THE EFFECTS OF WEATHER ON CROP YIELDS AND FARM INCOME IN NORTHEASTERN KANSAS

by

STEPHEN HSIEN-CHANG CHOU

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Approved by:

Orlan Buller

Major Professor

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INTRODUCTION

Historical Background

For about a century, agronomists, economists, and statisticians have studied the cause-and-effect relationship between weather and crop production. Agronomists have studied the reactions of plant to environment, whereas economists have studied the relationship of weather to farm and rural economies.

There are many factors that influence crop yield, such as plant physiology, soils, weather, cultural practices, etc. Specifying the relationship of weather to crop yield is difficult. For example, hot weather has a beneficial effect on corn yield only if sufficient moisture is available, but is detrimental under drought condition. Similarly, rain has a markedly beneficial effect in warm weather but is less beneficial in cold weather.

The ideal approach to measuring the cause-and-effect of weather throughout the entire growing season would be to separate the weather factors from the non-weather factors.[1] Theoretically, such a procedure is not impossible. However, in practice it would be extremely difficult. The required data for such an extensive analysis is not available.

A variety of techniques for measuring the relationship between crop yield and weather has been used. For example, Shaw and Durost[2] developed a weather index for measuring the effect of weather on agricultural output. Thompson used multiple linear and curvilinear regression models to study

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1 Hendricks, Walter A. and Scholl, John C., THE JOINT EFFECTS OF TEMPERATURE AND PRECIPITATION ON CORN YIELD, Technical Bulletin, Vol. 74, April, 1943.

2 Shaw, Lawrence H. and Durost, Donald D., MEASURING THE EFFECT OF WEATHER ON AGRICULTURAL OUTPUT, U.S.D.A., Economic Research Service, Washington D.C., October, 1962.

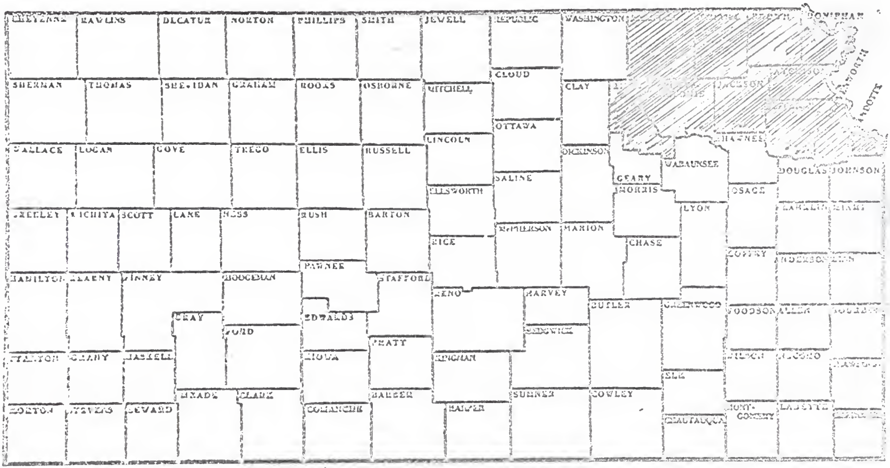

Fig. 1. Area Studied in Northeastern Kansas.

select crops.[1] Doll[2] established a rainfall index to study the effect of weather on corn yield. Lin[3] measured the influence of weather using drought severity index, as defined and computed by Palmer[4], on crops and farm income.

Objective of the study

The objective of this study is to evaluate the effect of weather on crop yield and farm income in northeastern Kansas. Four crops are studied: grain sorghum, corn, soybean, and wheat. Farm income is total value of field crops.

Scope of the study

This study is limited to northeastern Kansas during the period of 1932 through 1966. This area includes Atchison, Brown, Doniphan, Jackson, Jefferson, Leavenworth, Marshall, Nemaha, Pottawatomie, Riley, and Wyandotte counties, Fig. 1. This study considers the main small grain crops; grain sorghum, corn, soybean, wheat and farm income from field crops.

The data used in this study was obtained from the yearly reports, FARM FACTS. Weather variables used were calculated by the Department of Physics, Kansas State University, using Thornwaite's method for calculating evapotranspiration[5]. This variable considers rainfall, runoff, temperature, soil moisture and radiation.

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1 Thompson, Louis M., WEATHER AND TECHNOLOGY IN THE PRODUCTION OF CORN AND SOYBEANS, CAED Report 17, Iowa State University of Science and Technology, Ames, Iowa, 1963.

2 Doll, John P., "An Analytical Technique for Estimating Weather Index from Meteorological Measurements", Journal of Farm Economics, Vol. 49, No. 1, part 1, February, 1967, pp. 79-88.

3 Lin, W., THE INFLUENCE OF WEATHER ON CROP YIELDS AND FARM INCOME IN NORTH-WESTERN KANSAS, Unpublished M.S. Thesis, Kansas State University, June 1968.

4 Palmer, Wayne C., METEOROLOGICAL DROUGHT, U.S. Department of Commerce, Weather Bureau, Research Paper No. 45, Washington, D.C., February, 1965.

5 Ibid., p. 11.

It is necessary to make a distinction between weather and climate. Weather is defined as "the state of the air in the atmosphere with respect to heat or cold, wetness or dryness, calm or storm, clearness or cloudiness, or any other meteorological phenomena".[1] Shaw and Durost make a further distinction, indicating that "Climate refers to the average conditions of the air or atmosphere over a period of years, while weather refers to individual year-to-year or day-to-day variation in the conditions. Weather then refers to the conditions of the atmosphere in relation to what one would expect on the average".[2]

The most important weather variables are rainfall and temperature, and as such have a dominant influence on crop yield. Hence, in some studies they are used synonymously with weather. However, strictly speaking, weather includes many other meteorological phenomena, such as wind, sunshine, hail, frost, and humidity.

Evapotranspiration is a combination of two words, 'evaporation' and 'transpiration'. It means, "loss of water from the soil both by evaporation from the surface and by transpiration from the plants growing thereon."[3]

Measurement of Weather Variables

In this study, weather variables used are the difference between actual monthly evapotranspiration (ET) and monthly CAFEC (Climatically Appropriate For Existing Condition) evapotranspiration, and actual monthly evapotranspiration. Evapotranspiration is estimated from temperature and precipitation

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1 WEBSTER'S NEW COLLEGIATE DICTIONARY, 1957, p. 969.

2 Ibid., Shaw, L. H. and Durost, Donald D., MEASURING THE EFFECT OF WEATHER ON AGRICULTURAL OUTPUT, p. 3.

3 Philip Babcock Gove, WEBSTER'S THIRD NEW INTERNATIONAL DICTIONARY, G. C. Merriam Company, Springfield, Massachusetts, U.S.A., 1961, p. 787.

data by the Thornwaite method.[1] The method can be used for any location at which daily maximum and minimum temperature are recorded. CAFEC evapotranspiration is derived by multiplying potential evapotranspiration[2] by the coefficient of evapotranspiration, α.[3] The coefficient of evapotranspiration is calculated by dividing long-term mean evapotranspiration for a month by long-term mean potential evapotranspiration for the same month. For example, in Kansas, if a particular June was much warmer than normal with potential evapotranspiration equal to 6.00 inch and the coefficient of evapotranspiration for June is 0.71, then CAFEC evapotranspiration would be 4.26 inch (or 0.71 X 6.00 inch).

CAFEC evapotranspiration estimates the evapotranspiration needed by the plant for normal growth and yield for a particular location. Thus, the long-term average actual evapotranspiration is the same as CAFEC evapotranspiration. CAFEC evapotranspiration and actual evapotranspiration are seldom equal for months April through October, whereas for November through March they are usually the same.

A measure of the abnormality of weather can be obtained by comparing calculated CAFEC evapotranspiration and actual evapotranspiration. The difference between actual evapotranspiration and CAFEC evapotranspiration

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1 Palmer, W. C. and Havens, A. Vaughn, "A Graphical Technique for Determining Evapotranspiration by Thornthwaite Method", Monthly Weather Review, Vol. 86, No. 4, April, 1958, p. 123.

2 Potential evapotranspiration is defined as "the amount of water which will be lost from a surface completely covered with vegetation if there is sufficient water in the soil at all times for use of vegetation".

3 In humid climates, evapotranspiration is usually nearly equal to potential evapotranspiration; but in rather dry climates the evapotranspiration falls a good deal short of the potential evapotranspiration. Therefore, α, in humid climate is larger than that in dry climate, also true for CAFEC evapotranspiration.

measures the moisture supply needed by the plant for normal growth. If the difference is negative, moisture supply is less than plant requirement and if positive, moisture supply is an excess of plant needs for normal growth.

The difference between the actual monthly evapotranspiration and monthly CAFEC evapotranspiration is used as a measurement of weather in this study.

REVIEW OF LITERATURE

Measurement of Meteorological Variables

Weather plays an important role in agricultural production. There are many studies related to the effect of weather on crop production. Most of the early studies concentrated on the effect of one or more weather components, such as rainfall, temperature or evapotranspiration on crops. As early as 1924, Smith related corn yield to monthly rainfall of June, July, and August, from 1854 to 1913, and found that rainfall is an important weather factor.[1] Fisher[2] studied the effect of rainfall on wheat at Rothamsted using simulateous equations, but his methodology did not differ markedly from that used in the usual multiple correlation analysis. Hodges studied the relationship of rainfall and temperature to corn yield in Kansas. He used a multiple curvilinear correlation method, and concluded that rainfall and temperature have different effects on eastern Kansas than on western Kansas.[3] Davis[4] and Pallesen[5] studied rainfall and evaporation during a given season as an indicator of meteorological phenomena. Some studies were concerned with only short periods in weather, and used such variables as weekly temperature and

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1 Smith, Warren J., "The Effect of Weather upon the Yield of Corn", Monthly Weather Review, U.S. Department of Commerce, Weather Bureau, Washington, D.C., February, 1914, pp. 78-87.

2 Fisher, R. A., "The Influence of Rainfall on Yield of Wheat at Rothamsted", Royal Society Philosophy Translation Series B, Vol. 213, pp. 89-142.

3 Hodges, J. A., "Effect of Rainfall and Temperature on Corn Yield in Kansas", Journal of Farm Economics, Vol. XIII, No. 2, April, 1931, pp. 308-318.

4 Davis, Floyd E., and Harrell, G. D., "Relation of Weather and its Distribution to Corn Yield", Journal Agricultural Research, Vol. 60, pp. 1-23, U.S.D.A., Technique Bulletin, No. 806, p. 67.

5 Davis, Floyd E., and Pallesen, J. E., "Effect of the Amount and Distribution of Rainfall and Evaporation during the Growing Season on Yield of Corn and Spring Wheat", Journal Agricultural Research, No. 60, p. 1-23.

weekly rainfall.[1]

Other measurements of weather phenomena have also been used to study the effect of weather on crop production. Dale used a 'moisture-stress-day'[2] and estimated the potential evapotranspiration by measuring the evaporation from a pan. He then related this to soil moisture, which was estimated using the method described by Shaw.[3] Blake[4] applied Penman's formula as a measurement of moisture excess. Oury[5] used the de Martonne and Angstron formula to construct an aridity index to study variation crop production.

Shaw[6] and Durost used the plot data approach to construct a weather index. They assumed that yield variations due to changes in soil productivity were gradual and the change could be estimated by finding the trend. Variation in yield due to weather was measured as deviation from the trend. Auer[7] and Heady used phenological data to estimate a corn-weather index for measuring weather as an input. Most of the measurements of weather were based on botanical characteristics of plants, which mainly related to

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1 Ibid., Hendricks and Scholl, THE JOINT EFFECT OF TEMPERATURE AND PRECIPITATION ON CORN YIELD, p. 24.

2 Dale, Robert F., CHANGE IN MOISTURE STRESS DAYS SINCE 1933, CAED Report 20, Ames, Iowa, 1964, pp. 23-43.

3 Shaw, L. H., ESTIMATION OF SOIL MOISTURE UNDER CORN, Iowa Agricultural Station Research Bulletin 520, 1963.

4 Blake, G. R. et al., AGRICULTURAL DROUGHT AND MOISTURE EXCESS IN MINNESOTA, University of Minnesota Agricultural Experiment Station, Technical Bulletin, 235, May, 1960.

5 Oury, Bernard, "Allowing for Weather in Crop Production Model Building", Journal of Farm Economics, Vol. 47, No. 2, May, 1965, p. 272.

6 Ibid., Shaw and Durost, MEASURING THE EFFECT OF WEATHER ON AGRICULTURAL OUTPUT, p. 3.

7 Auer, Ludwig and Heady, Earl O., THE PRODUCTION OF WEATHER AND YIELD TECHNOLOGY TO CHANGES IN U.S. CORN PRODUCTION 1939 TO 1961, CAED Report 20, pp. 45-74.

evapotranspiration.

A weather index can be constructed by using direct meteorological phenomena, such as rainfall and temperature, and also by observation of secondary weather effects, such as the percentage of abandoned acres, or the incidence of crop disease. Stalling[1] constructed a weather index by taking the deviation of per acre yield from estimated trend in per acre yield and divided it by the estimated trend. This approach was first introduced by Wallace[2]. Shaw and Durost with little modification of the approach found this approach to be successful. In their study, chi-square values of yield variation data were significantly different from what would be expected if yield variation were only due to chance.

According to Shaw and Durost[3], there are several weakness in constructing a weather index. (1) It is difficult to use computer methods for other crops or other regions, and a large body of experimental data must be collected. (2) Measurement should include an allowance for abnormal acreage abandonment. (3) The use of linear trend to describe technological changes in the experimental data may be inappropriate. But, the advantage of the weather index approach is that, with the choice of appropriate yield data from which to measure the effect of weather, weather is measured relevent to existing levels of technology.

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1 Stalling, J. L., "Weather Indexes", Journal of Farm Economics, Vol. XIII, February, 1960, pp. 180-186.

2 Wallace, H. A., "Mathematical Inquiry into the Effect of Weather on Corn Yield in the Eight Corn Belt States", Monthly Weather Review, U.S. Department of Commerce, August, 1920, Vol. 48, pp. 439-446.

