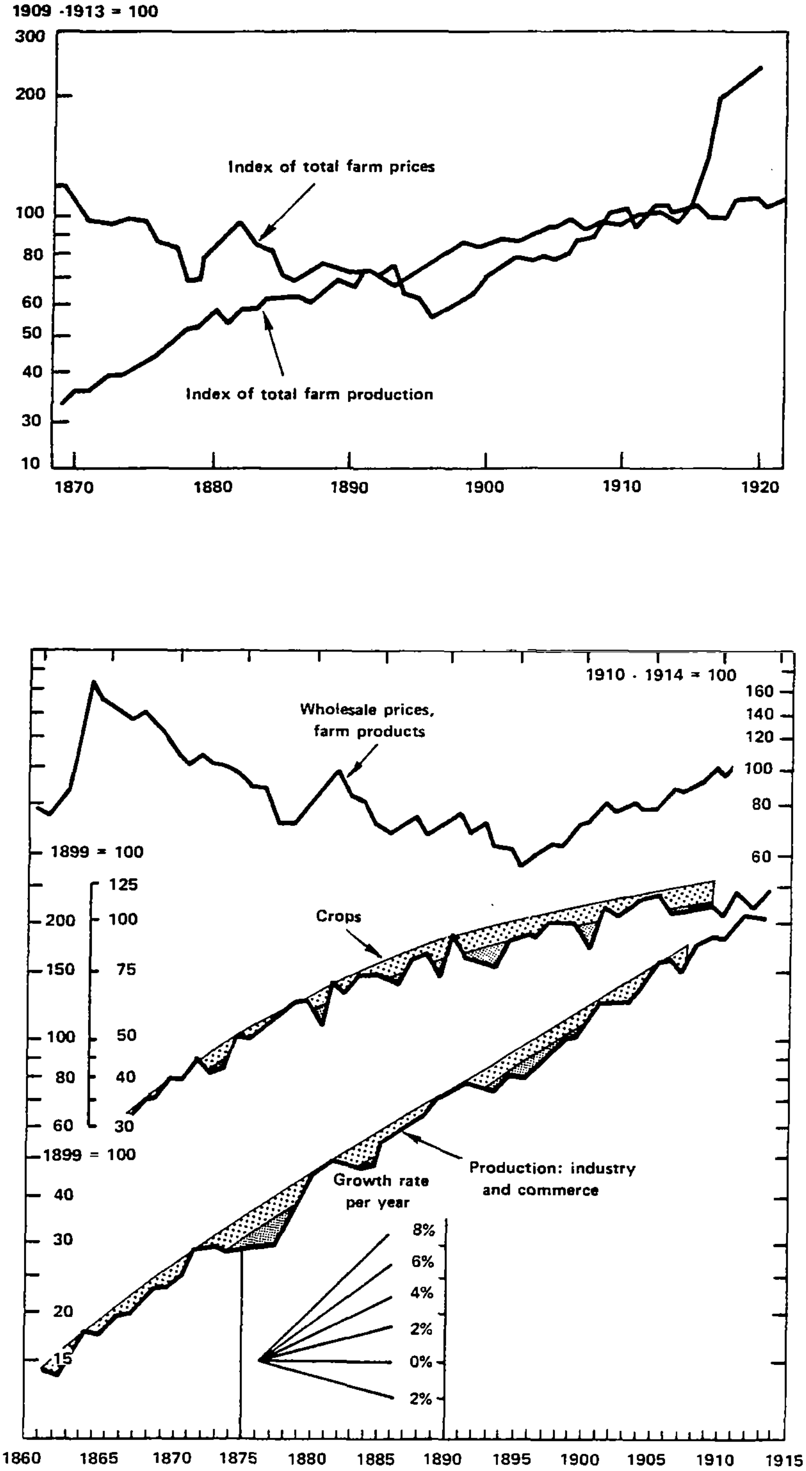


Figure E.1. Agricultural production and prices in the United States during the late 19th and early 20th Centuries.[49,50]

Ratio of prices received by farmers to prices paid by farmers, 1914 - 59.
(5 - year moving averages: 1910 - 14 = 100)

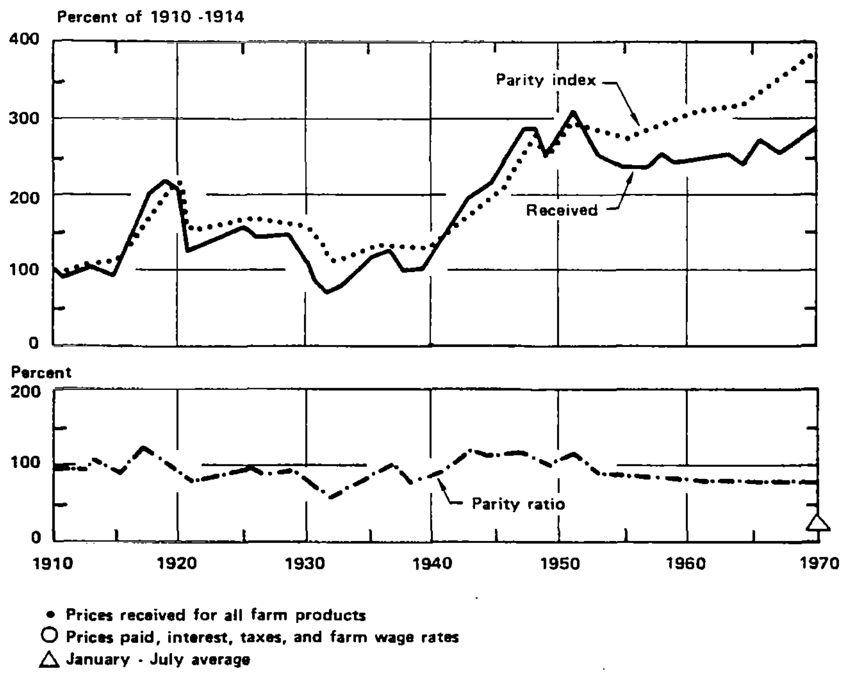


Figure E.2. Agricultural prices in the United States, 1910-1970, United States Department of Agriculture.[51]

huge debts and mortgages. Long-term agricultural debt went from 3.2 to 8.4 billion dollars between 1910 and 1920 and, after the rapid drop in agricultural prices, reached 11 billion dollars by 1923. Industrial prices were bad but agricultural prices suffered much more. At the end of 1921, wheat that had sold for 2.58 dollars a bushel a year and a half earlier, sold for 93 cents a bushel. Although the 1920's were very bad for the American farmer, the 1930's were even worse. The farm price index, as shown at the bottom of Figure E.2, had dropped from a value of 147 in January, 1930 to 57 by February, 1933. In 1932, the net realized income from agriculture was a little over 1.8 billion, less than one-third of the 1929 figure and less than one-half of that for 1921, the first poor year of the 1920's. These poor economic factors undoubtedly affected farm inputs and subsequent yields in the state of Kansas during the 1920's and 1930's.[53]

The first break in the agricultural price slide occurred after the election of Franklin D. Roosevelt. Farm prices began to climb in 1933, and then slid back again during the recession of 1937-1938. By 1941, increased demands for wheat for domestic consumption and exportation started a climb in the prices of agricultural produce, and this increase was sustained with the entrance of the United States into World War II. Contrary to expectations, prices remained high immediately after World War II, then started to fall in 1948. From the all-time high of 16.8 billion dollars in 1948, net agricultural income for the American farmer dropped to 13 billion dollars in 1950. By 1962, gross agricultural income had reached an all-time high of 40 billion dollars, but the net income was only 14.6 billion, still less than that of 1948. Gross agricultural income rose steadily from 1962 to 1970, but due to enormous increases in expenses, net farm income continued to fall below the 1948 high.[54]

Some of the effects of the inability of the American agricultural community to make more than 16.8 billion dollars per year through the 1960's is demonstrated in Figure E.3.[55] The number of farms declined rapidly through 1970, while the average acreage per farm increased dramatically. Total agricultural acreage also increased monotonically through 1960, before undergoing a decline through 1970. The results of a near-fixed net income for the agricultural community over the 1950's and 1960's, combined with rising land values, have caused the failure or closing of many marginally profitable farms and have directed agriculture toward larger, more highly mechanized, modern and efficient farming operations. This new direction has decreased crop losses and uncertainties in production from a variety of causes. The one notable exception to this trend is the production fluctuation due to variations in climate, which is still very difficult and expensive to alter in spite of improvements like modern irrigation methods.

Mechanization and scientific improvements have also affected yield since the nineteenth century. Modern farming practices can be separated into two categories; the effects of mechanization and technology, and those improvements gained from utilizing the new developments of pure science. In the mechanization and technology category, three overlapping periods can be identified.[56] The basic invention period occurred in the 1830-1880 time period, starting with the invention of McCormick's reaper and ending with the combined thresher-reaper or "combine," which came into extensive use in dry level wheatland such as that of the state of Kansas, in the 1880's. The second period of mechanization extended from 1860 to 1910, and was characterized by extensive use of machinery run by animal power. By 1900, there was almost as varied a selection of farming implements as exists today.[57] The third period of mechanization, starting in 1900 and continuing to

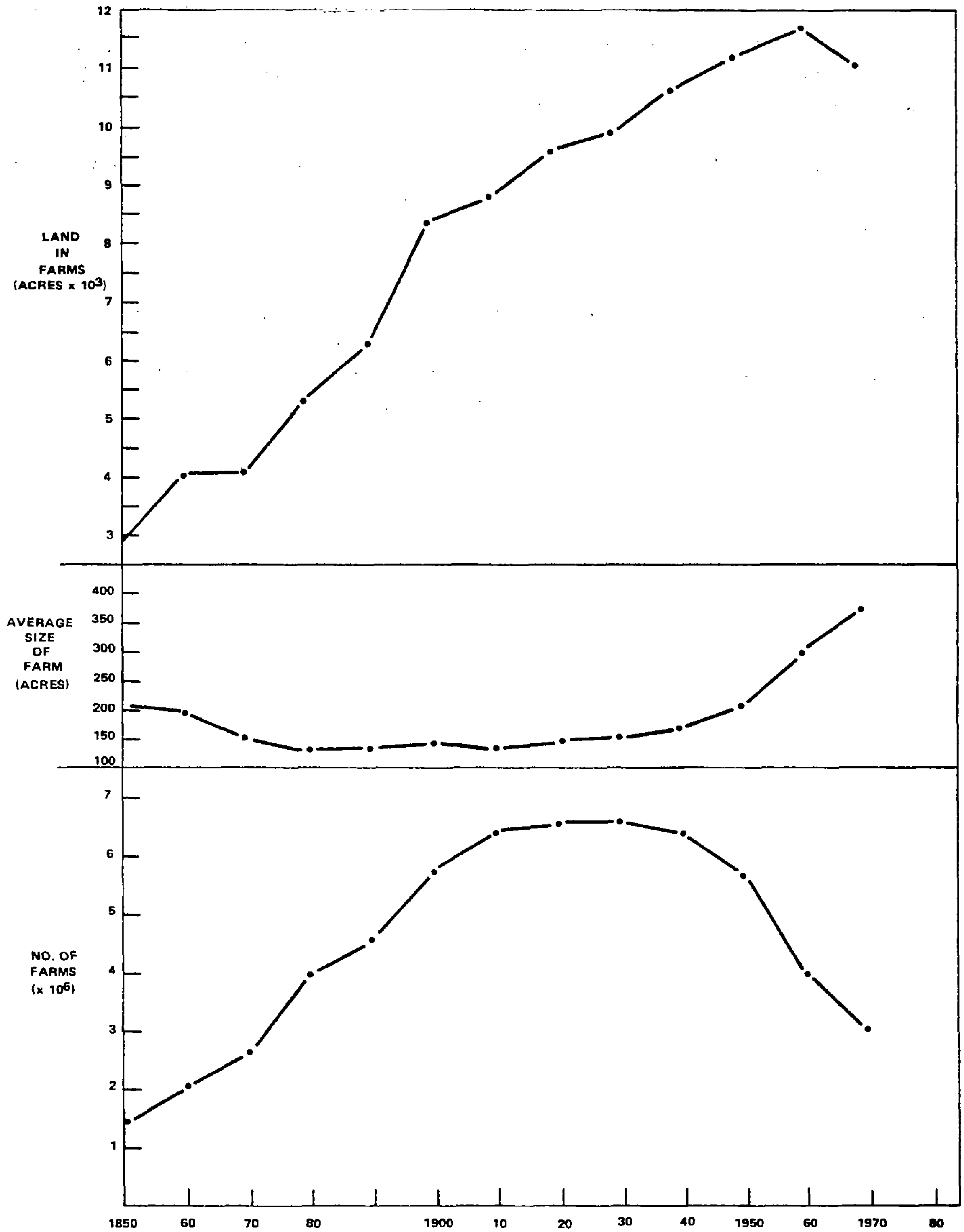


Figure E.3. Historical statistics of American agriculture over the period 1850-1970.[55]

the present, was one of conversion to power-driven equipment. The gasoline tractor was introduced in 1905, and by 1920, 250,000 were in operation. Prior to 1920, these three phases of mechanization and technology made the major contributions to improvements in modern farming practices. Although scientific discoveries fostered such improvements as plant breeding, varietal selection of grain seeds and natural hybridization, those developments were not in widespread use. Many developments in soil science, fertilization, and plant nutrients were also neglected in practice, as well as new insecticides and fungicides. These scientific improvements were only incorporated into American agriculture after World War I.[58]

The sudden upward growth trend in winter wheat yield after 1940 has been attributed by some to the great increase in agricultural technology caused by World War II. The two-part linear trend for LACIE models for the post-1940 period, shown in Figure 3, attributes the growth trend to "technology effects." There is some validity to these assumptions; the American agricultural community since World War II has undergone major changes due to scientific and technological improvements.[59]

APPENDIX F

CLIMATIC AND PHENOLOGICAL VARIATIONS AFFECTING THE KANSAS YIELD

TIME SERIES

CLIMATIC AND PHENOLOGICAL VARIATIONS AFFECTING THE KANSAS YIELD TIME SERIES

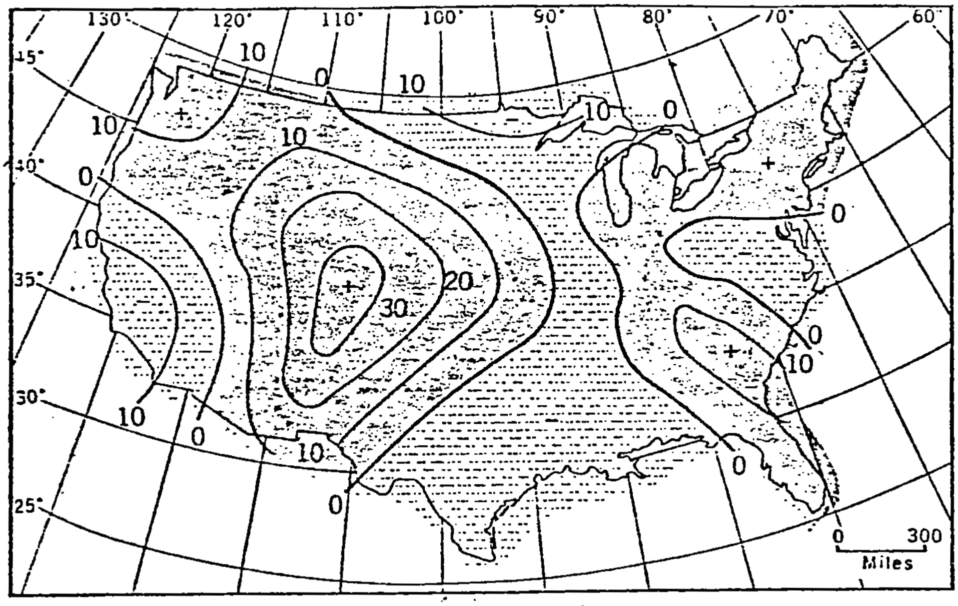
The effects of many climatic factors, severe storms, and phenologic variations have drastically changed Kansas winter wheat growth conditions over the 1887-1970 period. These changes have considerably altered the yield time series in this period. Despite the complexity of tracking and understanding the relative importance of these changes, the 1880's represent the beginning of the modern collection of agricultural statistics for Kansas. This set of statistical data is becoming increasingly important to the understanding of the extent of damage to agricultural production from episodic events, and for the construction of reliable yield models for remote sensing estimates of winter wheat yield production. LACIE yield models use multiple linear regression techniques for independent variables formed from monthly averages of air temperature and precipitation, the same variables which have been tested in this paper. LACIE yield models have also been constructed for each of the nine crop reporting districts of Kansas; this paper statistically analyzes data from Kansas crop reporting districts.[60] Figure 3 shows the Kansas wheat yield time series from 1885-1975 that has been used in this paper.[61] Figure 3, also compares the variability of collective September through December precipitation on the wheat yield for the State of Oklahoma.

LONG-TERM CLIMATIC VARIATIONS

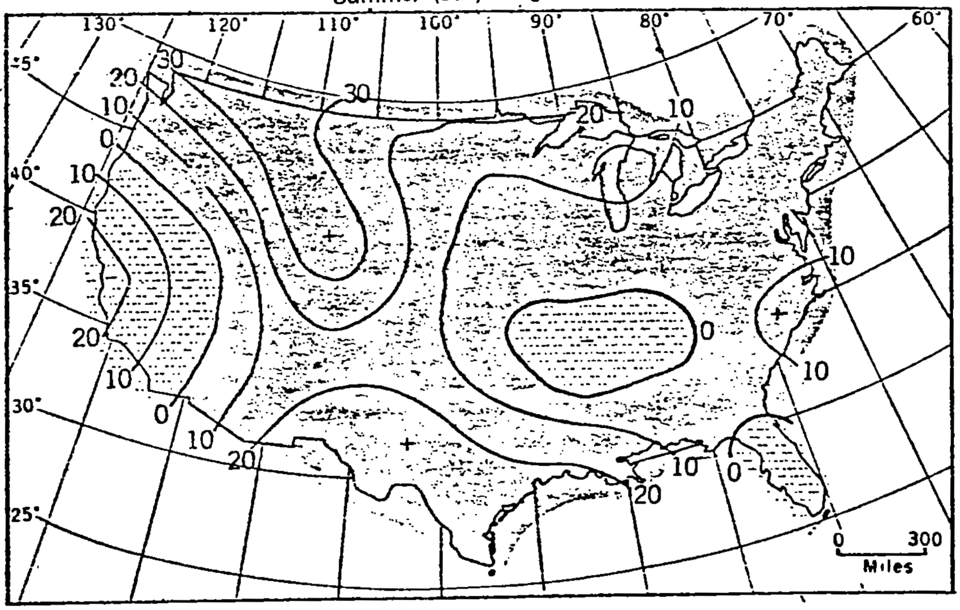
Although the time series in Figure 3 starts in the late 1880's, the model approach taken by LACIE initiated the yield time series analysis in 1932 and attributes year-to-year fluctuations from a linear trend to annual weather variations.[62] This approach limits possible interpretations of the more slowly varying components of climate with periods of a decade or longer, and their effect on winter wheat yield in Kansas. Recent ongoing research described in the open literature has been directed toward investigating these more slowly varying climatic components which span data sets from the nineteenth century.[63] Furthermore, there is evidence that suggests that the climate of future decades will be more like that of the mid-nineteenth century than climatic conditions indicated by 1930-1960 normals. Substantial precipitation and temperature deviations have occurred over the last century in Kansas which would affect soil moisture levels in the fall and resultant winter wheat yields, as shown, for example, in Figures F.1-F.4.[64] These reasons, among others, indicate that a closer look at the 1887-1970 yield time series data set may provide additional insights into the problem.

SEVERE STORM PHENOMENA

Statistical analyses of the Kansas yield time series also include assumptions and approximations for severe storm phenomena which are different from those found in crop growth simulations on an experimental farm. For example, Figure F.5 defines isolines in percentage of months in severe or extreme drought.[65] Kansas has a greater high probability drought area than any other state in the continental United States over the period considered. Droughts were very severe in the 1930's, especially for the years of 1934 and 1936.[66]

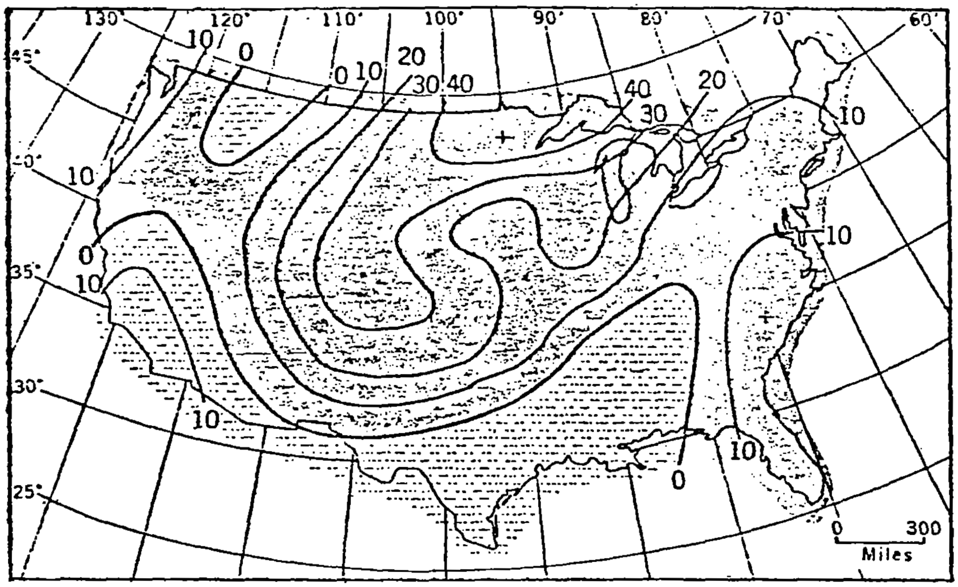


Summer (July–August)