3 Shaw, L. H. and Durost, D. D., The Weather Index Approach, CAED Report 20, Iowa State University of Science & Technology, Ames, Iowa, 1964, p. 93.

Weather Cycles and Weather-crop Function

Bean[1] studied weather changes and crop yields and found that weather and crop yield are related and that both cyclical and year-to-year patterns of production tend to repeat. Palmer[2] studied climatic variation and crop production and indicated that a serious drought tends to occur about every twenty years in central United States.

Thompson[3] found that periodic changes in weather patterns do occur, but they do not occur in regular cyclical patterns. Weakly[4] studied weather cycles from tree growth in Western Nebraska, and wrote the following in 1943:

> "There is considerable irregularity in the length of period represented by several climatic pulsations, so that the data are of little use in exacting forecasting of probable climate conditions. Their chief values lies in the fact that they show an alternation of wet and dry periods over a considerable extent of time, with no evidence that climate has changed greatly in the relatively recent past or is changing radically at present. In other words, droughts have occurred at more or less frequent intervals over the past 400 years periods and will in all probability continue to be so in the future. When these periods will occur that will be their intensity or duration remain yet to be considered."[5]

At the present time, the exact functional relationship between weather and crop yield is still not known. Most of the early studies can be classified into two groups.[6] One group attempted to measure the quantative variation of crop production which resulted directly from weather variation.

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1 Bean, Louis H., THE PREDICATABILITY OF CYCLES, TREND, AND ANNUAL FLUCTUATION IN WEATHER AND CROPS, CAED Report 20, Iowa State University of Science and Technology, Ames, Iowa, 1964, pp. 153-172.

2 Palmer, W. C., CLIMATIC VARIABILITY AND CROP PRODUCTION, CAED Report 20, Iowa State University of Science and Technology, Ames, Iowa, 1964, pp. 153-172.

3 Ibid., Thompson, L. M., WEATHER AND TECHNOLOGY IN THE PRODUCTION OF CORN AND SOYBEANS, p. 26-27.

4 Weakly, H. E., "A Tree Record of Precipitation in Western Nebraska", Journal of Forestry, Vol. 41, pp. 816-819.

5 Ibid., p. 819

6 Ibid., Lin, W., THE INFLUENCE OF WEATHER ON CROP YIELD AND FARM INCOME IN WESTERN KANSAS, p. 10.

The second group attempted to establish a weather index. The weather index approach has been discussed, and the first approach will be discussed in detail in the following section.

Statistical Techniques

Regression Model

Linear regression models assume that the effect of every unit change in the independent variables has the same influence on the dependent variable. However, this is not always true in the weather-crop yield relationship.[1] Ezekiel[2] applied multiple curvilinear regression models to study functions with two or more independent variables. Thompson[3] also employed this approach in his studies of corn, grain sorghum, and soybean.

Technological Improvement and Weather Effect on Yield

Technological improvement has been ever-present in the history of United States agriculture. Several methods have been used to separate the weather effect from the technological improvements. One method is to include a time variable to represent technological change as an independent variable.[4] Another method is to eliminate from crop yield trend due to technological improvement before the regression equations are fitted.

Yule[5] preferred the latter approach, because treating time as an

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1 Ibid., Thompson, L. M., WEATHER AND TECHNOLOGY IN THE PRODUCTION OF CORN AND SOYBEANS, p. 7.

2 Ezekiel, M. and Fox, K. A., METHOD OF CORRELATION AND REGRESSION ANALYSIS, 3rd. Edition, John Wiley & Sons, Inc., New York, 1966.

3 Ibid., Thompson, L. M., WEATHER AND TECHNOLOGY IN THE PRODUCTION OF CORN AND SOYBEANS, CAED Report 20, p. 75-91.

4 This method can be derived to include two time variables to represent a non-linear trend. A nonlinear trend is separated as two different linear subtrend.

5 Yule, G. U., "Why Do We Sometimes Get Nonsense-correlations Between Time Series--A Study in Sampling and The Nature of Time Series", Journal of Statistics, Vol. 89, p. 1-64.

independent variable may give spurious correlation and regression.[1] However, the latter method is criticized by some researchers because this method might result in losing some of the statistical information.

Choice of method should be based on data characteristics and properties of selected variables.

Moving Average and Least Square Method

Fluctuation in time series data may involve four parts:[2] (1) a trend, or long term movement; (2) cycles of greater or less regularity; (3) a seasonal effect; (4) and a random, unsystematic, or irregular component. The following equation defines the relationship.

$Y(t)=T(t)+C(t)+S(t)+I(t)$,

Where Y(t) is the fluctuation in time series data, C(t) is oscillations about a trend, S(t) is seasonal effect, I(t) is irregular component, and T(t) is trend. Trend effect can be separated by taking the three other effects out of time series data, i.e.;

$T(t)=Y(t)-C(t)-S(t)-I(t)$.

There are two common methods for fitting a trend; the moving average method and the least square method.

The moving average method is the simplest method for fitting a trend for non-linear and oscillated time series data, but there are two drawbacks involved in its use: (1) It does not provide trend values for the beginning and the end of the time series.[3] (2) A moving average of a series may

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1 Wold, Herman and Jureen, Lars, DEMAND ANALYSIS, John Wiley & Sons Inc., New York, 1966, p. 240.

2 Kendall, M. G. and Stuart, Anon, ADVANCE THEORY OF STATISTICS, Vol. III, Charles Griffen, London, England, p. 349.

3 Ibid., p. 373.

generate an oscillation, called the "Slutzky-Yule effect".[1]

The least square method can overcome these problems, but trend-line may be affected by the length of the time period.[2] In order to obtain a satisfactory trend-curve for data, higher order polynomial function are required.

1 Ibid., p. 378. Also, see Slutzky, Eugen, "The Summation of Random Causes as the Source of Cyclical Processes", Vol. 5, Econometrica, 1937, pp. 105-146.

2 Ibid., Kendall & Stuart, ADVANCED THEORY OF STATISTICS, Vol. 3, p. 366.

THE MODEL

Economic models are succinct statements of economic theory[1], and economic theory is a system of logical relations between certain sets of assumption and conclusions derived from them[2]. Economists use statistical estimation procedures to explain and predict economic phenomena. Both the model and its interpretation are based on previous logical assumptions. Supporting the model are economic theory and other relevent sciences.

Two models generally used in weather-crop yield studies are correlation and regression.[3] Correlation models require a random sample from normal bivariate or multivariate populations. Regression models require independent variables and dependent variables be selected in advance with no requirement that the distribution of independent variables in the sample to be representative of those in the population.

Regression Models

Regression models can be in linear and curvilinear forms. A linear function is a straight line and is the simplest function to fit, but a single independent variable may be inadequate for explaining the relation between crop production and weather. For this reason, a multiple linear or nonlinear regression model should be used. Both multiple linear and multiple curvilinear regression models are used in this study.

A multiple linear regression model can be justified in the same way as

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1 Ackley, Gardner, MACROECONOMIC THEORY, The MacMillan Company, New York, 1961, p. 14.

2 Vickrey, W. S., MICROSTATICS, Harcourt, Bruce & World, Inc., New York, 1964, p. 5.

3 Ibid., Ezekiel, Mordecai and Fox, Karl A., METHODS OF CORRELATION AND REGRESSION ANALYSIS, p. 279.

a simple linear regression model.[1] The model stipulates that the dependent variables are determinated simultaneously with the independent variables.

In multiple curvilinear regression models, nonlinear relationship between independent variables and dependent variable were studied. This model included variables in quadratic form instead of only linear form.

Statement of the Problem and Formulation of Models

Many factors jointly affect crop production such as weather, government policy, preceding marketing situation, price level, technology and cultural factors. In this study, only the effect of weather on crop yield were studied.

The use of only one single independent variable was considered inadequate because during a particular growing season many different weather-plant relations effect crop yield. For example, higher temperature with sufficient moisture was believed beneficial for germination, but detrimental for maturation. To investigate the effect of weather at different stages of growth, weather variables representing these periods were included in equations.

To study the effect of weather on farm income, income from small grain crops was used and weather variables in linear and quadratic forms were included. However, crop production was related to acres planted which may be affected by government policy and crop prices. In this study, consideration of government policy and price level were excluded and considered as exogenous variables to northeastern Kansas.

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1 Malinvaud, E., STATISTICAL METHODS OF ECONOMETRICS, Translated by Mrs. A. Silvey, Rand McNally & Co., 1966, p. 172.

Assumptions and Hypothesis

Assumptions of regression analysis are the following;[1]

(a) The trend in the effect of technological improvement can be estimated with either a moving average or a time variable.

(b) There is no interaction between weather variables and other factors.

(c) The expected value of the error is zero.

(d) The covariance between the error associated with yield of one crop and that associated with yield of another crop is zero.

(e) The variance of the error associated with yield of one crop is the same as the variance of the error associated with yield of another crop.

(f) The covariance between the error and each of the independent variance is zero.

(g) The observation of the independent variables are measured without error.

(h) Weather variables are independent each other. (Absence of multicollinearity).[2]

Simplified Model

The problem can be explained as in Fig. 2.

1 Heady and Dillon, AGRICULTURAL PRODUCTION FUNCTIONS, Iowa State University of Science and Technology, Ames, Iowa, Third Printing, 1966, p. 111.

2 Ibid., Malinvaud, E., STATISTICAL METHODS OF ECONOMETRICS, p. 174.

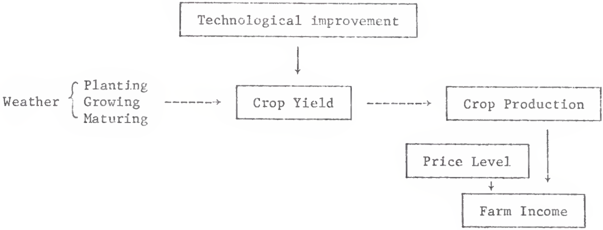

Fig. 2. Simplified model for the weather-crop yield study, and the weather-farm income study.

The above model can be formulated as:

Yield=F(Weather, Technological Improvement)=F_1(Weather)

Farm Income=f(Price Level, Crop Production)

=f_1(Price Level, Crop Yield)

=f_2(Price Level, Weather)

=f_3(Weather)

Above functions can be explained by following equations:

(4-1) $Y_{o,t}=Y_{T,t}+Y_{w,t}$

(4-2) $Y_{T,t}=\sum_{i=t-5}^{t+5} Y/11$

(4-3) $Y_{w,t}=Y_{o,t}-Y_{T,t}$

Where $Y_{o,t}$=Observed yield per acre in year t,

$Y_{T,t}$=Technological effect in year t,

$Y_{w,t}$=Yield variation in year t.

Based on above assumptions, trend of technological improvement is estimated using an eleven year moving average method, equation (4-2). By subtracting equation (4-2) from equation (4-1), technological effect is separated from other factors.

By assumption, effects of weather at different stages are additive. To investigate different monthly effects, different monthly weather variables are used.

$Y=G(\text{Weather})+e=\Sigma B_iX_i+e$

Where Y is crop yield per acre with trend removed,

B_i is estimated effect of weather variable on yield per acre,

X_i is weather variables in year t,

e is error term.

Fig. 2 also shows how farm income is affected by price level and crop production, which is affected by weather and technology.
These relationships can be expressed as:

(4-4) Farm income=g(Crop price level, Crop production, Technology)+ e.

One way to estimate the effect of price changes on farm income from small grain crops is to treat it as an independent variable in the equation. Another way is to deflate farm income by dividing farm income by the price index of price received for crops which removes the effect of price changes on farm income. The second method may eliminate statistical information, whereas including the variable in the equation might cause spurious correlation.[1]

1 Ibid., Wold, Herman and Jureen, Lars, DEMAND ANALYSIS, p. 240.

Basis for Selecting the Independent Variables

Independent and dependent variables in a multiple regression equation should be selected on the basis of what is believed to be a logical cause-and-effect relationship. However, this does not mean that all independent variables which correlate with dependent variable must be chosen. Correlation might be due to chance fluctuation rather than true correlation. Choice of independent variables was based on several criteria. These criteria were (1) botanical reactions of plants to weather during growing season, (2) correlation among independent and dependent variables, (3) and economic relationship.

Independent variables should be chosen in relation to crop season as plants germinate, grow, and ripen according to season.[1] The choice of independent variables during the growth period is based on this concept. The growing season, from planting until harvest, may last several months. During the growing season, the reaction of plants to meteorological factors are different at different stages. Therefore, weather variable for months during the growing season of selected crops were used. The weather variables used for grain sorghum, corn, and soybean was the difference between the actual monthly evapotranspiration and CAFEC evapotranspiration, and for wheat was actual monthly evapotranspiration.

Correlation and Number of Independent Variables

As was mentioned before, absence of multicollinearity among independent variables is an assumption in multiple regression models. If independent variables are correlated, then the regression coefficients are less accurate and may result in lower "t" values of correlated variables.

1 Sanderson, Fred H., METHODS OF CROP FORECASTING, Harvard University Press, Cambridge, Massachusetts, 1954, p. 196.

Table 1. Matrix of Simple Correlation Coefficients of Independent Variables for Weather-crop Studies, Northeastern Kansas, 1932-1966. [a/]

Variables	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13	X14	X15
X1(Sept)	1.00														
X2(Oct)	0.65	1.00													
X3(Nov)	0.10	0.17	1.00												
X4(Dec)	-.02	0.04	0.21	1.00											
X5(Jan)	-.01	-.25	-.17	0.06	1.00										
X6(Feb)	-.05	-.10	0.20	0.27	-.14	1.00									
X7(Mar)	0.02	0.03	-.07	0.21	0.05	0.17	1.00								
X8(Apr)	0.01	-.08	0.06	-.10	-.07	0.21	-.04	1.00							
X9(Apr)[c]	-.06	0.12	-.04	-.29	-.12	-.06	0.09	0.29	1.00						
X10(May)	0.04	-.12	0.01	0.04	0.12	-.49	-.38	0.02	-.19	1.00					
X11(May)[c]	0.03	0.14	0.38	0.10	-.09	0.15	-.21	-.15	-.17	0.23	1.00				
X12(Jun)	-.06	-.20	0.21	0.32	0.31	0.43	-.02	0.02	-.27	0.01	0.18	1.00			
X13(Jun)[c]	-.08	0.16	0.67	0.18	-.13	0.25	0.03	0.11	-.01	-.08	0.57	0.32	1.00		
X14(Jul)[c]	-.09	0.30	0.59	0.17	-.20	-.03	-.08	0.00[b]	-.02	-.03	0.52	-.13	0.75	1.00	
X15(Aug)[c]	-.03	0.20	0.40	0.20	0.12	0.13	-.16	0.02	0.14	-.16	0.42	0.06	0.63	0.70	1.00

a. X1 to X8, X10, X12 are monthly evapotranspiration variables.
b. The simple correlation between X8 and X14 is less than 0.01, but is greater than 0.00.
c. The difference of monthly evapotranspiration and CAFEC evapotranspiration.