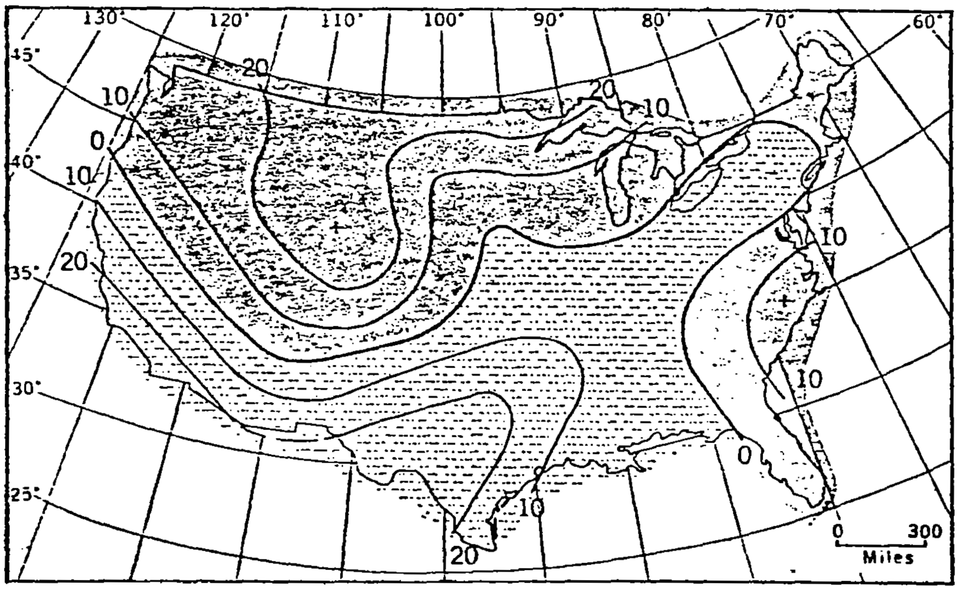


Early Fall (September–October)

Figure F.1. Precipitation deviations (%) of the 1850's and 1860's from the 1931-1960 climatic normals for the summer and early fall seasons in the United States.[64]

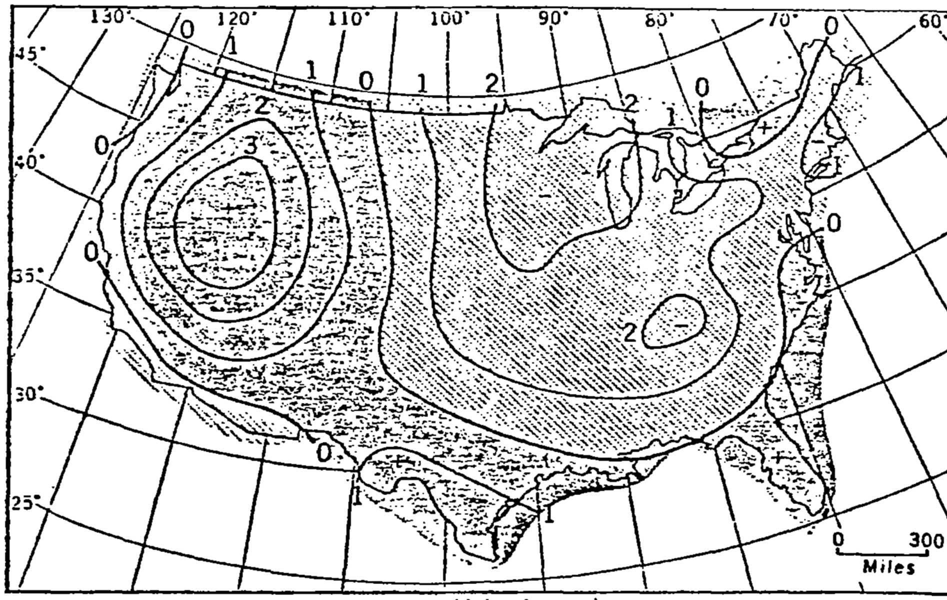


Winter (January-March)

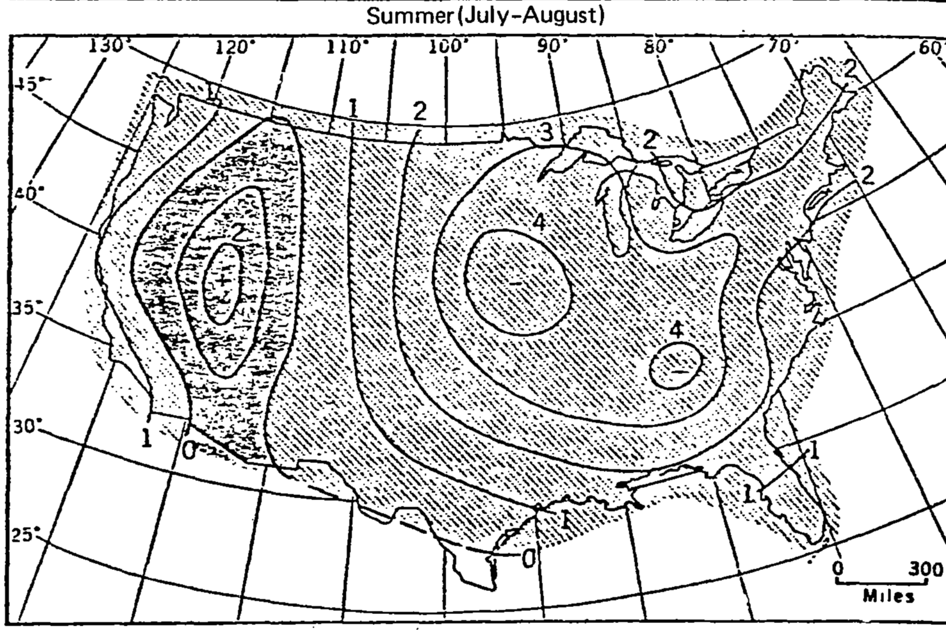


Spring (April-June)

Figure F.2. Precipitation deviations (%) of the 1850's and 1860's from the 1931-1960 climatic normals for the winter and spring seasons in the United States.[64]

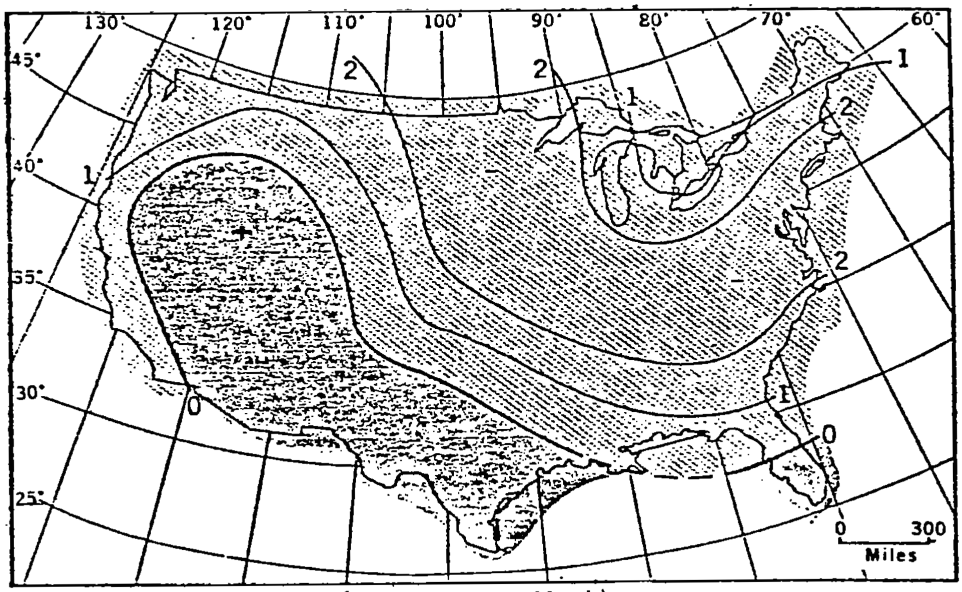


Summer (July-August)

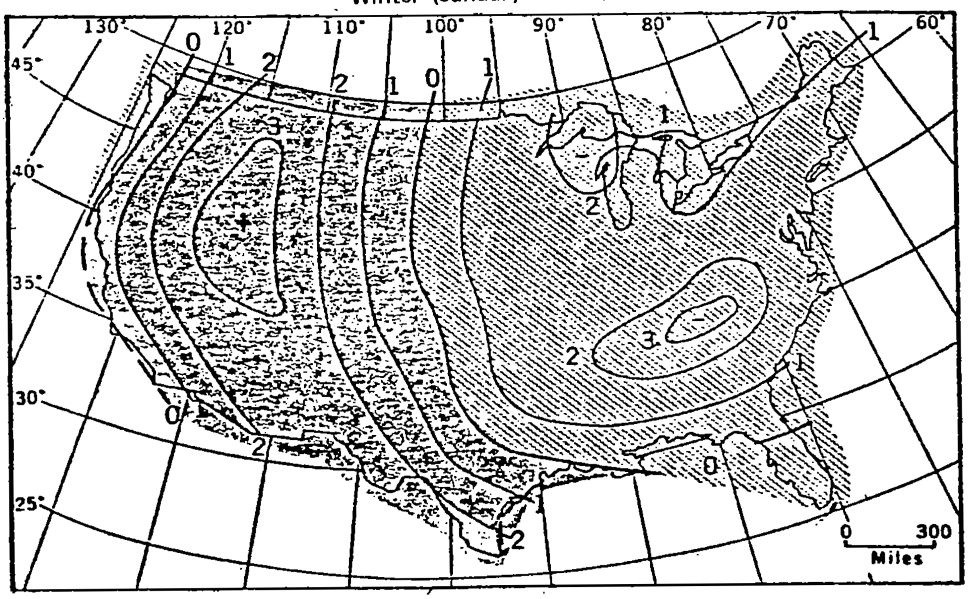


Early Fall (September-October)

Figure F.3. Temperature deviations (in °F) of the 1850's and 1860's from the 1931-1960 climatic normals for the summer and early fall seasons in the United States.[64]



Winter (January-March)



Spring (April-June)

Figure F.4. Temperature deviations (in °F) of the 1850's and 1860's from the 1931-1960 climatic normals for the winter and spring seasons in the United States.[64]