However, it is often the case that independent variables are correlated. Hence, the assumption of absence of multicollinearity is not very realistic. The simple correlation coefficients of independent variables are given in Table 1. The weather variables of months September and October, June and July, June and August, and July and August show fairly high correlation. Correlation of weather variable of other months are low and considered insignificant.

In a multiple regression model, the larger the number of independent variables in the equation, the higher the multiple correlation coefficient providing each variable can explain at least some portion of dependent variable. However, with many independent variables the probability of high multicollinearity among at least some independent variables increases. Selection of equation is based on coefficient of determination, small standard errors, and "t" value of variables and plant physiology.

DATA AND DATA ADJUSTMENT

Source of Data

The period 1932-1966 is used as monthly evapotranspiration and CAFEC evapotranspiration data are not available prior to 1932. Crop yields and farm income are obtained from FARM FACTS;[1] while the weather variables, monthly actual evapotranspiration and CAFEC evapotranspiration, have been calculated by Department of Physics, Kansas State University.

Characteristics of the Data

Four small grain crops are studied; grain sorghum, corn, soybeans, and wheat. Grain sorghum is an aggregate of various types and varieties, of milo, kafir and feterila in years from 1932-1936, while it is primarily grain sorghum in later years. Corn is composed of hybrid and cross-pollinated types. Soybeans include all different varieties of soybeans, and wheat includes spring and winter wheat although spring production is of minor importance.

The mean, standard deviation, and coefficient of variation of per acre yield of these crops, from 1932 to 1966 in northeastern Kansas, are in Table 2. Times series of observed yield, and the trend calculated by moving average method are shown in Figures 3, 4 and Tables 13, 14, 15 and 16 in the appendix. Fluctuation of crop yield with yield adjusted for trend is shown in figures 5 and 6, and also in above mentioned tables. The original data are in Tables 9, 10, 11, and 12 in the Appendix.

1 Kansas State Board of Agriculture, FARM FACTS, Topeka, Kansas, 1932-1966.

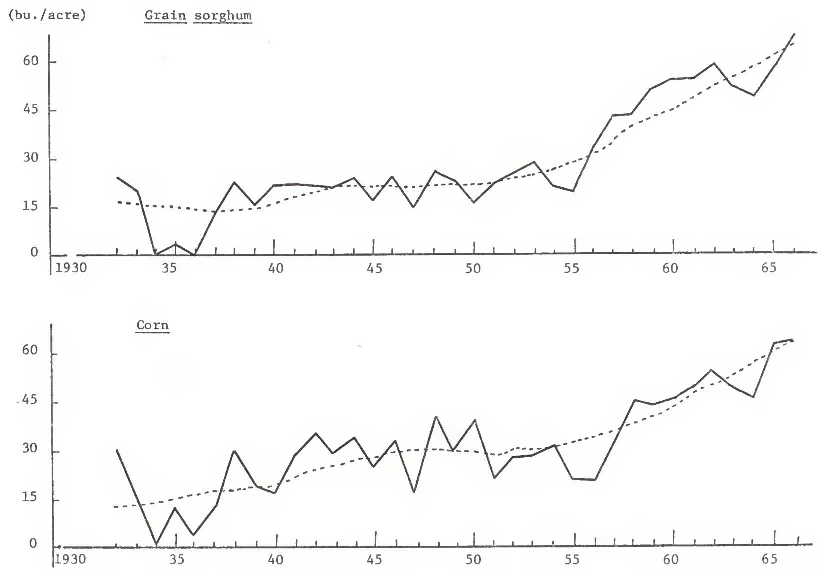

Fig. 3. Fluctuation of actual yield per acre and moving average in grain sorghum and corn, Northeastern Kansas, 1932-1966.

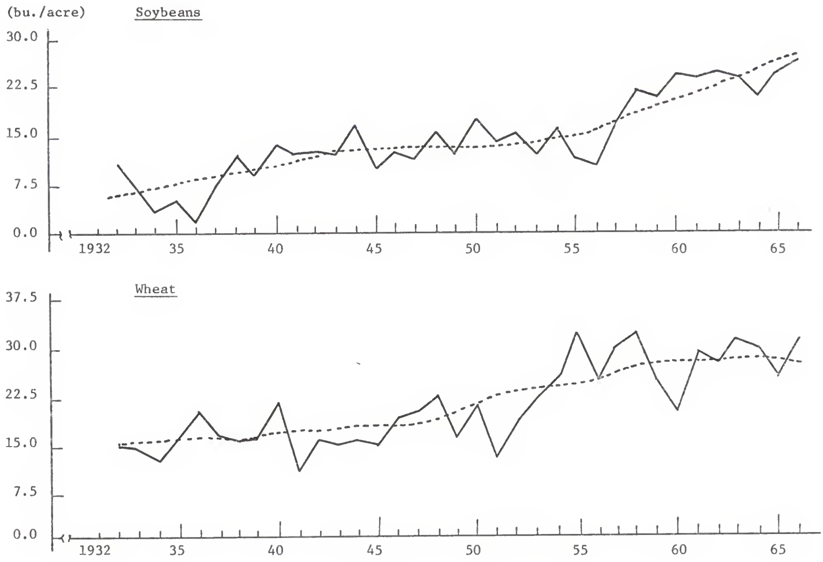

Fig. 4. Fluctuation of actual yield per acre and moving average in soybeans and wheat, Northeastern Kansas, 1932-1966.

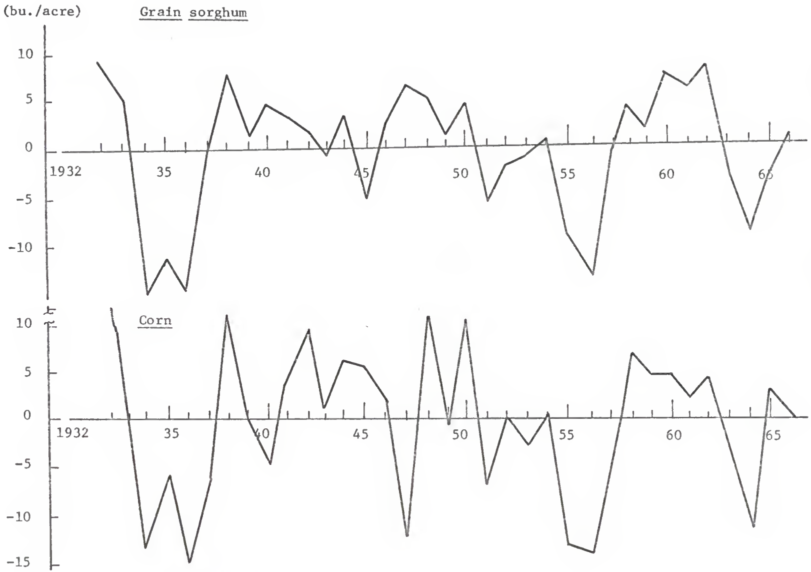

Fig. 5. The fluctuation of per acre yield with trend removed in grain sorghum and corn, Northeastern Kansas, 1932-1966.

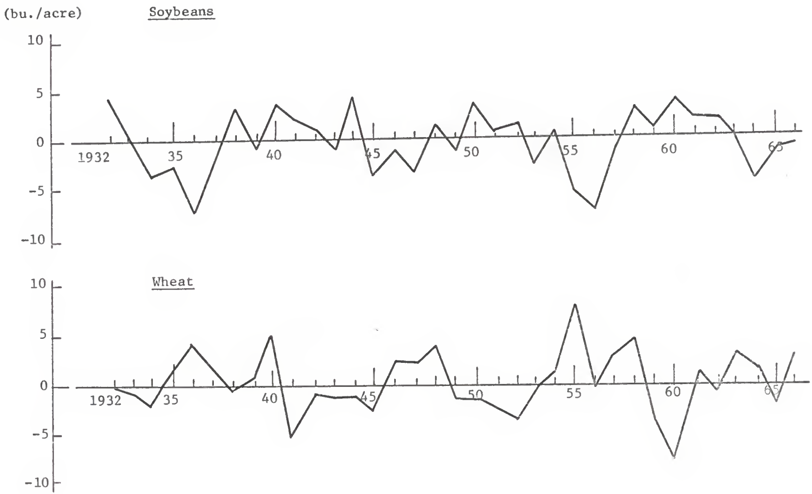

Fig. 6. Fluctuation of per acre yield with trend removed, in soybeans and wheat, Northeastern Kansas, 1932-1966.

Table 2. Mean, variance and coefficients of variation of weather variables and crops, Northeastern Kansas, 1932-1966.

Variables	Mean	Standard Deviation	Coefficients of Variation
Grain sorghum[a]	0.27	6.58	24.3703
Corn[a]	-.27	7.86	-29.1111
Soybeans[a]	-.16	3.14	19.6250
Wheat[a]	0.11	3.65	33.1818
Farm income from crops	5373.14	2473.79	0.4603
Jan.(ET)	0.02	0.06	3.0000
Feb.(ET)	0.07	0.13	1.8571
Mar.(ET)	0.57	0.42	0.7368
Apr.(ET-CAFEC)	-.02	0.14	-7.0000
Apr.(ET)	3.14	0.41	0.1305
May(ET-CAFEC)	0.11	0.22	2.0000
May(ET)	3.72	0.51	0.1370
Jun.(ET-CET)	0.51	0.45	0.8823
Jun.(ET)	5.25	0.52	0.099
July(ET-CET)	0.99	1.01	1.0202
Aug.(ET-CET)	1.27	1.03	0.8110
Sept.(ET-CET)	-.48	6.61	-13.7708
Oct.(ET)	1.78	0.46	0.2584
Nov.(ET)	0.49	0.21	0.4285
Dec.(ET)	0.05	0.08	1.6000

[a]Yield per acre with trend removed.

Farm income is total value of field crops produced as reported in FARM FACTS. The price index used is the average of the price index of food grain and of feed grain and hay. The price index is based on 1932 equal to 100. Both farm income and price index are in Table 3. Fluctuation of farm income and deflated farm income are shown in figures 7 and 8.

Two different weather variables are used. The difference of the actual evapotranspiration and CAFEC evapotranspiration is used in the equations of grain sorghum, corn, and soybean, while the actual evapotranspiration is used in the wheat equation. From April to October, the actual evapotranspiration is usually different from the CAFEC evapotranspiration. The other months are cold and dry, so in most cases, actual evapotranspiration is often equal to the CAFEC evapotranspiration. Thus weather variables measured by the difference of actual evapotranspiration and CAFEC evapotranspiration for winter months would not be useful because the difference would frequently be zero. Therefore, actual evapotranspiration is used instead of the difference of actual evapotranspiration and CAFEC evapotranspiration for wheat during fall, winter and early spring months.

Actual evapotranspiration, CAFEC evapotranspiration and their difference are presented in Tables 17, 18, and 19 in the Appendix. The fluctuation of weather variables are shown in figures 9, 10, 11, 12, and 13.

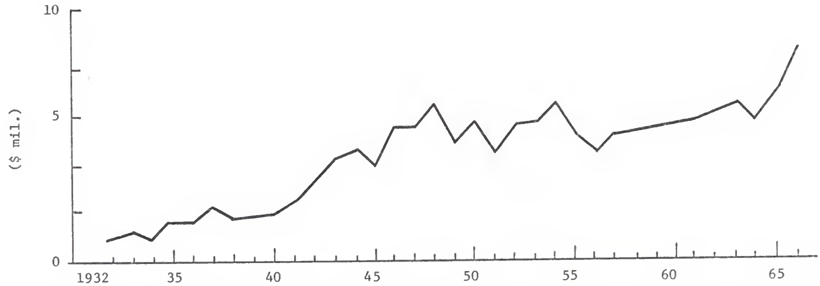

Fig. 7. Fluctuation of farm income from field crops, Northeastern Kansas, 1932-1966.

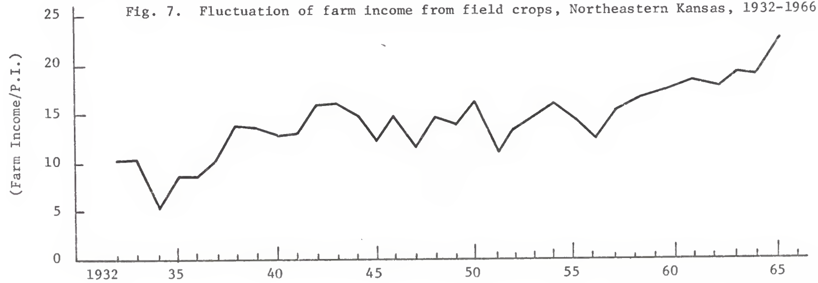

Fig. 8. Fluctuation of deflated farm income, farm income/price index, Northeastern Kansas, 1932-1966.

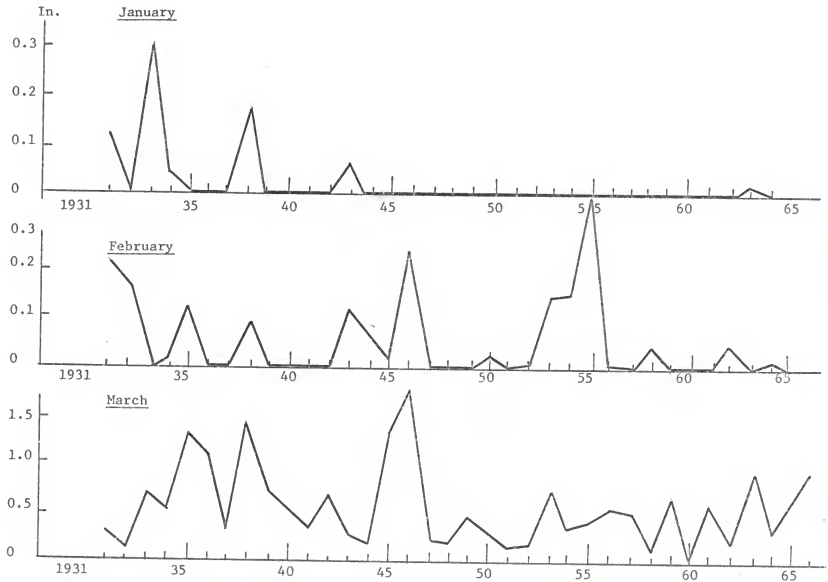

Fig. 9. Actual monthly evapotranspiration in January, February, March, Northeastern Kansas, 1932-1966.

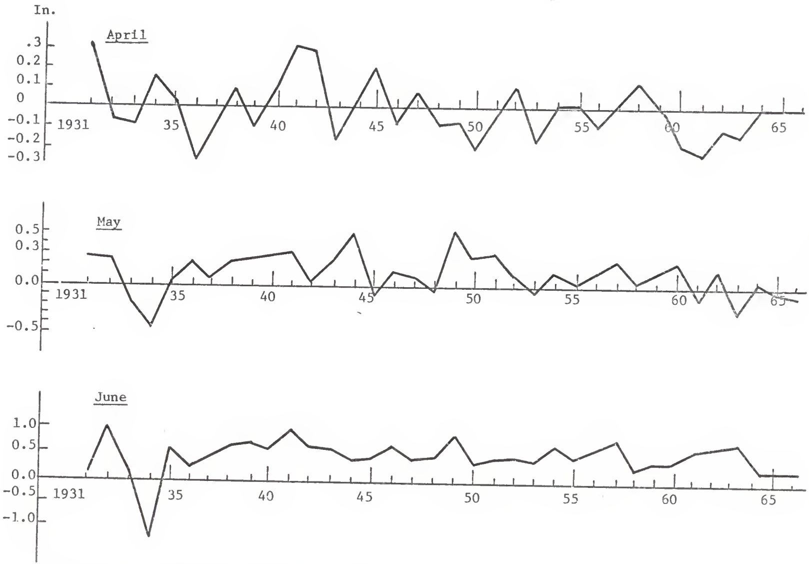

Fig. 10. The difference between monthly actual evapotranspiration and CAFEC evapotranspiration, in April, May, and June, Northeastern Kansas, 1932-1966.

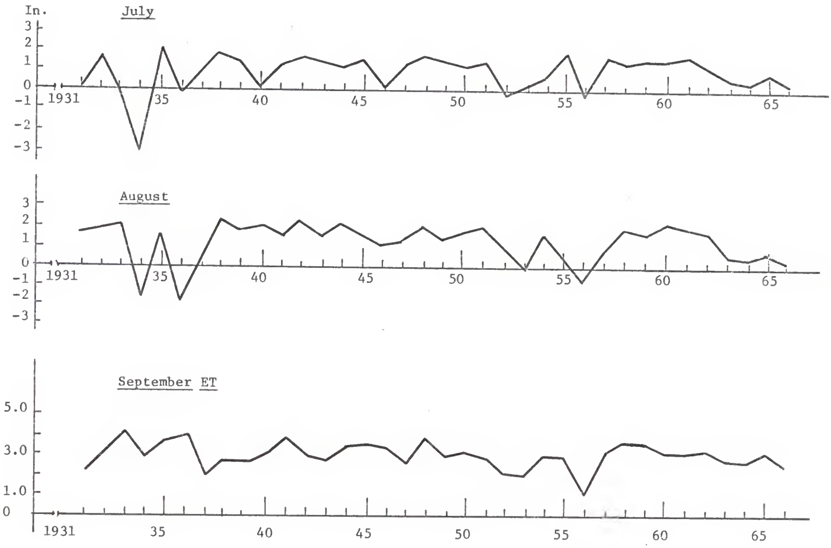

Fig. 11. The difference between monthly actual evapotranspiration and CAFEC evapotranspiration in July and August, and evapotranspiration in September, Northeastern Kansas, 1932-1966.

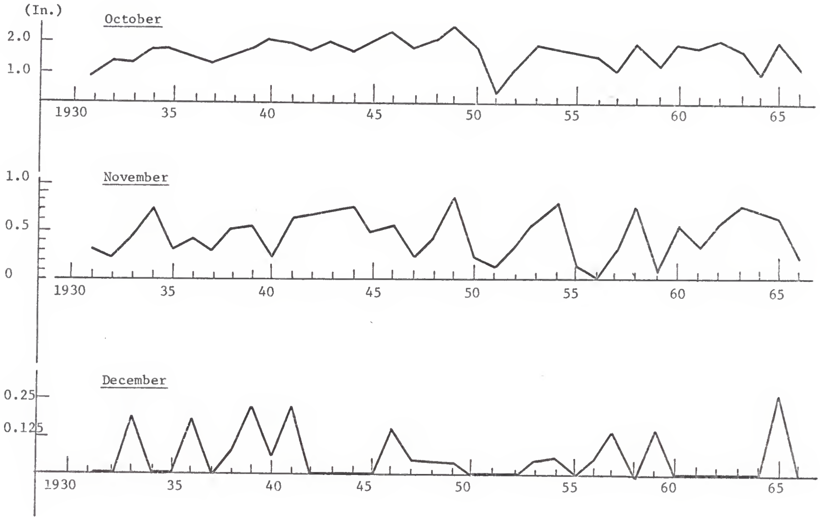

Fig. 12. Actual monthly evapotranspiration in October, November, and December, Northeastern Kansas, 1931-1965.

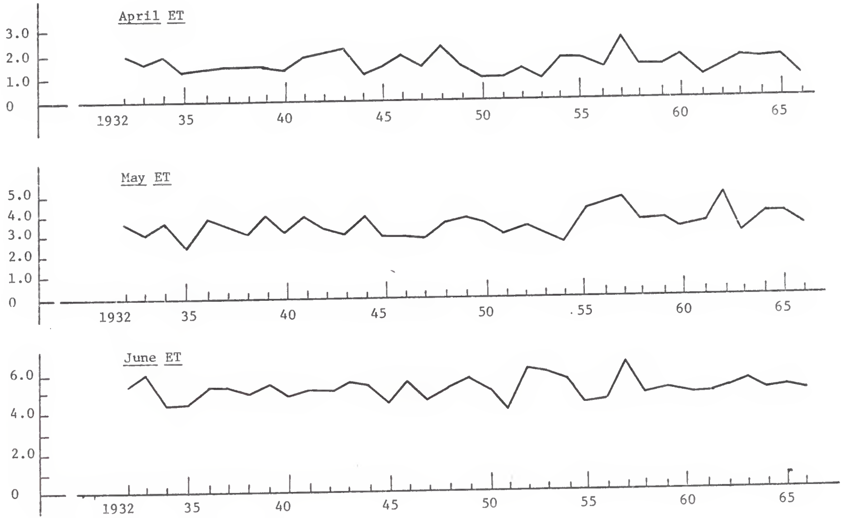

Fig. 13. Actual monthly evapotranspiration in April, May, and June, Northeastern Kansas, 1932-1966.

Table 3. Farm income from field crops and calculated price index, based on 1910-1914 price, and 1932=100, Northeastern Kansas, 1932-1966.

Year	Farm Income from Field Crops ($10,000)	Price Index of Food Grain (1910-14=100)	Price Index of Feed Grain and Hay (1910-14=100)	Calculated Price Index (1910-14=100)	(1932=100)
(1)	(2)	(3)	(4)	(5)	(6)
1966	10267.0	185	181	183.0	397.8
1965	8174.0	164	174	169.0	362.4
1964	7264.0	190	166	178.0	382.8
1963	8095.0	224	164	194.0	417.2
1962	7567.0	226	153	189.5	407.5
1961	7302.0	209	151	180.0	387.1
1960	6899.0	203	151	177.0	380.6
1959	6728.0	202	156	179.0	384.9
1958	6575.0	208	154	181.0	389.2
1957	6450.0	228	183	205.5	441.9
1956	5579.0	224	182	203.0	436.6
1955	6408.0	228	183	205.5	441.9
1954	7973.0	232	203	217.5	467.7
1953	7178.0	234	206	220.0	473.1
1952	6904.0	244	234	239.0	514.0
1951	5409.0	243	226	234.5	504.3
1950	7263.0	224	193	208.5	448.4
1949	5934.0	218	177	197.5	424.7
1948	7911.0	250	249	249.5	536.6
1947	6736.0	271	246	258.5	555.9
1946	6706.0	201	195	198.0	425.8
1945	4511.0	172	161	166.5	358.1
1944	5459.0	165	166	165.5	355.9
1943	5132.0	148	147	147.5	317.2
1942	4040.0	120	111	115.5	248.4
1941	2741.0	97	89	93.0	200.0
1940	2435.0	84	82	83.0	178.5
1939	2143.0	72	69	70.5	151.6
1938	2191.0	75	71	73.0	157.0
1937	2706.0	120	125	122.5	263.4
1936	1999.0	108	102	105.0	225.8
1935	1867.0	97	107	102.0	219.4
1934	1078.0	91	95	93.0	200.0
1933	1411.0	66	57	61.5	132.3
1932	1025.0	45	48	46.5	100.0

Data Adjustment and Techniques

Several data adjustment are required, such as fitting a trend for technological improvement and separating the effect of weather from other factors.

Fitting a Trend for Technological Improvement

Several methods can be used to fit trend estimating technological improvement, a moving or a linear trend by least square method.

Moving Average Method

A moving average series was extrapolated because of the lack of values for both beginning and terminal years, as discussed in Chapter 2.

There are several ways to extrapolate the moving average; a line fit to the moving average using least square regression can be extrapolated backward and foreward to the both beginnings and terminal years. Another procedure is using average changes in beginning years to extrapolate backward to the beginning years and average changes in terminal years to extrapolate foreward to the terminal years. The latter method is used in this study.

Extrapolation backward and forward is based on an average change in beginning and ending years. Average change in the period 1959-61 was used to extrapolate forward to the terminal years, and average change in period 1937-39 was used to extrapolate backward, except for corn. Average change in the period 1937-43 was used for corn.

Most extrapolations show a continuation of the trend, except for grain sorghum and wheat. Trend of grain sorghum has a negative slope at the beginning years and trend of wheat turns down at the terminal years. These extrapolations seem illogical. However, this is a problem of using a moving average approach.

Trend of technological improvement also can be estimated by fitting a trend line to data by the least square method. The slope of the trend can be effected by the length of the time period if regular fluctuation in data are present.[1]

Effect of technological improvement on farm income was estimated by fitting a linear trend to farm income in the weather-farm income study.

Data Adjustment for the Effect of Technology

Deviation of crop yield from trend is due to the effect of weather and other factors (except for technology). The deviation from the trend can be measured in two different ways. The first method is to subtract the moving average from observed yield, and the difference is still bushel per acre. The second method is to divide the observed yield by moving average, and the result is the observed yield relative to the moving average. This study used the method of subtracting the moving average from actual yield although the other approach was tested.

Deflating farm income eliminates the effect of price changes on farm income. A trend was fitted to deflated farm income to estimate the effect of technological improvements on farm income. The difference of deflated farm income and trend is the dependent variable in the weather-farm income study (see Table 4).

1 Ibid., Kendall & Stuart, ADVANCE THEORY OF STATISTICS, p. 373.

Table 4. Deflated farm income, and deviation of deflated farm income from the technological trend, Northeastern Kansas, 1932-1966.

Year	Deflated farm income ($10,000)	Trend of technological improvement ($10,000)	Deviation from trend ($10,000)
1966	25.81	19.98	5.83
1965	22.25	19.66	2.59
1964	18.72	19.34	- .62
1963	19.15	19.03	0.12
1962	18.27	18.71	- .44
1961	18.61	18.39	0.22
1960	17.88	18.07	- .19
1959	17.29	17.75	- .46
1958	16.71	17.43	- .72
1957	15.18	17.11	-1.93
1956	12.64	16.80	-4.16
1955	14.17	16.48	-2.31
1954	16.75	16.16	0.59
1953	15.04	15.84	- .80
1952	13.29	15.52	-2.23
1951	10.63	15.20	-4.57
1950	16.02	14.89	1.13
1949	13.82	14.57	- .75
1948	14.33	14.25	0.08
1947	11.76	13.93	-2.17
1946	15.31	13.61	1.70
1945	12.24	13.29	-1.05
1944	14.86	12.97	1.89
1943	15.74	12.66	3.08
1942	15.82	12.34	3.48
1941	13.34	12.02	1.32
1940	13.26	11.70	1.56
1939	13.69	11.38	2.31
1938	13.81	11.06	2.75
1937	10.16	10.75	- .59
1936	8.72	10.43	-1.71
1935	8.42	10.11	-1.69
1934	5.36	9.79	-4.43
1933	10.55	9.47	1.08
1932	10.25	9.15	1.10

ANALYSIS AND ECONOMIC INTERPRETATION OF RESULTS

In this chapter, economic analysis of statistical estimates is divided into two sections, weather-crop relationship and weather-farm income relationship. Statistics presented are regression coefficients, Student's "t" values, coefficients of determination, and standard errors.

Influence of Weather on Crop Yield

The difference of monthly actual evapotranspiration and CAFEC evapotranspiration during May to August were used in equations relating weather to per acre yield of grain sorghum, corn, soybean. Actual evapotranspiration variables during September through June were used in the study of wheat. These periods are the growing season for crops. Regression equations were selected on the basis of high multiple correlation coefficient, lower standard errors, "t" values of individual regression coefficient, and relevent botanical considerations.