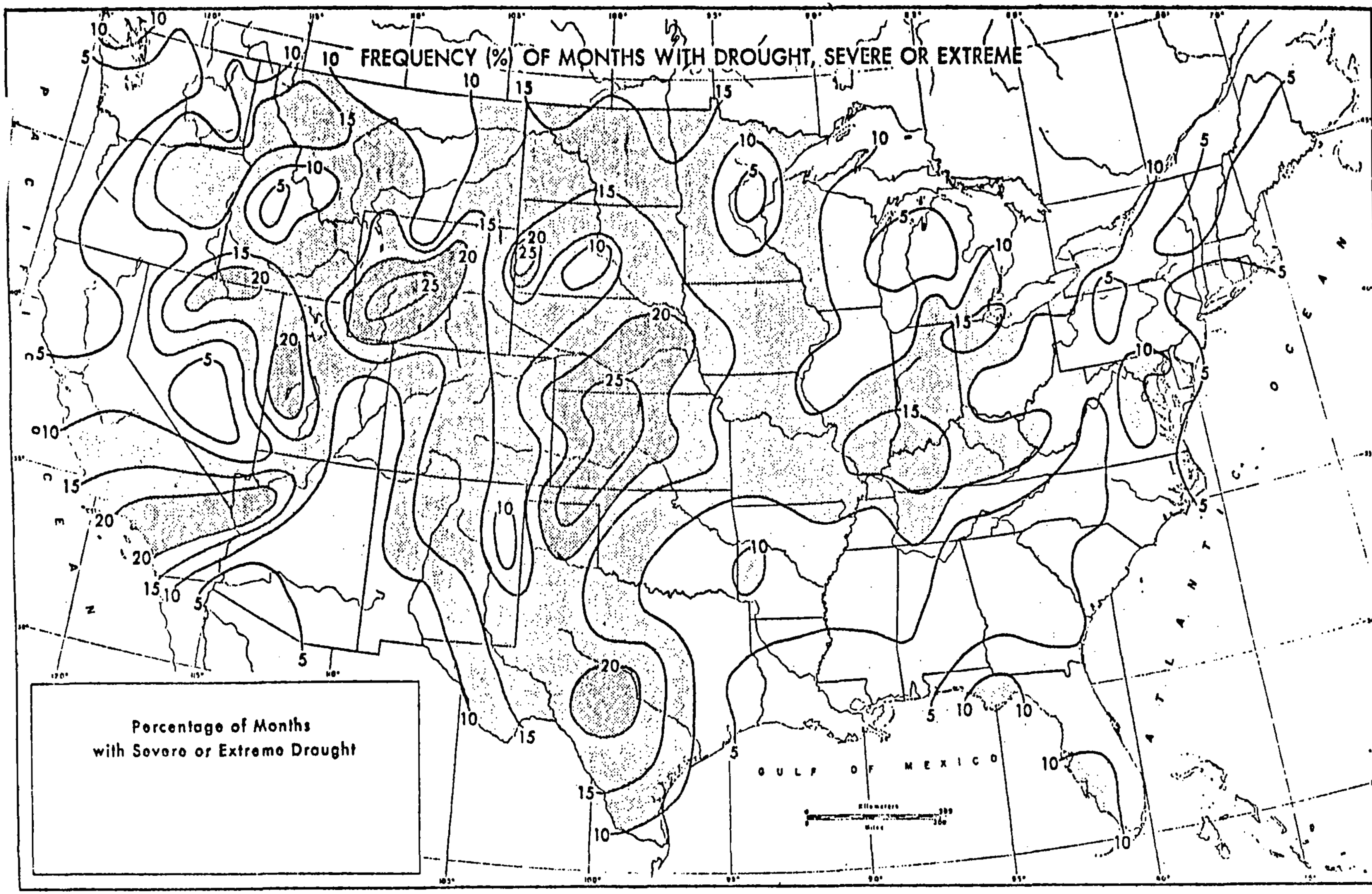


Figure F.5. Frequency (%) of months with severe or extreme drought in the United States over the 1931-1960 period (Eastern United States) and the 1931-1967 period (Western United States). (Manuscript map supplied by Dr. Wayne C. Palmer).[65]

EPISODIC EVENTS

Kansas also has a high incidence of other severe weather conditions injurious to winter wheat yield, as shown in Figure F.6.[67] High frequency zones for both the mean annual incidence of large hail (> 19 mm) and tornadoes per 26,000 km^2, for data sets over 1955-1967, lie in the vicinity of Kansas wheat areas. Tornadoes, the most violent of meteorological storms, are found more frequently in the central United States than any other place in the world.[68]

Another significant short-term weather factor contributing to the degradation of winter wheat yield is the phenomenon of winterkill. Winterkill was an acknowledged loss factor from the earliest years in the 1887-1970 yield time series, as demonstrated by the data in Tables F.1 and F.2.[69] The hard red Turkey or "Crimean" wheats had been in use for more than a decade by 1887; these are the same general kinds of wheats which accounted for 60 percent of the wheat plantings in the United States for 1969.[70] Traditionally, hard red winter wheat is supposed to be more resistant to winterkill than the soft winter wheat varieties. Malin claims this to be only relatively true, and supports his claim by quoting the 10 year average winterkill losses over the period 1911-1920. The eastern third of the state of Kansas, planted mostly to soft winter wheat, lost 8.5 percent, while the central and western thirds of the state, both planted to hard red winter, lost 18.3 and 34.4 percent respectively, for this ten year period. These losses accounted for a state total average of 19.9 percent.[71] Of the many separate contributors to the phenomenon of winterkill, one of the most damaging combines low temperatures with loss of the snow cover which acts primarily as a thermal blanket protecting the wheat plant. Winterkill damage of this type is greatest when temperatures colder than -20°C persist for a number of days.[72] Figures F.7-F.10 indicate the extremes of low temperatures, the duration of the days below freezing, and the range of calendar dates for 2.5 cm of snow cover for the state of Kansas within the framework of the mapping of these conditions throughout the continental United States.[73]

STEADY-STATE CLIMATIC CONDITIONS AND PHENOLOGY

Turning to the "steady-state" climatic conditions, the ranges of variability in the "normal" agroclimate are very often responsible for fluctuations in wheat yield, rather than the extreme conditions of severe storms and episodic events. Although the statistical analyses of the Kansas yield time series included the independent variables of average monthly precipitation and temperatures, other variables may have been more significant. The determination of more appropriate variables and an eventual model development for yields in Kansas would be a logical continuation of this present study. Nevertheless, variations due to phenology and degree-day summations are so important that some indication of the ranges of these variables over Kansas will be made here. The annual growing degree-days for the state, based on normal temperature conditions, is indicated in Figure F.11.[74] Figure F.11 also shows that Upper Southern Maryland, the site of the BARC Project, has approximately the same annual growing degree-days as central Kansas. For a particular experimental farm station located at Hays in Ellis County in the Central Crop Reporting District of Kansas, Figure F.12 and Table F.3 describe the phenology and degree-day summations over the 1932-1951 period.[75] The years 1947-1948 and 1948-1949 had extremely late emergence dates, while 1939-1940 winter wheat plantings failed to emerge until the following spring. Whether these phenological abnormalities were characteristic for those years of the larger substate regions has not been determined.

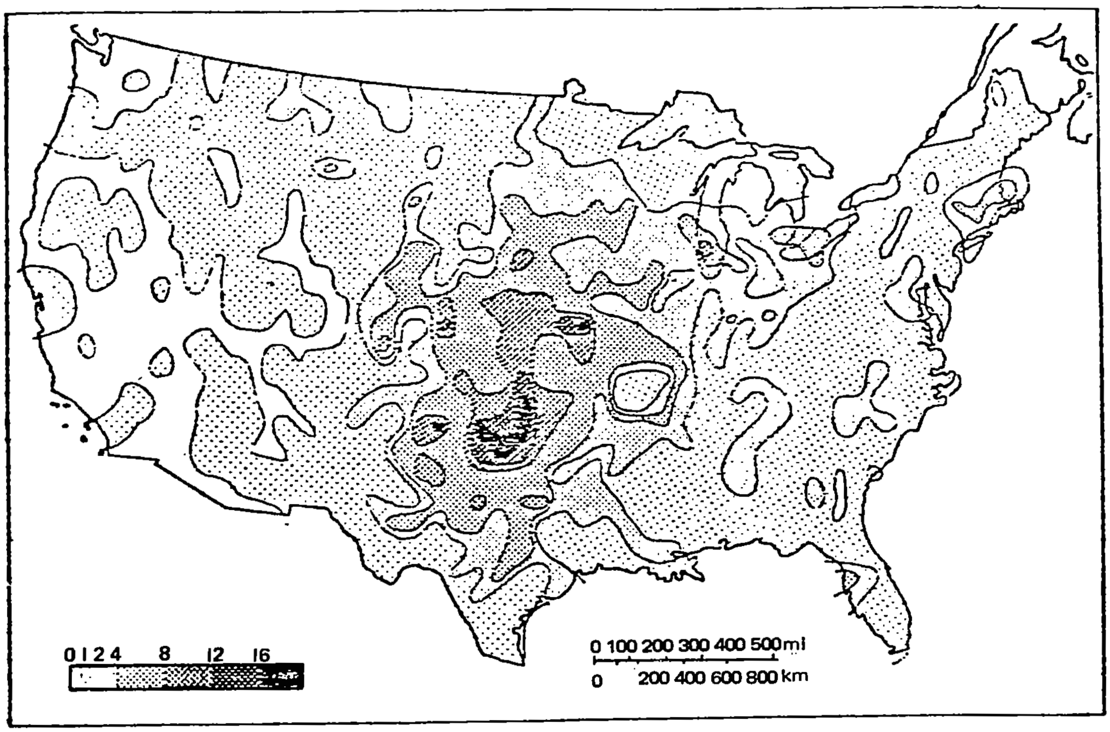


Figure F.6a. Mean annual incidence of large hail (> 19 mm) per 26,000 km^2, 1955-1967.[67]

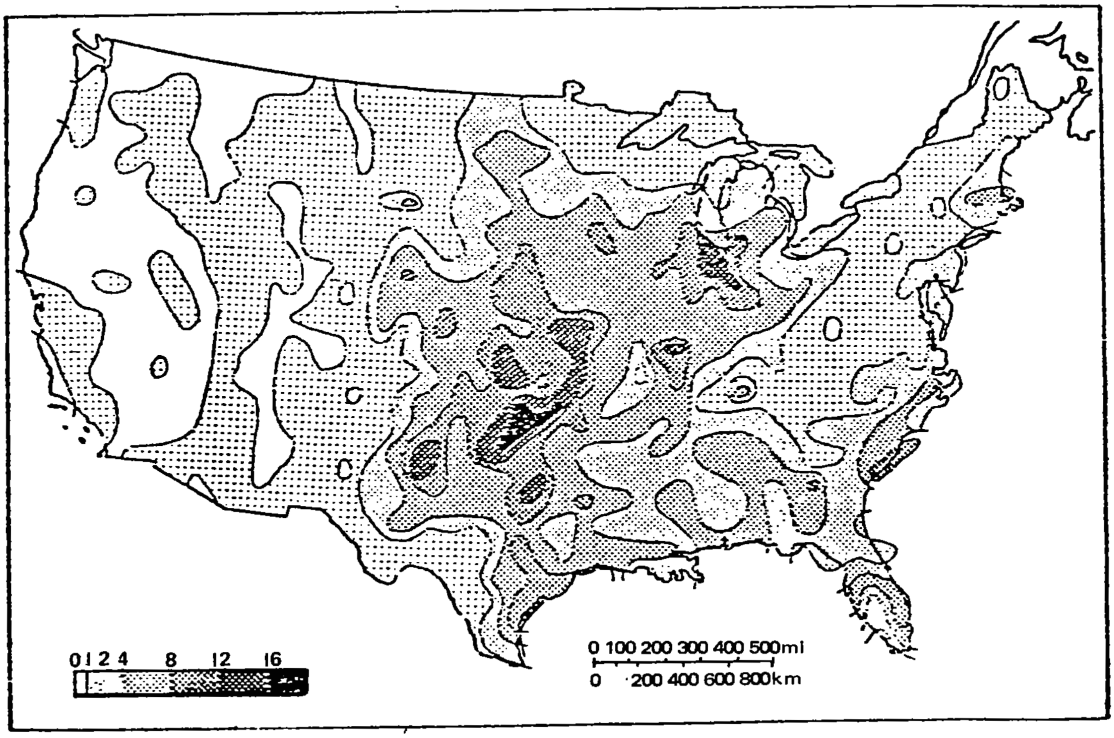


Figure F.6b. Mean annual incidence of tornadoes per 26,000 km^2, 1955-1967.[67]

Table F-1
Planted and Harvested Acres[72] of Wheat in Kansas, 1883-1902

	Winter Wheat					Spring Wheat		
Year	Planted acres	Yield bu.	Harvested acres	Bushels	Yield bu.	Acres	Bushels	Yield bu.
1883			1,480,204	28,958,884	19.5	79,098	1,066,052	13.5
1884			2,151,868	46,681,321	21.7	85,260	1,369,110	16.0
1885	[1,199,723]*	8.6						
	1,999,723	4.9	1,049,458	9,784,395	9.3	90,826	987,786	10.9
1886	1,674,890	8.2	982,029	13,580,592	13.8	83,503	990,441	11.8
1887	1,298,619	6.6	738,199	8,616,244	11.6	75,296	662,257	8.8
1888	1,078,943		936,369	16,135,120	17.2	41,176	589,597	14.3
1889			1,505,947	34,130,048	22.6	88,338	1,189,803	13.5
1890	2,144,065		1,900,588	27,940,401	14.7	177,048	860,813	4.9
1891	Winter-kill 2%		3,582,006	56,170,694	15.1	151,904	2,379,959	15.7
1892	19% East Third Little in Central		3,820,013	70,035,980	18.3	309,816	4,502,926	14.5
1893	14%		4,909,972	24,634,414	5.0	200,901	193,109	0.9
1894	14%		4,675,704	28,175,656	6.2	165,188	30,044	0.18
1895			4,056,514	15,512,241	3.8	115,457	488,819	4.2
1896			3,193,635	27,153,365	8.5	164,092	601,523	3.6
1897			3,318,763	50,040,374	15.7	125,601	986,230	7.8
1898			4,505,459	59,674,105	13.2	119,272	1,116,556	9.4
1899			4,796,129	42,815,471	8.9	192,823	871,542	4.5
1900			4,268,704	76,595,443	17.9	109,829	743,648	6.8
1901			5,248,547	90,045,514	17.1	67,935	287,581	4.2
1902			6,254,747	54,323,839	8.6	46,293	325,397	7.0

* The bracketed figures for wheat acres and yield in 1885 are derived from "Wheat in Kansas," [69]

Table F-2
Winter Wheat Abandonment Due to Winterkilling in Four Counties in Kansas; Comparative Yields, Planted and Harvested Acres, 1885-1890[69]

County	Year	Planted acres	Harvested acres	Planted acres yield	Harvested acres yield
Riley	1885	10,709	6,452	7.2	12
	1886	10,709	2,008	2.0	11
	1887	3,878	2,714	7.0	10
	1888	2,625	2,336	17.0	19
	1890	2,316	2,270	19.0	20
Geary (Davis)	1885	19,557	6,845	2.1	6
	1886	10,660	2,132	2.2	11
	1887	6,420	3,210	3.0	6
	1888	4,472	4,383	22.5	23
	1890	12,398	9,918	8.0	10
Dickinson	1885	98,152	39,539	2.0	5
	1886	57,372	14,343	3.8	15
	1887	45,741	18,296	3.6	9
	1888	34,765	29,898	16.3	19
	1890	68,605	68,605	21.0	21
Saline	1885	91,517	22,458	1.2	5
	1886	70,975	28,390	6.3	16
	1887	65,655	32,827	4.0	8
	1888	66,190	62,880	16.1	17
	1890	90,000	88,200	16.6	17

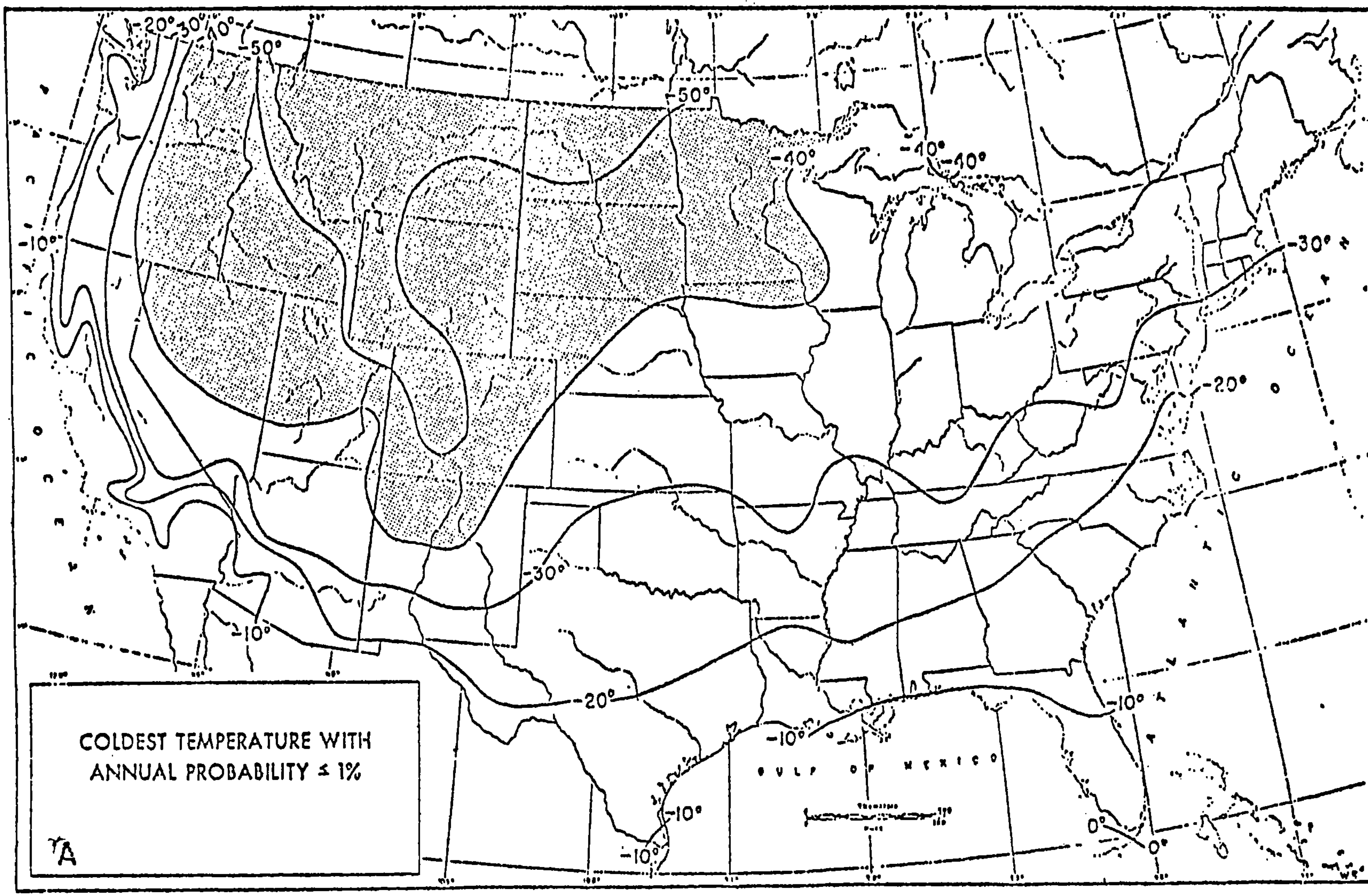


Figure F.7. Coldest temperatures in the United States with annual probability of 1 percent or less, estimated from annual extremes, 1931-1960, at 220 first order stations.[73]

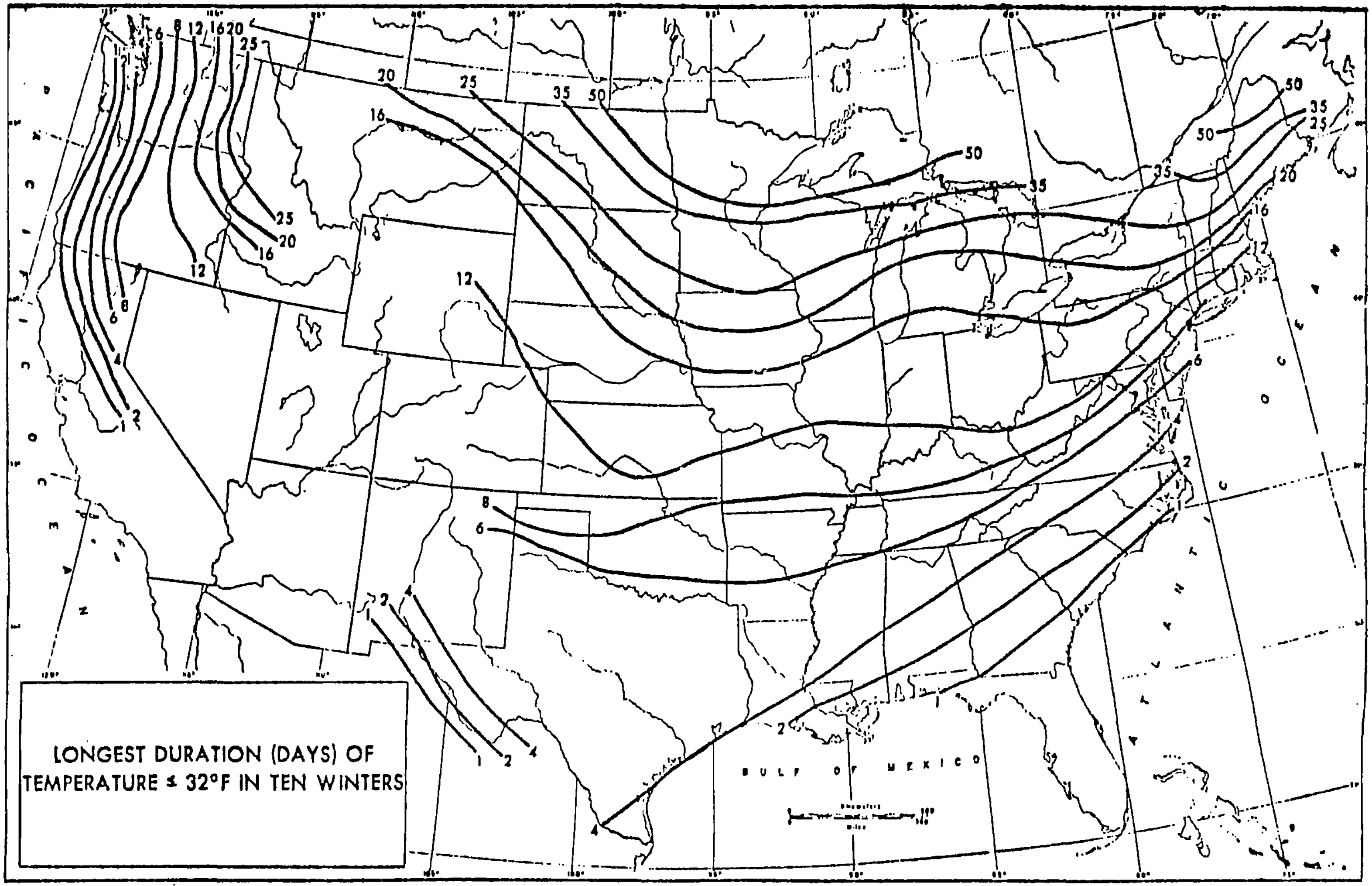


Figure F.8. Longest duration, in days, of temperatures below 0° C in ten winters, 1980-51 to 1959-60, based on data for 108 stations in North America, 59 in the conterminous United States.[73]