The regression coefficients and their "t" values for the independent variables are presented in Table 5.

Regression Coefficient and "t" Values

The sign of the regression coefficient was positive for the August weather variable in grain sorghum equation. The evapotranspiration (ET-CAFEC) variable for August was correlated with May, and highly correlated with June, and July. The simple correlation coefficient of August for a single month will reflect most of the importance of the other months. An equation with weather variables for all months was tested but because of the correlation among independent variables, signs of individual month were illogical and "t" values were low (see equations in Appendix II). August was the most important month as shown in the equation for grain sorghum with a coefficient of 5.004. This means that if the actual evapotranspiration was one unit higher than the long term normal evapotranspiration in August, yield per acre for grain sorghum would be about 5 bushels higher than normal. Student's test shows the "t" value is significant at 1% level.

The sign of regression coefficient and "t" value shows that weather in August has much the same effect on corn as on grain sorghum. The sign is the same, and the "t" value is also significant at 1% level, but the regression coefficient is little larger, and "t" value is smaller than for grain sorghum.

Results for soybean are different from those for the two crops discussed above. The sign of the regression coefficients are positive in June and August, and negative in July. This indicates that if evapotranspiration is greater than long term normal evapotranspiration in June and August, higher than normal yields results, while the opposite is true for July. It is believed that the correlation between August and July weather variables is responsible for the negative sign for July. Comparing regression coefficients it is found that August has the largest value, June the second largest, followed by July. However, the smaller standard deviation for July indicates that July is more significant than June. As with grain sorghum and corn, the effect of August weather is most important for soybean yield. One inch higher evapotranspiration than the long term evapotranspiration results in 2.950 bushels increase in per acre yield for soybean. T values show that July, and August are significant at 1% level.

For wheat signs of regression coefficients are positive, except for September, indicating that the higher values of actual evapotranspiration in September decreases wheat yields. December is correlated with March and April, so it reflects some of the effect of March and April. As a result, the regression coefficient for December is the largest. T values for all variables are high; but only September is significant at 1% level, December is significant at 5% level and March is significant at 10% level. September can be expected to be important because it is the month preceding the planting and seeds need soil moisture and warm temperature to germinate. Spring months were expected to be significant but were not. March, April, and May were expected to be more important than December, as during this period the plant grows and the heads fill.

Generally speaking, weather has almost the same effect on grain sorghum, corn, and soybean. During the growing period, soil moisture and warm weather are helpful to plant's development, but high evapotranspiration is harmful to wheat during the flowering period. Weather during September is important for wheat, July is important for soybean, however, August is the most important month for grain sorghum, corn, and soybean.

The Coefficient of Determination

The coefficient of determination for equations discussed in this section are shown in Table 5.

In the weather-grain sorghum equation, R-square is 0.624. The selected equation thus explains almost sixty-two per cent of the variation of yield by using August as a variable.

In the weather-corn equation, almost fifty per cent of the yield variation can be explained by the selected equation, and for soybean almost sixty-seven per cent of yield variation can be explained by selected weather variables. R-square is low for wheat, only 0.345, as less than thirty-five per cent of yield variation is explained. As mentioned in the last section, there is high collinearity between August and June, and July. Thus August reflects the effects of these correlated months and the true effect of each individual independent variables during growing season is difficult to measure.

Table 5. Regression coefficients and t-values for independent variables of the weather-crop yield studies, for grain sorghum, corn, soybeans and wheat, Northeastern Kansas, 1932-1966.

Dependent Variables	Constant	Sept.	Nov.	Dec.	Apr.	May	June	July	Aug.
Grain sorghum									
	- 6.473								5.0443
T-value									(7.40)**
Std. Err.	4.099								
R-square	0.624								
Corn									
	- 7.133								5.4234
T-value									(5.80)**
Std. Err.	5.612								
R-square	0.50								
Soybeans									
	- 3.178						1.524	-1.496	2.9501
T-values							(1.35)	(-2.7)**	(6.49)**
Std. Err.	1.899								
R-square	0.667								
Wheat									
	- 9.3986	-2.27	4.70	16.67	2.98	2.00	1.84		
T-values		(-3.4)**	(1.66)	(2.14)*	(1.95)	(1.4)	(1.4)		
Std. Err.	3.280								
R-square	0.345								

** Indicated the variable is significant at 1% level.
 * Indicated the variable is significant at 5% level.

Weather variables for grain sorghum, corn, and soybeans, are the difference of monthly actual evapotranspiration and CAFEC evapotranspiration, while for wheat is the monthly actual evapotranspiration.

The Fluctuation of Crop Yield Due To Weather

Estimation of yield variation per acre for grain sorghum, corn, soybean, and wheat are presented in Tables 6 and 7.

In 1934, and 1956, it was dry during May through August in northeastern Kansas. It was also particularly dry in August of 1936. Actual yield per acre for grain sorghum was very low for these years as August was abnormally dry. High yields in 1938, 1948 and 1959-61 were due to favorable weather. In general, favorable weather during the heading period is more beneficial for crop yield than any other period.

The results for corn are very similar to that for grain sorghum. Less the normal evapotranspiration in August causes low yield per acre, and low yields in 1934, 1936, and 1956 can thus be related to poor weather conditions during August. Similarly, higher yield in 1938, 1948 and 1958-61 can be related to a favorable weather during August.

The effect of weather on soybean is similar to that on grain sorghum, and corn. Low evapotranspiration during August causes a low yield per acre for soybean. For this reason, there were low yields in 1934, 1936 and 1956. However, there favorable weather for soybean in 1938, 1944, 1950, 1958 and 1960, with higher evapotranspiration than normal during August.

The effect of weather on wheat was estimated and is shown in Table 7. The results were not as good as those for other crops. In 1942, 1951 and 1960 yields of wheat were low due to much evapotranspiration prior to September. Yield per acre was higher in 1955, 1957-58, and 1963 than normal. This was related to less adverse weather in September or more beneficial weather during June in these years.

The above results lead to the conclusion that weather is an important factor on crop yields in northeastern Kansas. Effects of weather are

Table 6. Estimated influence of weather on yield per acre of grain sorghum and corn, Northeastern Kansas, 1932-1966.

	Grain sorghum			Corn		
Year	Adj. Yield	Est. Yield	Error	Adj. Yield	Est. Yield	Error
1966	1.30	-4.61	5.91	0.10	-5.13	5.03
1965	-3.20	-2.69	-0.51	2.70	-3.07	5.77
1964	-9.30	-3.90	-5.40	-11.70	-4.37	-7.33
1963	-3.00	-3.75	0.75	-4.80	-4.20	-0.60
1962	7.90	3.31	4.59	4.30	3.39	0.91
1961	5.90	3.77	2.13	2.70	3.88	-1.18
1960	7.30	4.42	2.88	4.30	4.58	-0.28
1959	1.90	2.86	-0.96	4.40	2.90	1.50
1958	3.90	3.21	0.69	7.10	3.28	3.82
1957	-2.20	2.08	-0.12	-3.80	-2.41	-1.39
1956	-13.40	-9.10	-4.30	-13.30	-9.95	-3.35
1955	-9.10	-4.05	-5.05	-12.10	-4.53	-7.57
1954	0.80	3.31	-2.51	0.20	3.39	-3.19
1953	-0.40	-6.22	5.82	-2.30	-7.46	5.10
1952	-1.80	-1.43	-0.37	0.50	-1.71	2.21
1951	-6.00	3.51	-9.51	-6.20	3.61	-9.81
1950	4.30	3.26	1.04	10.20	3.33	6.87
1949	0.90	0.79	0.11	-0.30	0.68	-1.18
1948	4.90	3.72	1.18	10.80	3.82	6.98
1947	-6.40	0.64	-7.04	-12.80	0.51	-13.31
1946	2.90	0.27	3.17	2.10	-0.46	2.56
1945	-5.80	-1.40	-7.20	4.60	1.33	3.27
1944	3.20	4.12	-0.92	6.40	4.26	2.14
1943	-0.50	1.75	-1.80	1.20	1.71	-0.51
1942	1.60	5.13	-3.53	9.60	5.34	4.26
1941	3.10	1.75	1.35	4.00	1.71	2.29
1940	4.60	4.32	0.28	-5.20	4.47	-9.67
1939	1.00	3.41	2.41	-1.00	3.50	-4.50
1938	7.30	5.43	1.87	11.00	5.67	5.33
1937	-0.80	-4.00	32.0	-6.20	-4.48	-1.72
1936	-14.75	-15.20	0.45	-14.50	-16.52	2.02
1935	-11.00	1.70	-12.70	-5.10	1.65	-6.75
1934	-14.85	-15.20	0.35	-13.50	-15.92	2.42
1933	5.20	3.50	1.70	0.80	3.77	-2.97
1932	9.00	2.05	6.95	16.50	3.55	12.95

Table 7. Estimated influence of weather on yield per acre of soybean and wheat, Northeastern Kansas, 1932-1966.

Year	Soybean Adj. Yield	Soybean Est. Yield	Soybean Error	Wheat Adj. Yield	Wheat Est. Yield	Wheat Error
1966	-0.40	-2.29	1.89	3.32	4.15	-0.83
1965	-1.20	-1.94	0.74	-1.80	0.90	-2.70
1964	-4.10	-2.02	-2.08	2.07	2.13	-0.06
1963	0.10	-1.55	1.65	3.45	1.40	2.05
1962	2.00	1.72	0.28	-0.18	-0.19	0.01
1961	2.30	1.05	1.25	1.40	-1.39	2.79
1960	3.80	1.67	2.13	-8.03	-2.29	-5.74
1959	1.40	0.72	0.68	-3.55	-0.35	-3.20
1958	3.40	0.88	2.52	4.70	0.09	4.61
1957	-0.80	-1.93	1.13	3.20	3.57	-0.37
1956	-7.40	-5.69	-1.71	-0.10	-2.61	2.51
1955	-5.20	-3.79	-1.41	9.10	2.85	6.25
1954	0.70	2.61	-1.91	1.40	1.82	-0.42
1953	-2.80	-2.92	0.12	-0.20	-0.72	0.52
1952	1.90	1.09	0.81	-4.00	-3.86	-0.14
1951	0.90	0.90	1.45	-8.60	-4.51	-4.09
1950	3.80	3.80	1.18	-1.20	0.46	-1.66
1949	-1.20	-1.20	0.04	-1.80	-0.50	-1.30
1948	1.80	1.80	1.00	4.50	0.43	4.07
1947	-3.40	-0.18	-3.22	2.40	1.44	3.84
1946	-0.60	1.22	-1.82	2.50	1.04	1.46
1945	-3.40	-0.16	-3.24	-2.90	-0.14	-2.76
1944	4.20	1.76	2.44	-1.20	-2.47	1.27
1943	-0.40	0.50	-0.90	-1.50	1.61	0.11
1942	0.90	2.13	-1.23	-0.80	2.36	-3.16
1941	2.00	1.06	0.94	-5.70	0.91	-6.61
1940	3.20	3.77	-0.57	5.40	3.55	1.85
1939	-0.70	1.50	-2.20	0.60	2.23	-1.63
1938	3.40	1.94	1.46	-0.20	2.90	-3.10
1937	-1.60	-2.33	0.73	1.20	-1.94	3.14
1936	-7.20	-7.36	0.16	4.00	-0.62	4.62
1935	-2.70	-0.49	-2.21	-0.10	0.35	-0.45
1934	-3.60	-5.15	1.55	-2.60	-0.33	-2.27
1933	0.30	3.21	-2.91	-1.00	-2.07	1.07
1932	4.90	1.60	3.30	-0.10	-0.43	0.33

similar for grain sorghum, corn, soybean, and wheat as shown by standard error of estimate these four crops are 4.099, 5.612, 1.899 and 3.280. These figures imply that corn yield is more, and soybean yield is less subject to variation in weather.

Table 8. Regression coefficients and t-values for independent variables for farm income with farm income/price index as dependent variable, Northeastern Kansas, 1932-1966

Dependent Variable	Constant (10000)	Dec. (10000)	Aug. (10000)	$Dec.^2$ (10000)
Farm income				
Price index	-1.1562	-33.2942	0.9903	188.8363
T-values		(2.65)**	(3.32)**	(3.35)**
Std. Err.	1.792			
R-square	0.435			

** Indicated the variable is significant at 1% level.

Influence of Weather on Farm Income

Estimating the effect of weather on farm income was with a regression equation where farm income from field crops divided by price index was the dependent variable, see Table 4. All the important weather variables with "t" value significant at 5% level in the weather-crop yield relationship and their square term were used in this model. Equation was selected on basis of high multiple correlation coefficient, lower standard error, and significant regression coefficients. The regression coefficients and "t" values are shown in Table 8.

The sign of this regression coefficient for December is negative but is positive for its square term and for August. The sign of most variables are in agreement with the assumptions of this study, except for December. August weather variable was significant at 1% level for grain sorghum, corn, and soybean, and for farm income. Regression coefficients indicate that December and its square term are also important. T values of all independent variables used in regression equation are significant at 1% level. August weather is very important for farm income because it was very important in most crops. December is not only correlated with the square term of July, but also with farm income in this study. This is also true for its square term.

The coefficient of determination is not very high, as R-square is little larger than 0.435 for the farm income equation. This means that after eliminating the effect of price changes, only 43.5 per cent of variation in farm income can be explained by weather variables.

The fluctuation of farm income was significantly related to weather variability. Farm income in 1934, 1951, and 1956 was much lower, due to poor yield, than would be expected with normal weather. Given the price index, the effect of weather can be evaluated in dollar terms by using equation in

Table 8. During the period 1932-1966, average farm income was 53,772,000 dollars, average price index was 351.2, average August (ET-CAFEC) variable was 1.27 inches and average December evapotranspiration was 0.05 inch. On the average August weather increased farm income was $4,415,430, while average December weather decreased farm income $4,187,220. If (ET-CAFEC) variable increased by one inch during August, the estimated effect was an increase of $3,476,800 in farm income in northeastern Kansas. If actual monthly evapotranspiration exceeds the average evapotranspiration by one inch during December, the estimated increase in farm income is $577,577,470 dollars. However, for December, the occurance of one inch above the average evapotranspiration did not occur during the 1932-1966 period. The average evapotranspiration is 0.05 inch and standard deviation is 0.08 inch. For August, one inch difference between actual evapotranspiration and CAFEC evapotranspiration occurred frequently as the average is 1.27 inch and its standard deviation is 1.03 inch (see Table 2).

The effect of weather variability in August on farm income as measured by one standard deviation from the mean was ± $3,581,220 dollars, which was 6.7% of average received from farm crops. However, the relationship between December weather and farm income was estimated as quadratic. The minimum point of the function was at evapotranspiration value of 0.088 inch. December evapotranspiration values larger or smaller than 0.088 inch resulted in increasing farm income. The quadratic relationship does not seem to give logical estimates of the influence of December weather on farm income when values below the mean occur.

Weather during the growing season greatly effects farm income in northeastern Kansas. Weather during the summer months has generally been favorable for crop production and farm income, but weather during the winter months has had an adverse influence on farm income in northeastern Kansas.

SUMMARY AND CONCLUSION

The objective of this study was to evaluate the effect of weather on crop yield and farm income. Per acre yield of grain sorghum, corn, soybean, and wheat, and farm income from field crops during the period 1932-1966 in northeastern Kansas were studied. The difference of actual monthly evapotranspiration and CAFEC evapotranspiration were used to measure weather in equations for grain sorghum, corn, and soybean. Actual monthly evapotranspiration was the weather variable in the wehat equation. A multiple linear regression model was used for the weather-crop yield study, and a multiple curvilinear regression model was used in the weather-farm income study.

The effect of technological improvements was estimated with an eleven-year moving average. Actual crop yield was adjusted by substracting from actual yield the increase in yield per acre due to technology. The period of May through August as the growing season was used in grain sorghum, corn, and soybean equations, while the period of September through June was used in wheat equation.

In this study, independent variables are selected on the basis of three criteria, botanical relationship of plants to weather during the growing season,statistical significance of weather variable, and economic relationship.

Government policy, preceding marketing situations were not included in the weather-farm income study. Two main effects, weather and general price level were considered. Effects of prices changes on farm income were eliminated by dividing farm income by price index for that year. Only those significant weather variables determined in the weather-crop yield studies and their square terms were selected as independent variables in the weather-farm income equation. Farm income divided by price index was the dependent variable.

Results of weather-crop yield studies show that August weather had the most effect on grain sorghum, corn, and soybean yield. Evapotranspiration higher than long term normal evapotranspiration caused higher than normal crop yield for three crops. July was significant for soybean and evapotranspiration during September and December effected wheat yield. Results of weather-farm income study show that most variables had the same effect on farm income as on crop yield. Multocollinearity among independent variables was believed to have caused some signs of regression coefficents to be contrary to logic.

Results of the study lead to the following conclusions: (1) Effect of weather on crop yield was improtant in northeastern Kansas during the period 1932-1966. (2) Low yield of grain sorghum, corn, soybean in 1934, 1936, and 1956 were caused by evapotranspiration less than normal. (3) Farm income in 1934, 1951, and 1956 was very low because adverse weather. The fluctuation of farm income is directly related to the fluctuation of crop production in case of a constant price level. (4) If actual evapotranspiration exceeds CAFEC evapotranspiration by one inch during August, the estimated effect was an increase of $3,476,800 of farm income. If actual evapotranspiration exceeds the average evapotranspiraation by one inch during December, the estimated increase in farm income was $577,577,470 in northeastern Kansas. However, the latter case did not occur during the 1932-1966 period (see Table 2.) (5) A variation in the August variable of one standard deviation caused an estimated change of ± $3,581,220 in farm income. (6) December evapotranspiration values larger or smaller than 0.088 inch resulted in increased farm income. The quadratic relationship between December and farm income does not seem to give a logical estimate of the influence of December weather on farm income.

APPENDIX I

TABLE 9 Grain sorghum, production and value data for Northeastern Kansas, 1932--1966[a]

Year (1)	Acres Harvested (Mil. Acre) (2)	Yield (bu./Acre) (3)	Production (Mil. bu.) (4)	Farm Value (Mil.$) (5)	Value ($/bu.) (6)
1966	0.356	65.9	24.432	24.591	1.01
1965	0.342	58.0	19.830	19.037	0.96
1964	0.253	48.5	12.281	12.649	1.03
1963	0.233	51.4	11.996	11.276	0.94
1962	0.186	58.9	10.959	10.521	0.96
1961	0.199	53.7	10.698	9.726	0.91
1960	0.315	51.0	16.048	12.357	0.77
1959	0.254	42.9	10.918	8.843	0.81
1958	0.244	42.8	10.434	9,932	0.95
1957	0.241	34.0	8.193	6.719	0.82
1956	0.121	18.9	2.303	2.834	1.23
1955	0.121	20.7	1.841	2.044	1.11
1954	0.089	28.1	2.157	2.740	1.27
1953	0.077	25.4	0.942	1.121	1.19
1952	0.037	21.4	0.513	0.805	1.57
1951	0.024	16.3	0.191	0.279	1.46
1950	0.117	26.3	0.900	0.981	1.09
1949	0.034	23.2	0.388	0.349	0.90
1948	0.017	26.5	0.716	0.794	1.11
1947	0.027	14.7	0.174	0.351	2.02
1946	0.012	24.0	0.528	0.660	1.25
1945	0.022	15.7	0.350	0.416	1.19
1944	0.035	23.7	0.841	0.795	0.91
1943	0.023	19.9	0.449	0.530	1,18
1942	0.034	20.8	0.714	0.470	0.66
1941	0.042	21.0	0.883	0.504	0.57
1940	0.057	20.7	1.182	0.473	0.40
1939	0.049	15.6	0.762	0.427	0.56
1938	0.051	21.6	1.108	0.421	0.38
1937	0.035	13.9	0.485	0.272	0.56
1936	0.000	0.0	0.0	0.0	0.0
1935	0.019	3.9	0.074	0.048	0.65
1934	0.000	0.0	0.0	0.0	0.0
1933	0.025	20.1	0.494	0.170	0.34
1932	0.028	24.0	0.579	0.153	0.23

a Data reported in FARM FACTS, while 1934 and 1936 were reported as very little and were assumed equal 0.

TABLE 10 Corn, production and value data for Northeastern Kansas, 1932--1966[a]

Year (1)	Acre Harvested (1000 Acre) (2)	Yield (bu./acre) (3)	Production (mil.bu.) (4)	Farm Value (mil.$) (5)	Value ($/bu.) (6)
1966	339	64.0	21.685	28.077	1.21
1965	335	63.2	21.186	24.364	1.15
1964	247	46.0	15.951	18.903	1.19
1963	458	49.0	22.410	24.825	1.10
1962	438	54.8	23.975	25.825	1.08
1961	443	50.0	22.192	24.725	1.11
1960	612	47.7	29.271	28.392	0.97
1959	617	45.0	27.793	28.905	1.04
1958	462	46.2	21.325	22.178	1.04
1957	518	33.5	17.363	19.621	1.13
1956	554	21.1	11.664	16.330	1.40
1955	669	21.4	14.327	20.007	1.40
1954	691	32.1	22.218	33.935	1.53
1953	718	29.3	21.011	30.005	1.43
1952	734	29.5	21.658	33.849	1.56
1951	595	22.8	13.599	23.172	1.70
1950	687	39.6	27.220	37.536	1.38
1949	718	30.4	21.856	26.009	1.19
1948	717	41.3	29.624	39.696	1.34
1947	718	18.2	12.940	29.111	2.25
1946	781	33.1	25.868	33.112	1.28
1945	730	25.9	18.898	23.055	1.22
1944	836	35.1	29.325	30.205	1.03
1943	782	29.9	23.396	25.293	1.07
1942	694	35.7	24.747	20.293	0.82
1941	623	28.8	17.934	12.554	0.70
1940	638	17.6	11.216	6.617	0.59
1939	736	19.7	14.517	8.131	0.56
1938	566	30.0	16.970	7.805	0.45
1937	611	12.8	7.846	4.781	0.60
1936	824	3.8	3.171	2.805	0.89
1935	821	11.9	9.775	5.949	0.61
1934	862	2.6	2.204	1.831	0.63
1933	1,062	15.9	16.936	6.638	0.39
1932	1,053	30.6	32.183	4.562	0.14

a Data reported in FARM FACTS, 1932-1966.

TABLE 11 Soybeans, production and value data for Northeastern Kansas, 1932--1966[a]

Year (1)	Acres Harvested (1000 acre) (2)	Yield (bu./acre) (3)	Production (mil.bu.) (4)	Farm Value (mil.$) (5)	Value (4/bu.) (6)
1966	159.0	26.9	4.285	12.036	2.10
1965	158.7	25.0	3.968	9.323	2.35
1964	100.0	21.0	2.096	5.346	2.55
1963	99.6	24.0	2.314	5.924	2.56
1962	88.7	24.8	2.196	4.809	2.19
1961	58.4	24.1	1.410	3.046	2.16
1960	35.6	24.2	0.860	1.608	1.87
1959	26.2	20.9	0.545	1.014	1.86
1958	22.4	22.1	0.494	0.929	1.88
1957	10.7	17.1	0.183	0.358	1.96
1956	12.7	9.5	0.121	0.253	2.09
1955	15.2	11.1	0.169	0.337	1.99
1954	16.2	16.0	0.258	0.656	1.38
1953	20.0	11.9	0.238	0.577	2.43
1952	15.5	15.5	0.240	0.650	2.71
1951	8.4	14.1	0.119	0.320	2.69
1950	9.0	17.0	0.153	0.334	2.19
1949	4.2	12.5	0.052	0.110	2.12
1948	4.7	15.2	0.071	0.166	2.35
1947	7.8	10.0	0.078	0.248	3.19
1946	9.2	12 6	0.116	0 299	2.58
1945	18.5	9.7	0.179	0 369	2.06
1944	27.2	16.5	0.449	0.920	2.05
1943	45.9	11.9	0.544	0.979	1.79
1942	38.8	12.4	0.485	0.800	1.65
1941	11.5	12.8	0.147	0.198	1.35
1940	4.8	13.3	0.064	0.058	0.89
1939	2.7	8.8	0.024	0.019	0.79
1938	0.8	12.0	0.010	0.009	0.95
1937	0.6	6.9	0.004	0.004	0.94
1936	2.3	1.8	0.004	0.006	1.55
1935	3.2	4.8	0.015	0.019	1.24
1934	2.6	3.4	0.009	0.014	1.50
1933	4.0	6.8	0.027	0.027	1.00
1932	1.6	10.9	0.017	0.008	0.048

a Data reported in FARM FACTS, 1932-1966.

Table 12. Wheat production and value data for Northeastern Kansas 1932-1966[a]

Year (1)	Acres Harvested (1000 acre) (2)	Yield (bu/acre) (3)	Production (mil. bu.) (4)	Farm Value (mil.$) (5)	Value ($/bu.) (6)
1966	295	30.0	8.836	15.110	1.11
1965	230	25.0	5.758	7.889	1.37
1964	350	29.0	10.141	14.603	1.44
1963	324	30.5	9.871	19.051	1.93
1962	290	27.0	7.829	15.971	2.04
1961	340	28.7	10.005	18.209	1.82
1960	291	19.4	5.658	10.071	1.78
1959	375	24.0	8.986	15.815	1.76
1958	348	31.7	11.016	18.948	1.72
1957	326	29.1	9.472	18.565	1.96
1956	356	25.5	9.079	18.159	2.00
1955	344	32.8	11.310	22.733	2.01
1954	366	24.9	9.102	19.934	2.19
1953	460	23.2	10.643	21.819	2.14
1952	402	18.3	7.343	15.715	2.14
1951	423	12.9	5.447	11.710	2.15
1950	443	19.3	8.564	17.299	2.01
1949	551	17.2	9.471	17.710	2.02
1948	479	22.6	10.843	22.120	2.04
1947	413	19.9	8.210	18.884	2.30
1946	381	19.3	7.354	13.826	1.88
1945	373	14.7	5.468	8.311	1.52
1944	368	16.2	5.943	8.646	1.45
1943	303	15.8	4.772	6.776	1.42
1942	344	16.0	5.567	6.068	1.09
1941	501	11.1	5.551	5.440	0.98
1940	572	21.9	12.547	8.156	0.65
1939	583	16.0	9.874	6.409	0.65
1938	857	16.0	13.741	7.420	0.54
1937	797	17.3	13.816	14.231	1.03
1936	429	19.9	8.515	8.791	1.03
1935	378	15.6	5.910	5.338	0.90
1934	293	12.9	3.779	3.225	0.86
1933	237	14.3	3.388	2.402	0.71
1932	199	15.1	2.994	0.963	0.32

[a]Data reported in FARM FACTS, 1932-1966.

Table 13. Actual and adjusted yield per acre for grain sorghum, Northeastern Kansas, 1932-1966.

Year	Yield (bu/acre)	11 Years a moving average (bu/acre)	Trend of Tech. improvement (bu/acre)	Yield variation (bu/acre)
1966	65.9		64.6	1.30
1965	58.0		61.2	-3.20
1964	48.5		57.8	-9.30
1963	51.4		54.4	-3.00
1962	58.9		51.0	7.90
1961	53.7	47.8	47.8	5.90
1960	51.0	43.7	43.7	7.30
1959	42.9	41.0	41.0	1.90
1958	42.8	38.9	38.9	3.90
1957	34.0	36.2	36.2	-2.20
1956	18.0	32.3	32.3	-13.40
1955	20.7	29.8	29.8	-9.10
1954	28.1	27.3	27.3	0.80
1953	25.4	25.8	25.8	-0.40
1952	21.4	23.2	23.2	-1.80
1951	16.3	22.3	22.3	-6.00
1950	26.3	22.0	22.0	4.30
1949	23.2	22.3	22.3	0.90
1948	26.5	21.6	21.6	4.90
1947	14.7	21.1	21.1	-6.40
1946	24.0	21.1	21.1	2.90
1945	15.7	21.5	21.5	-5.80
1944	23.7	20.5	20.5	3.20
1943	19.9	20.4	20.4	-0.50
1942	20.8	19.2	19.2	1.60
1941	21.0	17.9	17.9	3.10
1940	20.7	16.1	16.1	4.60
1939	15.6	14.6	14.6	1.00
1938	21.6	14.3	14.3	7.30
1937	13.9	14.7	14.7	-0.80
1936	0.0*	15.3	14.75	-14.75
1935	3.9		14.8	-11.00
1934	0.0*		14.85	-14.85
1933	20.1		14.9	5.20
1932	24.0		15.0	9.00

*The yield of 1936 and 1934 are not given, they are very little, due to the weather.