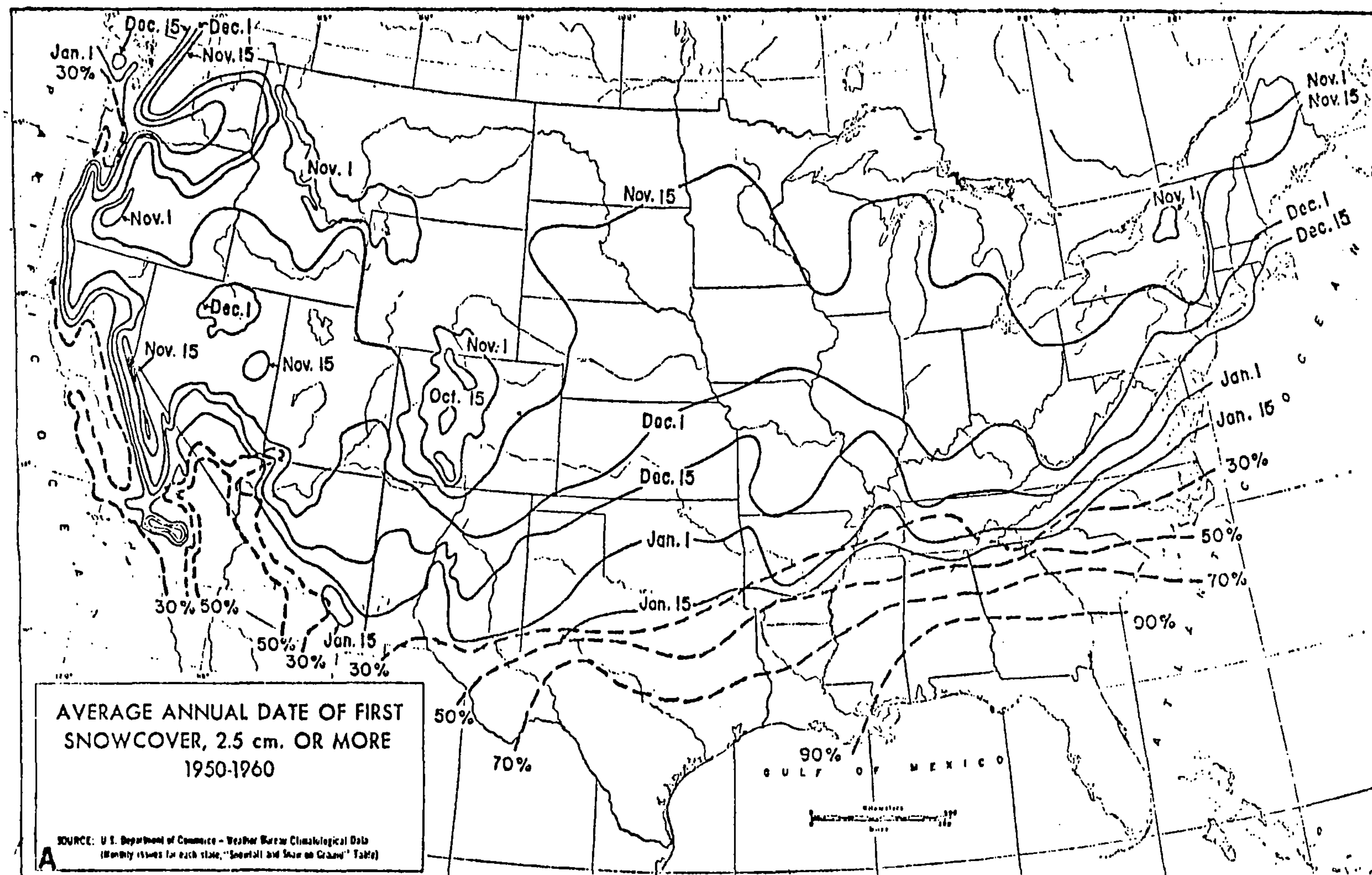


Figure F.9. Average annual date of first snowcover in the United States, 2.5 cm or more, 1950-1960. Dashed lines give percent of years without snowcover.[73]

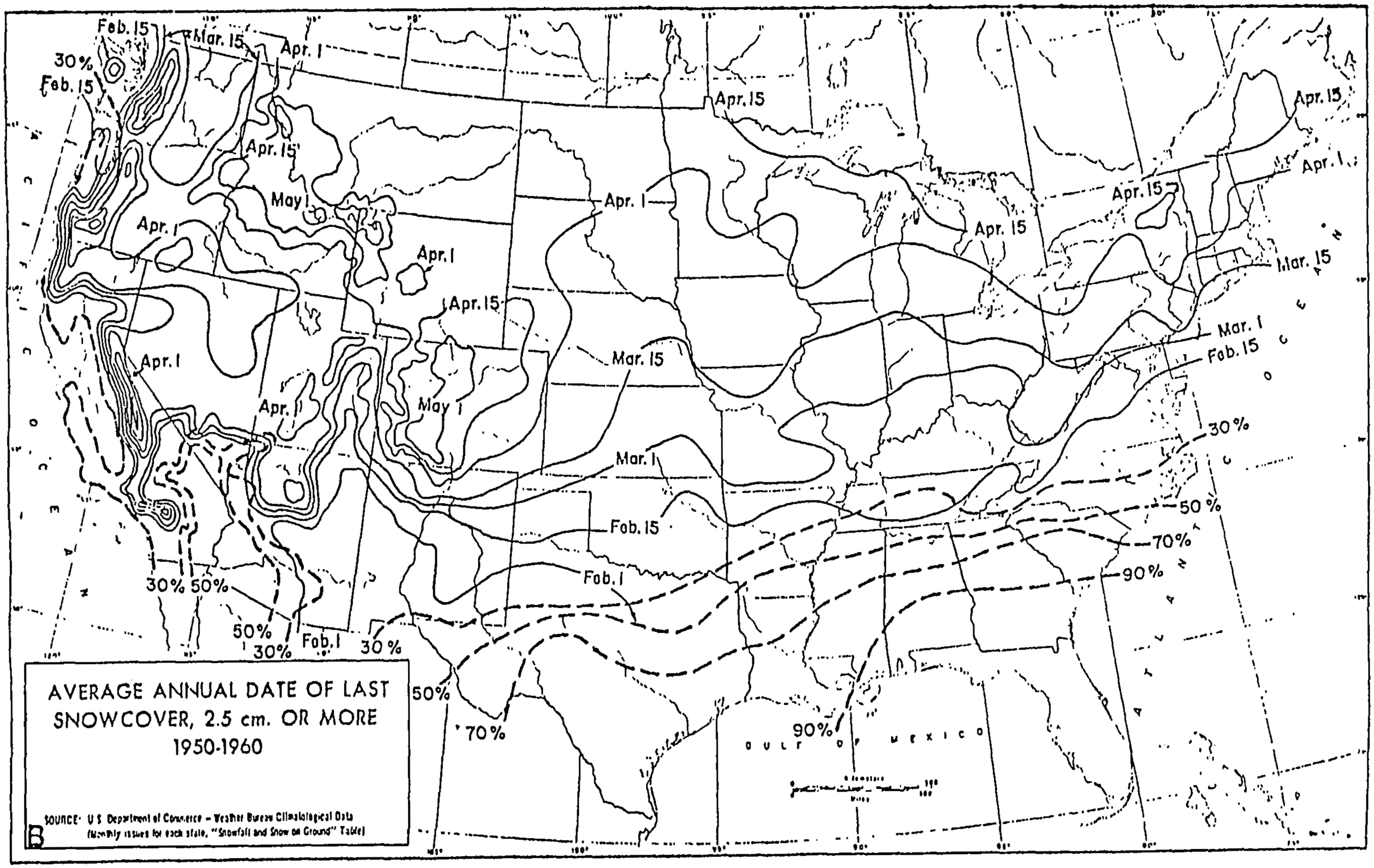


Figure F.10. Average annual date of last snowcover of 2.5 cm or more, 1950-1960. Dashed lines give percent of years without snowcover.[73]