The moving average was extrapolated forward and backward.

TABLE 14. Actual and adjusted yield per acre for Corn, Northeastern Kansas, 1932-1966.

Year (1)	Yield (bu./acre) (2)	11 years moving average[a] (bu./acre) (3)	Trend of tech. improvement (bu./acre) (4)	Yield variation (bu./acre) (5) (2)-(4)
1966	64.0		63.9	0.10
1965	63.2		60.5	2.70
1964	46.0		57.2	-11.70
1963	49.0		53.8	-4.80
1962	54.8		50.5	4.30
1961	50.0	47.3	47.3	2.70
1960	47.7	43.4	43.5	4.30
1959	45.0	40.6	40.6	4.40
1958	46.2	39.1	39.1	7.10
1957	33.5	37.3	37.3	-3.80
1956	21.1	34.4	34.4	-13.30
1955	21.4	33.5	33.5	-12.10
1954	32.1	31.9	31.9	0.20
1953	29.3	31.6	31.6	-2.30
1952	29.5	29.0	29.0	0.50
1951	22.8	29.0	29.0	-6.20
1950	39.6	29.4	29.4	10.20
1949	30.4	30.7	30.7	-0.30
1948	41.3	30.5	30.5	10.80
1947	18.2	31.0	31.0	-12.80
1946	33.1	31.0	31.0	2.10
1945	25.9	30.5	30.5	4.60
1944	35.1	28.7	28.7	6.40
1943	29.9	28.7	28.7	1.20
1942	35.7	26.1	26.1	9.60
1941	38.8	24.5	24.8	4.00
1940	17.6	22.8	22.8	-5.20
1939	19.7	20.7	20.7	-1.00
1938	30.0	19.0	19.0	11.00
1937	12.8	19.0	19.0	-6.20
1936	3.8		18.3	-14.50
1935	11.9		17.0	-5.10
1934	2.6		16.1	-13.50
1933	15.9		15.1	0.80
1932	30.6		14.1	16.50

[a] The moving average was extrapolated backward and forward by method discussed in Chapter 4.

TABLE 15 Actual and adjusted per acre for soybean, Northeastern Kansas, 1932--1966.

Year (1)	Yield (bu./acre) (2)	11 years moving average[a] (bu./acre) (3)	trend of tech. improvement (bu./acre) (4)	yield variation (bu./acre) (5) (2)-(4)
1966	26.9		27.3	-0.40
1965	25.0		26.2	-1.20
1964	21.0		25.1	-4.10
1963	24.0		23.9	0.10
1962	24.8		22.8	2.00
1961	24.1	21.8	21.8	2.30
1960	24.2	20.4	20.4	3.80
1959	20.9	19.5	19.5	1.40
1958	22.1	18.7	18.7	3.40
1957	17.1	17.9	17.9	-0.80
1956	9.5	16.9	16.9	-7.40
1955	11.1	16.3	16.3	-5.20
1954	16.0	15.3	15.3	0.70
1953	11.9	14.7	14.7	-2.80
1952	15.5	13.6	13.6	1.90
1951	14.1	13.2	13.2	0.90
1950	17.0	13.2	13.2	3.80
1949	12.5	13.7	13.7	-1.20
1948	15.2	13.4	13.4	1.80
1947	10.0	13.4	13.4	-3.40
1946	12.6	13.2	13.2	-0.60
1945	9.7	13.1	13.1	-3.40
1944	16.5	12.3	12.3	4.20
1943	11.9	12.3	12.3	-0.40
1942	12.4	11.5	11.5	0.90
1941	12.8	10.8	10.8	2.00
1940	13.3	10.1	10.1	3.20
1939	8.8	9.5	9.5	-0.70
1938	12.0	8.6	8.6	3.40
1937	6.9	8.5	8.5	-1.60
1936	1.8		8.0	-7.20
1935	4.8		7.5	-2.70
1934	3.4		7.0	-3.60
1933	6.8		6.5	0.30
1932	10.9		6.0	4.90

[a] The moving average was extrapolated forward and backward, as discussed in Chapter 4.

TABLE 16 Actual and adjusted per acre yield for wheat, Northeastern Kansas, 1932--1966.

Year (1)	Yield (2)	11 years moving average[a] (3)	trend of tech. improvement (4)	yield variation (5)
1966	30.0		26.68	3.32
1965	25.0		26.80	-1.80
1964	29.0		26.93	2.07
1963	30.5		27.05	3.45
1962	27.0		27.18	-0.18
1961	28.7	27.3	27.3	1.40
1960	19.4	27.43	27.43	-8.03
1959	24.0	27.55	27.55	-3.55
1958	31.7	27.0	27.0	4.70
1957	29.1	25.9	25.9	-3.20
1956	25.5	25.6	25.6	-0.10
1955	32.8	23.7	23.7	9.10
1954	24.9	23.5	23.5	1.40
1953	23.2	23.4	23.4	-0.20
1952	18.3	22.3	22.3	-4.00
1951	12.9	21.5	21.5	-8.60
1950	19.3	20.5	20.5	-1.20
1949	17.2	19.0	19.0	-1.80
1948	22.6	18.1	18.1	4.50
1947	19.9	17.5	17.5	2.40
1946	19.3	16.8	16.8	2.50
1945	14.7	17.6	17.6	-2.90
1944	16.2	17.4	17.4	-1.20
1943	15.8	17.3	17.3	-1.50
1942	16.0	16.8	16.8	-0.80
1941	11.1	16.8	16.8	-5.70
1940	21.9	16.5	16.5	5.40
1939	16.9	16.3	16.3	0.60
1938	16.0	16.2	16.2	-0.20
1937	17.3	16.1	16.1	1.20
1936	19.9		15.9	4.00
1935	15.6		15.7	-0.10
1934	12.9		15.5	-2.60
1933	14.3		15.3	-1.00
1932	15.1		15.2	-0.10

[a] The moving average was extrapolated forward and backward as discussed in Chapter 4.

Table 17. Actual Evapotranspiration, Northeastern Kansas, 1931-1966[a]

Year (1)	Jan. (2)	Feb. (3)	Mar. (4)	Apr. (5)	May (6)	Jun. (7)	Jul. (8)	Aug. (9)	Sept. (10)	Oct. (11)	Nov. (12)	Dec. (13)
1966	0.00	0.00	0.97	1.51	3.40	5.12	6.55	4.45	2.60	1.25	0.29	0.00
1965	0.00	0.00	0.00	2.20	4.35	5.12	6.09	5.20	3.30	2.14	0.67	0.28
1964	0.02	0.02	0.35	2.12	4.36	5.07	6.58	4.78	2.88	0.93	0.72	0.00
1963	0.00	0.00	0.94	2.30	3.78	5.47	5.75	4.24	2.88	1.97	0.79	0.00
1962	0.00	0.00	0.22	1.71	5.10	5.11	5.86	5.57	3.21	2.28	0.57	0.00
1961	0.00	0.08	0.62	1.38	3.61	5.00	6.16	5.09	3.06	2.02	0.35	0.00
1960	0.00	0.00	0.00	2.18	3.47	5.04	5.65	5.68	3.05	2.13	0.56	0.00
1959	0.00	0.00	0.71	1.77	4.00	5.27	5.52	5.60	3.60	1.50	0.14	0.17
1958	0.00	0.00	0.14	1.71	3.85	4.99	5.65	5.29	3.76	2.13	0.75	0.00
1957	0.00	0.08	0.52	1.60	3.39	5.06	6.79	4.52	3.14	1.56	0.35	0.18
1956	0.00	0.00	0.58	1.60	4.14	4.71	4.65	3.38	1.02	1.91	0.04	0.07
1955	0.00	0.00	0.44	2.72	3.95	4.57	7.00	4.14	3.31	1.99	0.15	0.00
1954	0.00	0.58	0.37	2.61	2.88	5.81	6.27	5.98	3.45	2.10	0.82	0.07
1953	0.00	0.23	0.76	1.38	3.41	6.46	4.49	3.19	2.28	1.21	0.65	0.04
1952	0.00	0.22	0.22	1.67	3.58	6.51	4.51	4.75	2.45	0.33	0.40	0.00
1951	0.00	0.01	0.19	1.35	3.67	4.41	5.47	5.57	3.06	1.80	0.18	0.00
1950	0.00	0.05	0.33	1.39	3.75	5.19	4.99	4.64	3.28	2.43	0.27	0.00
1949	0.00	0.00	0.50	1.83	4.16	5.66	6.28	4.57	2.86	2.24	0.88	0.03
1948	0.00	0.00	0.18	2.71	3.62	5.23	6.11	5.25	3.56	1.76	0.56	0.03
1947	0.00	0.00	0.23	1.71	3.07	4.95	5.68	5.39	2.48	2.40	0.24	0.04
1946	0.00	0.37	1.72	2.49	3.01	5.59	5.38	4.77	3.48	2.10	0.58	0.14
1945	0.00	0.03	1.36	1.75	2.99	4.25	5.48	5.13	3.79	1.85	0.50	0.00
1944	0.07	0.10	0.23	1.24	4.28	5.51	5.66	5.64	3.64	2.05	0.73	0.00
1943	0.00	0.20	0.29	2.28	3.15	5.62	6.63	5.73	3.00	1.66	0.35	0.00
1942	0.00	0.00	0.69	2.57	3.41	5.17	6.48	5.53	3.38	2.05	0.68	0.00
1941	0.00	0.00	0.38	2.37	4.41	5.21	6.01	5.23	4.08	2.16	0.64	0.21
1940	0.00	0.00	0.59	1.77	3.42	5.12	5.13	5.40	3.05	1.75	0.29	0.05
1939	0.18	0.00	0.74	1.78	4.32	5.53	6.62	5.50	2.59	1.52	0.57	0.21
1938	0.00	0.14	1.41	1.97	3.52	5.20	6.73	6.30	2.88	1.42	0.51	0.06
1937	0.00	0.00	0.32	1.85	3.95	5.11	5.88	4.52	2.11	1.60	0.30	0.00
1936	0.00	0.00	1.10	1.73	4.30	5.50	5.15	2.53	4.28	1.78	0.40	0.14
1935	0.00	0.17	1.34	1.61	2.81	4.66	7.20	5.42	3.69	1.77	0.31	0.00
1934	0.05	0.02	0.55	2.26	3.67	4.45	2.31	2.50	3.22	2.21	0.77	0.00
1933	0.31	0.00	0.71	1.90	3.62	6.23	5.03	5.34	4.30	1.32	0.47	0.16
1932	0.00	0.28	0.12	2.26	3.87	5.51	6.66	5.62	3.30	1.41	0.26	0.00
1931	0.13	0.34	0.33	1.94	3.12	5.10	4.88	4.89	2.46	0.89	0.32	0.00

[a]Data calculated by Department of Physics, Kansas State University, Manhattan, Kansas.

Table 18. Monthly CAFEC Evapotranspiration, Northeastern Kansas, 1931-1966

Year (1)	Jan. (2)	Feb. (3)	Mar. (4)	Apr. (5)	May (6)	June (7)	July (8)	Aug. (9)	Sept. (10)	Oct. (11)	Nov. (12)	Dec. (13)
1966	0.00	0.00	0.97	1.51	3.50	4.87	6.16	4.08	2.69	1.64	0.59	0.00
1965	0.00	0.00	0.00	2.20	4.40	4.87	5.18	4.45	2.79	1.87	0.71	0.28
1964	0.02	0.02	0.35	2.12	4.31	4.82	6.09	4.27	3.06	1.54	0.70	0.00
1963	0.00	0.22	1.22	2.44	4.04	4.92	4.94	3.70	3.06	2.81	0.77	0.00
1962	0.00	0.22	0.57	1.82	4.91	4.32	4.50	3.63	2.25	1.72	0.51	0.10
1961	0.01	0.17	0.78	1.61	3.15	4.32	4.29	3.06	2.02	1.50	0.29	0.00
1960	0.00	0.00	0.07	2.37	3.21	4.57	4.15	3.52	2.62	1.63	0.55	0.02
1959	0.00	0.06	0.85	1.75	3.81	4.82	4.02	3.75	2.43	1.15	0.24	0.27
1958	0.10	0.00	0.08	1.56	3.83	4.60	4.18	3.37	2.53	1.57	0.65	0.03
1957	0.00	0.30	0.61	1.57	3.14	4.14	4.97	3.65	2.04	1.22	0.33	0.36
1956	0.00	0.06	0.90	1.70	4.31	5.53	4.83	3.90	2.91	1.99	0.45	0.18
1955	0.06	0.00	0.70	2.71	3.90	3.99	5.05	3.66	2.72	1.63	0.32	0.03
1954	0.00	0.74	0.53	2.59	2.71	5.01	5.50	4.04	3.10	1.61	0.77	0.16
1953	0.19	0.36	1.10	1.55	3.44	6.03	4.32	3.24	2.77	1.72	0.53	0.10
1952	0.12	0.34	0.38	1.55	3.49	5.92	4.79	3.75	2.61	1.28	0.37	0.00
1951	0.00	0.18	0.40	1.44	3.32	3.83	4.34	3.59	2.07	1.30	0.21	0.02
1950	0.00	0.28	0.56	1.61	3.45	4.77	3.67	2.71	2.17	1.92	0.33	0.06
1949	0.00	0.02	0.68	1.88	3.60	4.74	4.65	3.13	2.02	1.54	0.81	0.08
1948	0.00	0.00	0.25	2.78	3.64	4.64	4.32	3.23	2.69	1.47	0.38	0.09
1947	0.03	0.02	0.40	1.63	2.98	4.42	4.36	3.98	2.97	2.29	0.29	0.06
1946	0.09	0.50	1.53	2.56	2.86	4.81	5.10	3.54	2.48	1.57	0.50	0.29
1945	0.03	0.08	1.32	1.52	3.12	3.77	4.29	3.57	2.42	1.43	0.64	0.00
1944	0.06	0.24	0.45	1.37	3.70	5.06	4.36	3.54	2.38	1.56	0.66	0.00
1943	0.00	0.38	0.40	2.44	2.88	4.92	4.89	4.10	2.30	1.32	0.43	0.00
1942	0.01	0.03	0.84	2.26	3.36	4.41	4.72	3.23	2.22	1.54	0.59	0.02
1941	0.08	0.10	0.46	2.05	4.05	4.19	4.59	3.60	2.60	1.54	0.56	0.25
1940	0.00	0.08	0.88	1.86	3.42	4.49	4.91	3.26	2.56	2.06	0.33	0.18
1939	0.28	0.00	1.00	1.88	4.07	4.79	5.13	3.54	3.06	1.87	0.52	0.29
1938	0.12	0.24	1.45	7.85	3.29	4.47	4.75	3.94	2.76	2.15	0.43	0.16
1937	0.00	0.05	0.45	1.93	3.85	4.59	4.95	4.03	2.59	1.42	0.34	0.01
1936	0.00	0.00	1.29	2.01	4.05	4.12	5.38	4.26	2.65	1.21	0.44	0.25
1935	0.12	0.30	1.51	1.57	2.74	4.02	5.15	3.80	2.40	1.41	0.27	0.06
1934	0.14	0.19	0.82	2.10	4.11	5.78	5.52	4.12	2.10	1.87	0.72	0.07
1933	0.36	0.02	1.01	1.99	3.75	5.94	5.04	5.34	4.30	1.32	0.47	0.16
1932	0.00	0.48	0.26	2.34	3.60	4.49	4.93	3.65	2.46	1.35	0.33	0.00
1931	0.19	0.47	0.39	1.62	2.85	5.04	4.85	3.20	3.46	1.89	0.68	0.30