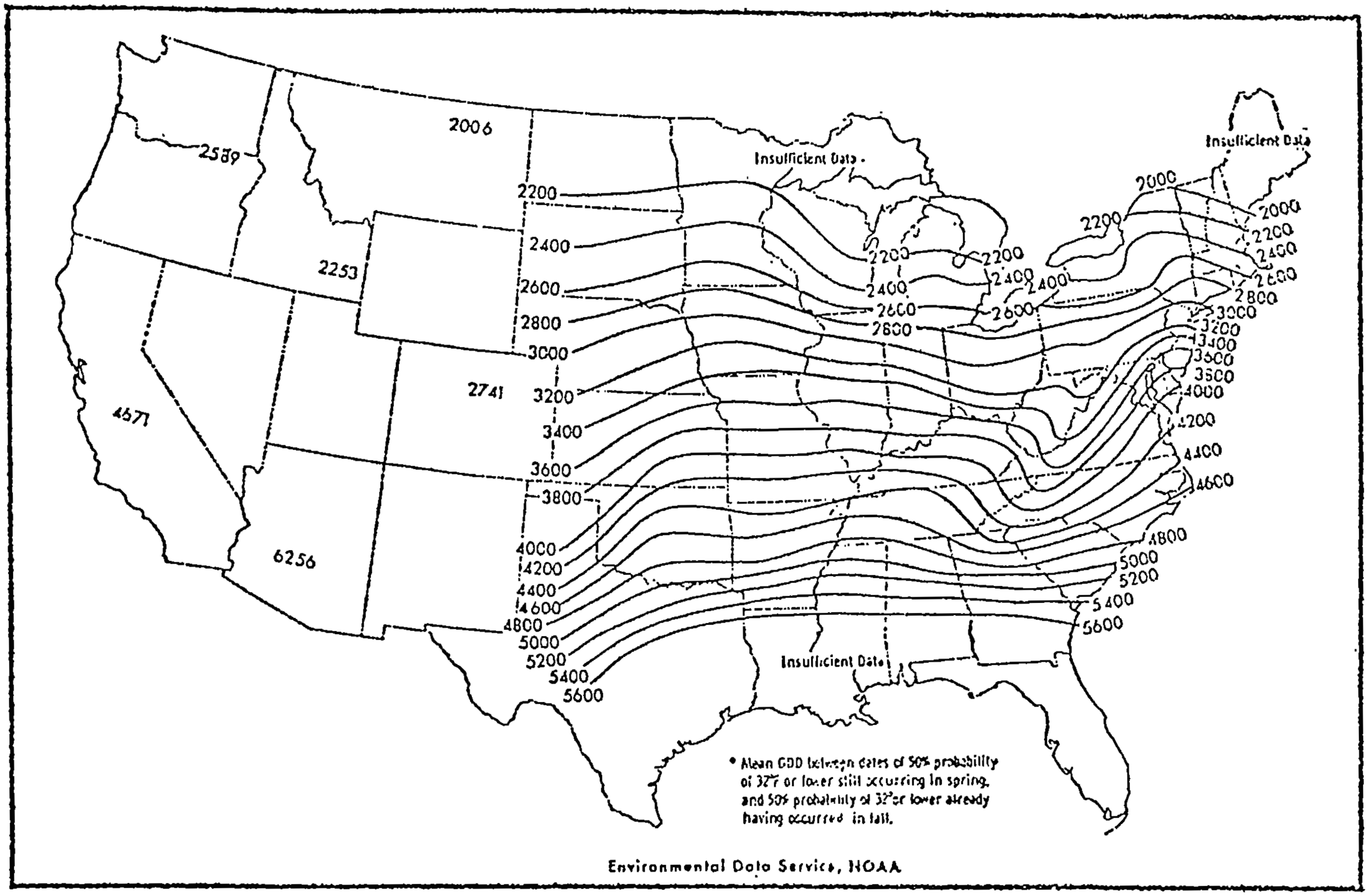


Figure F.11. Normal annual growing degree days, in the United States, based on normal temperatures, 1931-1960.[74]

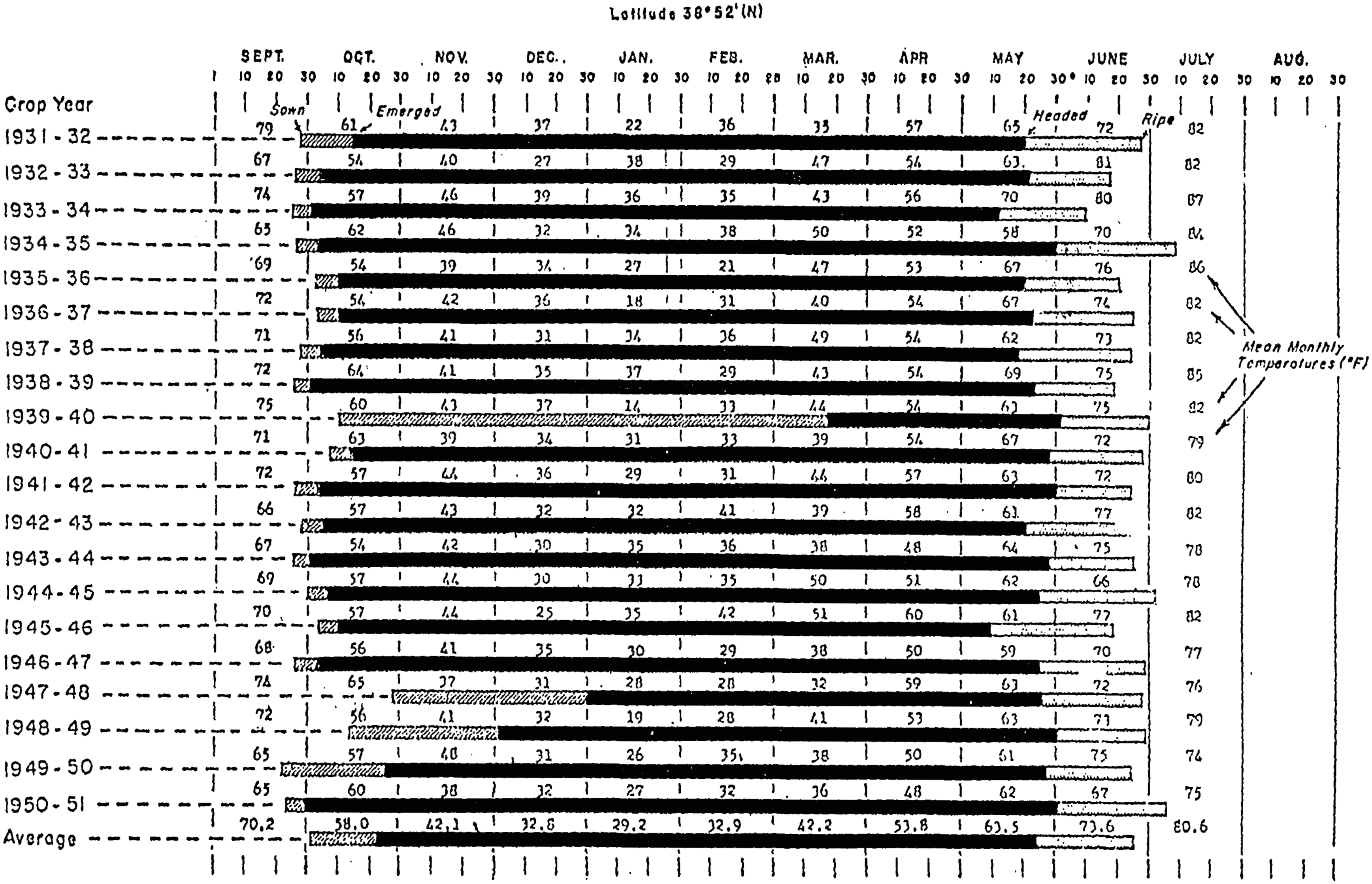


Figure F.12. Phenology of winter wheat at the Agricultural Experimental Station at Hays, Kansas, 1931-1951.[75]

Table F-3

Phenology and Day-degree[1] Summations for Winter Wheat[2] at the Agricultural Experimental Station at Hays, Kansas, 1938-1951[75]

Lat. (N) 38° 52'; Long. (W) 99° 20'; Alt. 2,000 ft.

CROP YEAR	DATE SOWN	DATE EMERGED	DATE HEADED	DATE RIPE	*Summation of Day-Degrees (°F.)* EMERGENCE TO HEADED	MARCH 1 TO HEADED	HEADED TO RIPE	EMERGENCE TO RIPE	MARCH 1 TO RIPE
1931-32	Sept. 28	Oct. 15	May 20	June 27	1,408	968	1,130	2,538	2,098
1932-33	Sept. 27	Oct. 4	May 21	June 17	1,475	1,080	908	2,383	1,988
1933-34	Sept. 26	Oct. 2	May 11	June 9	1,569	861	956	2,525	1,817
1934-35	Sept. 27	Oct. 8	May 31	July 8	2,059	1,234	1,389	3,448	2,623
1935-36	Oct. 2	Oct. 10	May 20	June 20	1,422	1,110	1,013	2,435	2,123
1936-37	Oct. 8	...do...	May 22	June 24	1,356	988	1,063	2,419	2,051
1937-38	Sept. 28	Oct. 4	May 17	June 23	1,520	1,048	1,047	2,567	2,095
1938-39	Sept. 26	Oct. 1	May 23	June 18	1,925	1,139	859	2,784	1,998
1939-40	Oct. 10	Mar. 18	June 1	June 30	1,201	1,276	1,003	2,204	2,279
1940-41	Oct. 7	Oct. 13	May 28	June 27	1,582	1,144	929	2,511	2,073
1941-42	Sept. 29	Oct. 8	May 31	June 24	1,943	1,324	762	2,705	2,086
1942-43	Sept. 28	Oct. 5	May 20	...do...	1,526	937	1,091	2,617	2,028
1943-44	Sept. 29	Oct. 1	May 28	June 25	1,396	908	947	2,343	1,855
1944-45	Sept. 30	Oct. 7	May 24	July 2	1,701	1,140	1,000	2,701	2,140
1945-46	Oct. 3	Oct. 10	May 9	June 18	1,661	1,123	1,112	2,773	2,235
1946-47	Sept. 26	Oct. 8	May 24	June 28	2,121	716	951	3,072	1,667
1947-48	Oct. 27	Jan. 1	May 25	June 27	1,134	1,134	996	2,130	2,130
1948-49	Oct. 13	Dec. 1	June 1	June 29	1,140	1,140	918	2,058	2,058
1949-50	Sept. 22	Oct. 25	May 27	June 21	1,197	846	906	2,103	1,752
1950-51	Sept. 29	Sept. 30	June 1	July 5	1,585	946	961	2,546	1,907
Mean	Oct. 1	Oct. 22	May 24	June 26	1,546	1,063	997	2,543	2,060
Standard Deviation					279	168	110	201	174
Coefficient of Variation (%)					18.0	15.8	11.0	11.4	8.5

Source: Based on data from Agricultural Experiment Station, Hays, Kans., and U.S. Weather Bureau.

[1] Computed above 40°F. base.

[2] Data for Kharkof wheat.

APPENDIX G*

WHEAT YIELD AND PRODUCTION RANKINGS OF COUNTIES IN THE STATE OF KANSAS FOR THE PERIOD 1962-1976

***Unpublished statistical analysis and rankings made available by Dr. David Wood of the Goddard Space Flight Center.**

CRD		COUNTY	YIELD	SIGMA	AREA
SC	66	SUMNER	29.466	6.290	296206
SC	63	RENO	29.073	5.156	285740
SC	64	SEDGWICK	29.713	6.729	194080
CE	48	MCPHERSON	29.946	5.775	192393
SC	57	HARPER	27.633	6.005	201660
SC	65	STAFFORD	27.766	4.839	196246
NW	8	THOMAS	27.120	5.480	200093
SW	20	FORD	25.733	6.411	204140
SW	19	FINNEY	27.186	6.309	185125
CE	43	BARTON	24.260	5.991	203620
SC	62	PRATT	25.753	4.873	191393
CE	50	RICE	29.926	4.436	159246
SC	59	KINGMAN	26.966	5.190	173553
NC	35	MITCHELL	30.226	6.238	152673
SC	61	PAWNEE	25.300	5.719	178193
NW	7	SHERMAN	27.286	6.025	158153
SW	22	GRAY	26.560	7.894	157026
CE	44	DICKINSON	30.633	4.809	135366
NW	5	RAWLINS	28.940	4.498	137466
WC	13	NESS	24.533	7.234	160180
CE	49	MARION	29.113	6.139	129906
NC	33	CLOUD	31.880	6.277	117660
CE	53	SALINE	28.900	4.760	127626
SC	56	EDWARDS	25.153	5.277	145586
NC	37	OTTAWA	29.626	4.686	122993
NW	1	CHEYENNE	28.073	5.095	129033
NC	34	JEWELL	31.100	7.317	115886
CE	51	RUSH	23.353	6.913	152546
CE	47	LINCOLN	28.133	6.078	126340
SC	58	HARVEY	30.280	7.930	116486
WC	14	SCOTT	28.613	6.881	121180
NC	36	OSBORNE	27.233	7.337	124680
CE	52	RUSSELL	24.886	7.101	136213
NW	6	SHERIDAN	28.360	5.458	117666
WC	9	GOVE	28.506	7.042	115400
NC	42	WASHINGTON	33.220	5.256	98813
WC	11	LANE	27.540	7.756	115900
SE	97	COWLEY	31.286	5.921	101933
WC	12	LOGAN	24.360	6.035	129333
SC	54	BARBER	26.320	5.122	119113
NW	2	DECATUR	29.953	4.430	103906
SW	24	HASKELL	27.853	8.705	111633
NC	41	SMITH	31.040	5.963	98305
SW	25	HODGEMAN	24.440	6.390	123893
NC	40	ROOKS	25.806	5.502	117313
NC	39	REPUBLIC	32.940	6.491	91760
NW	4	NORTON	29.860	4.356	99080
CE	46	ELLSWORTH	26.786	6.049	109633
NW	3	GRAHAM	26.573	4.613	109693
SW	27	MEADE	23.066	7.080	125346
CE	45	ELLIS	22.733	5.343	126120
NC	32	CLAY	30.453	4.417	93840
WC	15	TREGO	25.200	6.569	110286

NC	38	PHILLIPS	29.753	4.510	90086
SC	60	KIOWA	23.866	5.683	111146
WC	10	GREELEY	20.953	7.966	124585
WC	17	WICHITA	24.140	6.379	104685
SW	23	HAMILTON	19.806	7.396	125913
NE	73	MARSHALL	33.106	4.764	67406
SW	26	KEARNY	23.440	6.800	95020
SW	31	STEVENS	23.806	6.637	88613
SW	30	STANTON	21.913	3.924	94466
SE	96	CHEROKEE	29.973	4.436	69053
SW	18	CLARK	21.660	5.161	91713
SW	21	GRANT	25.120	5.743	78286
SE	105	WOODSON	27.766	5.754	70500
SW	29	SEWARD	22.466	6.583	80586
SE	94	BUTLER	29.580	7.717	59453
SC	55	COMANCHE	19.740	4.442	88186
WC	16	WALLACE	21.740	5.584	75840
SE	101	LABETTE	30.213	4.170	52673
SE	102	MONTGOMERY	30.313	4.825	45680
EC	88	MORRIS	29.553	5.081	41933
SE	103	NEOSHO	29.300	4.833	40606
SE	104	WILSON	29.140	7.478	39213
SW	28	MORTON	17.046	5.563	62753
NE	74	NEMAHA	32.880	6.387	31700
NE	75	POTTAWATOMIE	31.506	5.387	31026
NE	68	BROWN	35.406	7.115	26773
SE	98	CRAWFORD	29.686	5.189	30173
EC	90	SHAWNEE	30.640	4.066	28293
NE	76	RILEY	32.540	5.215	25680
EC	83	GEARY	33.053	5.300	24420
EC	86	LYON	28.573	4.391	27586
NE	72	LEAVENWORTH	29.693	4.501	26080
SE	93	BOURBON	27.166	5.313	28493
EC	89	OSAGE	30.473	4.754	25366
NE	70	JACKSON	30.280	5.703	25453
EC	87	MIAMI	29.673	5.414	25580
EC	81	DOUGLAS	31.033	5.090	23913
EC	78	ANDERSON	30.280	5.701	23533
EC	80	COFFEY	30.306	4.849	23180
EC	91	WABAUNSEE	30.506	4.639	22933
SE	95	CHAUTAUQUA	30.960	6.643	21950
SE	92	ALLEN	29.440	4.986	22873
EC	85	LINN	28.786	5.728	23340
NE	67	ATCHISON	29.126	4.650	22660
EC	82	FRANKLIN	29.113	5.751	21213
SE	100	GREENWOOD	27.320	6.094	21293
NE	71	JEFFERSON	28.760	4.341	19426
EC	79	CHASE	30.033	5.208	18186
NE	69	DONIPHAN	33.746	6.204	15160
EC	84	JOHNSON	31.246	4.709	16366
SE	99	ELK	27.973	6.462	15253
NE	77	WYANDOTTE	32.353	4.722	7180

LIST BY SORT

CRD		COUNTY	YIELD	SIGMA	AREA
NE	68	BROWN	35.406	7.115	26773
NE	69	DONIPHAN	33.746	6.204	15160
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EC	84	JOHNSON	31.246	4.709	16366
NC	34	JEWELL	31.100	7.317	115886
NC	41	SMITH	31.040	5.963	98306
EC	81	DOUGLAS	31.033	5.090	23913
SE	95	CHAUTAUQUA	30.960	6.643	21960
EC	90	SHAWNEE	30.640	4.066	28293
CE	44	DICKINSON	30.633	4.809	135366
EC	91	WABAUNSEE	30.506	4.639	22933
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SE	102	MONTGOMERY	30.313	4.825	45680
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NE	70	JACKSON	30.280	5.703	25453
EC	78	ANDERSON	30.280	5.701	23533
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SC	64	SEDGWICK	29.713	6.729	194080
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NC	37	OTTAWA	29.626	4.686	122993
SE	94	BUTLER	29.580	7.717	59453
EC	88	MORRIS	29.553	5.081	41933
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SW	20	FORD	25.733	6.411	204140
SC	61	PAWNEE	25.300	5.719	178193
WC	15	TREGO	25.200	6.569	110286
SC	56	EDWARDS	25.153	5.277	145586
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WC	12	LOGAN	24.360	6.035	129333
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SC	60	KIOWA	23.866	5.683	111146
SW	31	STEVENS	23.806	6.637	88613
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SW	28	MORTON	17.046	5.563	62753

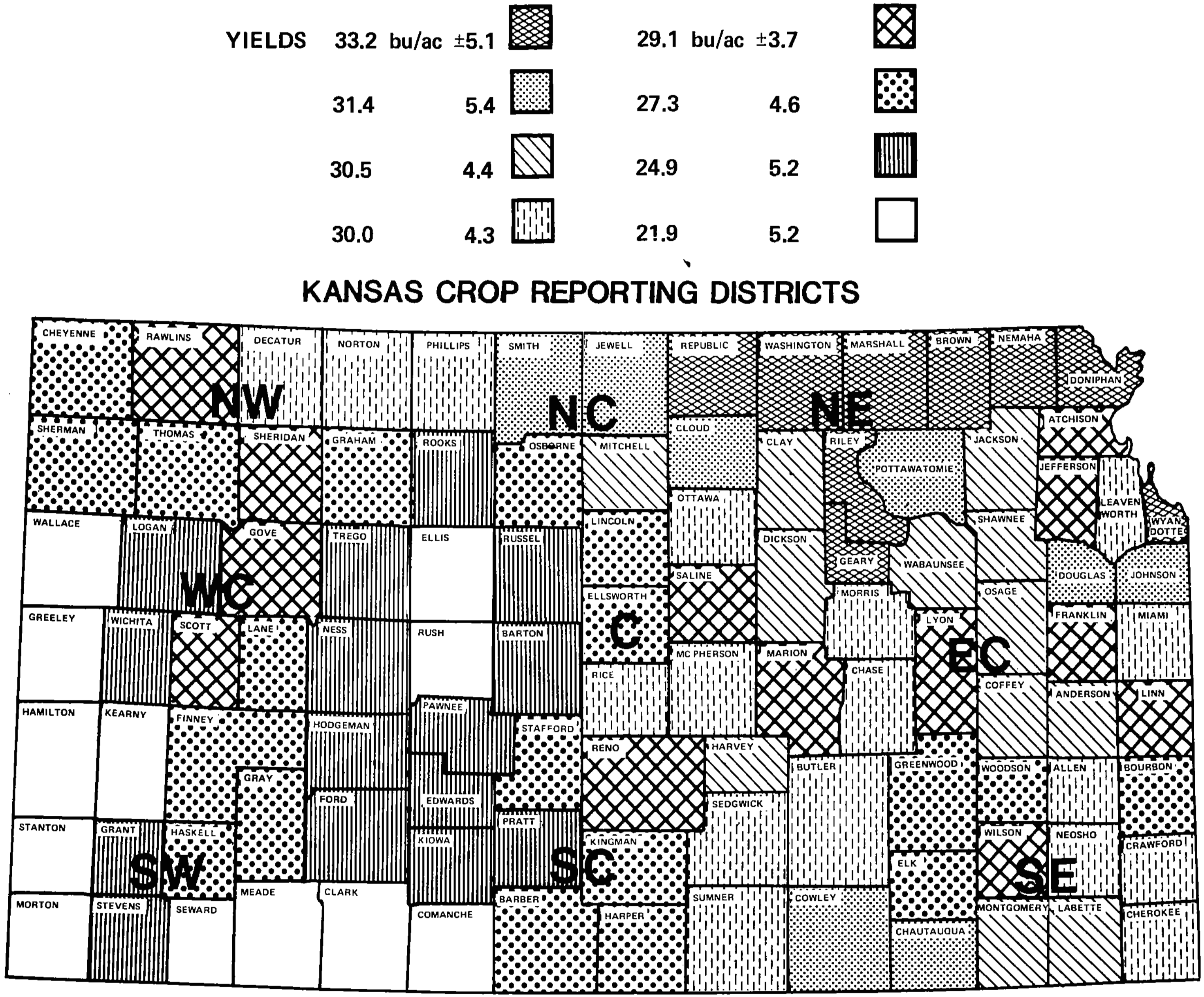

Figure G.1. Wheat yield in Kansas counties for the period 1962-1976.[40]

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16. Abstract

A histogram analysis of average monthly precipitation over 30- and 84-year periods for both Maryland and Kansas was made and the results compared. A second analysis, a statistical assessment of the effect of average monthly precipitation on Kansas winter wheat yield was made. The data sets covered the three periods of 1941-1970, 1887-1970, and 1887-1921. Analyses of the limited data sets used (only the average monthly precipitation and temperature were correlated against yield) indicated that fall precipitation values, especially those of September and October, were more important to winter wheat yield than were spring values, particularly for the period 1941-1970. Average monthly precipitation and temperatures analyzed in this paper represent only two of the many variables positively affecting Kansas winter wheat yield; they were analyzed because they appear in some current yield models. Agroclimatic research projects on macro-, meso-, and micrometeorological systems were also surveyed for the problem of extrapolating remote sensing data. Appendixes on economic and technological factors, slowly varying climatic changes, severe storms, and episodic events in Kansas were included to underline the complexities of a full yield model development.

17. Key Words (Selected by Author(s))	18. Distribution Statement
Agroclimatic Conditions, Economic Factors, Monthly Temperature and Precipitation, Statistical Analysis, U.S. Winter Wheat, Yield	Unclassified - Unlimited Subject Category 47

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