[a]Data reported in FARM FACTS, 1932-1966.

Table 19. Difference of monthly actual evapotranspiration and CAFEC evapotranspiration, i.e., ET-CAFEC, Northeastern Kansas, 1931-1966.

Year (1)	Jan. (2)	Feb. (3)	Mar. (4)	Apr. (5)	May (6)	June (7)	July (8)	Aug. (9)	Sept. (10)	Oct. (11)	Nov. (12)	Dec. (13)
1966	0.00	0.00	0.00	0.00	-.10	0.25	0.39	0.37	-.09	-.39	-.30	0.00
1965	0.00	0.00	0.00	0.00	-.05	0.25	0.91	0.75	0.51	0.27	-.04	0.00
1964	0.00	0.00	0.00	0.00	0.05	0.25	0.49	0.51	-.18	-.61	0.02	0.00
1963	0.00	-.22	-.28	-.14	-.26	0.82	0.81	0.54	-.18	-.84	0.02	0.00
1962	0.00	-.22	-.35	-.11	0.19	0.79	1.36	1.94	0.96	0.56	0.06	-.10
1961	-.01	-.09	-.16	-.23	-.14	0.68	1.87	2.03	1.04	0.52	0.06	0.00
1960	0.00	0.00	-.07	-.19	0.26	0.47	1.50	2.16	0.43	0.50	0.01	-.02
1959	0.00	-.06	-.14	0.02	0.19	0.45	1.50	1.85	1.17	0.36	-.10	-.10
1958	-.10	0.00	0.06	0.15	0.02	0.39	1.47	1.92	1.23	0.56	0.10	-.03
1957	0.00	-.22	-.09	0.03	0.25	0.92	1.82	0.87	1.10	0.34	0.02	-.18
1956	0.00	-.60	-.32	-.10	-.17	-.83	-.18	-.52	-1.89	-.08	-.01	-.11
1955	-.06	0.00	-.26	0.01	0.05	0.58	1.95	0.48	0.59	0.36	-.17	-.03
1954	0.00	-.16	-.16	0.02	0.17	0.80	0.77	1.94	0.35	0.49	0.05	-.09
1953	-.19	-.13	-.34	-.17	-.03	0.43	0.17	-.05	-.49	-.51	0.12	-.06
1952	-.12	-.12	-.16	0.12	0.09	0.59	-2.8	1.00	-0.16	-.95	-.03	0.00
1951	0.00	-.17	-.21	-.09	0.35	0.58	1.40	1.98	0.99	0.50	0.03	-.02
1950	0.00	-.23	-.23	-.22	0.30	0.42	1.32	1.93	1.11	0.51	-.06	-.06
1949	0.00	-.02	-.18	-.05	0.56	0.92	1.63	1.44	0.84	0.70	0.07	-.05
1948	0.00	0.00	-.07	-.07	-.02	0.59	1.79	2.02	0.87	0.29	0.18	-.06
1947	-.03	-.02	-.17	0.08	0.09	0.53	1.32	1.41	-.49	0.11	-.05	-.02
1946	-.09	-.13	0.19	-.07	0.15	0.78	0.28	1.23	1.00	0.62	0.08	-.15
1945	-.03	-.05	0.04	0.22	-.13	0.48	1.55	1.56	1.37	0.42	-.14	0.00
1944	0.01	-.14	-.22	-.13	0.58	0.45	1.30	2.10	1.26	0.49	0.07	0.00
1943	0.00	-.18	-.11	-.16	0.27	0.70	1.47	1.63	0.70	0.34	-.08	0.00
1942	-.01	-.03	-.15	0.31	0.05	0.76	1.76	2.30	1.16	0.55	0.09	-.02
1941	-.08	-.10	-.08	0.32	0.36	1.02	1.42	1.63	1.48	0.62	0.08	-.04
1940	0.00	-.08	-.29	0.09	0.00	0.63	0.22	2.14	0.49	-.31	-.04	-.13
1939	-.10	0.00	-.26	-.10	0.25	0.74	1.49	1.96	-.47	-.36	0.05	-.08
1938	-.12	-.10	-.04	0.12	0.23	0.73	1.98	2.36	0.12	-.73	0.08	-.10
1937	0.00	-.05	-.13	-.08	0.10	0.52	0.93	0.49	-.48	0.18	0.04	-.01
1936	0.00	0.00	-.19	-2.8	0.25	0.38	-.23	-1.73	1.63	0.57	-0.04	-.11
1935	-.12	-.13	-.17	0.04	0.07	0.64	2.05	1.62	1.29	0.36	0.04	-.06
1934	-.09	-.17	-.27	0.16	-.44	-1.33	-3.21	-1.62	1.12	0.34	0.05	-.07
1933	-.05	-.02	-.31	-.09	-.13	0.29	-.01	2.01	1.26	-.25	-.29	-.19
1932	0.00	-.20	-.14	-.08	0.27	1.02	1.73	1.97	0.84	0.06	-.07	0.00
1931	-.06	-.13	-.06	0.32	0.27	0.06	0.03	1.69	-1.00	-1.00	-.36	-.30

APPENDIX II

Other equations were tested and regression coefficients, T-values, and standard error follow:

Dependent Variables	Constant	May(ET-CAFEC)	June(ET-CAFEC)	July(ET-CAFEC)	August(ET-CAFEC)[a]
Grain sorghum	-7.0289	-2.5900	4.0729	-0.8968	4.8421
T-values		(-0.6364)	(1.5671)	(-0.8148)	(4.8950)
Std. Err.	4.132				
Corn	-7.2339	0.3121	0.9403	-0.3948	5.4104
T-values		(0.0539)	(0.2539)	(-0.2293)	(3.83)
Std. Err.	5.877				
Soybean	-3.1806	1.5719	1.2055	-1.5541	2.9386
T-values		(0.8364)	(1.0043)	(-2.7786)	(6.4324)
Std. Err.	1.908				

Dependent Variables	Constant	Sept t-1	Oct t-1	Nov t-1	Dec t-1	Jan	Feb	Mar	Apr	May	June[b]
Wheat	-21.58	-2.337	1.343	4.746	19.105	0.029	0.968	2.965	1.968	2.11	1.02
T-values		(-2.25)	(0.81)	(1.53)	(1.97)	(0.00)	(0.12)	(1.81)	(1.28)	(1.20)	(0.67)
Std. Err.	3.474										

[a] Weather variables used for grain sorghum, corn, soybean were the difference of actual monthly evapotranspiration and CAFEC monthly evapotranspiration during the period May through Aug.

[b] Weather variables used for wheat were actual monthly evapotranspirations during the period September through June.

BIBLIOGRAPHY

Books

1. Ackley, Gardner, MACROECONOMIC THEORY, The Macmillan Company, New York, 1961

2. Chen, Chao-chen, STATISTICS (CHINESE EDITION), Taiwan, Republic of China, 1961.

3. Chou, Ya-lun, APPLICATION BUSINESS AND ECONOMIC STATISTICS, Holt, Rinehart and Winston, 1963.

4. Ezekiel, Modecai and Fox, Karl A., METHODS OF CORRELATION AND REGRESSION ANALYSIS, New York, John Wiley & Sons, Inc., 1966.

5. Fryer, H.C., CONCEPTS AND METHODS OF EXPERIMENTAL STATISTICS, Allyn and Bacon, Inc., Boston, 1966.

6. Gove, Philip Babcock, WEBSTER'S THIRD NEW INTERNATIONAL DICTIONARY, G. C. Merriam Company, Springfield, Massachusetts, 1961.

7. Heady and Dillon, AGRICULTURAL PRODUCTION FUNCTIONS, Iowa State University, Ames, Iowa, Third Printing, 1966.

8. Johnston, J., ECONOMETRIC METHODS, McGraw-Hill Book Company, Inc., New York, 1960.

9. Kendall, M. G. and Stuart, Aron, ADVANCED THEORY OF STATISTICS, Charles Griffin, London, England, 1948-1966.

10. Malinvaud, E., STATISTICAL METHODS OF ECONOMETRICS, Translated by Mrs. A. Silvey, Rand McNally & Co., 1966.

11. Mood, Alexander M., and Graybill, Franklin, INTRODUCTION TO THE THEORY OF STATISTICS, Second Edition, 1965.

12. Sanderson, Fred H., METHODS OF CROP FORECASTING, Harvard University Press, Cambridge, Massachusetts, 1954.

13. Snedecor, George W., STATISTICAL METHODS, Iowa State University Press, Ames, Iowa.

14. Vickrey, W. W., MICROSTATICS, Harcourt, Brace & World, Inc., New York, 1964.

15. WEBSTER'S NEW COLLEGIATE DICTIONARY, 1957.

16. Wold, Herman and Jureen, Lars, DEMAND ANALYSIS, John Wiley & Sons, Inc., New York, 1966.

17. Yamame, Taro, MATHEMATICS FOR ECONOMISTS, Prentice-Hall, Inc., 1962.

Journals and Bulletins

1. Auer, Ludwig and Heady, Earl O., THE PRODUCTION OF WEATHER AND YIELD TECHNOLOGY TO CHANGES IN U.S. CORN PRODUCTION 1939 TO 1961, CAED Report 20.

2. Bean, Louis H., THE PREDICATABILITY OF CYCLES, TREND, AND ANNUAL FLUCTUATION IN WEATHER AND CROPS, CAED Report 20, Iowa State University of Science and Technology, Ames, Iowa, 1964.

3. Blake, G. R., at at., AGRICULTURAL DROUGHT AND MOISTURE EXCESS IN MINNESOTA, University of Minnesota Agricultural Experiment Station, Technical Bulletin 235, May 1960.

4. Dale, Robert F., CHANGE IN MOISTURE STRESS DAYS SINCE 1933, CAED Report 20, Ames, Iowa, 1964.

5. Davis, Floyd E., and Harrell, G. D., "Relation of Weather and its Distribution to Corn Yield", Journal of Agricultural Research, Vol. 60, U.S.D.A. Tech. Bulletin, No. 806.

6. Davis, Floyd E., and Pallesen, J. E. "Effect of the Amount and Distribution of Rainfall and Evapotranspiration during the Growing Season on Yield of Corn and Spring Wheat", Journal Agricultural Research, No. 60.

7. Doll, John P., "An Analytical Technique for Estimating Weather Indes from Meteorological Measurements", Journal of Farm Economics, Vol. 49, No. 1, Part 1, February, 1967.

8. Kansas State Bd. of Agriculture, FARM FACTS, Topeka, Kansas.

9. Fisher, R. A., "The Influence of Rainfall on Yield of Wheat at Rothamsted", Royal Society Philosophy Translation Series B, Vol. 123.

10. Hendricks, Walter A. and Scholl, John C., THE JOINT EFFECTS OF TEMPERATURE AND PRECIPITATION ON CORN YIELD, Technical Bulletin, Vol. 74.

11. Hodges, J. A., "Effect of Rainfall and Temperature on Corn Yield in Kansas", Journal of Farm Economics, Vol. XIII, No. 2, April, 1931.

12. Oury, Bernard, "Allowing for Weather in Crop Production Model Building", Journal of Farm Economics, Vol. 47, No. 2, May 1965.

13. Palmer, Wayne C., METEOROLOGICAL DROUGHT, U.S.D.C., Weather Bureau, Research paper No. 45, Washington D.C., February 1965.

14. Palmer, Wayne C., CLIMATIC VARIABILITY AND CROP PRODUCTION, CAED Report 20, Iowa State University of Science and Technology, Ames, Iowa, 1964.

15. Palmer, Wayne C. and Havens, A. Vaughn, "A Graphical Technique for Determining Evapotranspiration by Thornthwaite Method", Monthly Weather Review, Vol. 86, No. 4, April 1958.

16. Shaw, L. H. and Durost, Donald D, THE WEATHER INDEX APPROACH, CAED Report 20, Iowa State University of Science and Technology, Ames, Iowa 1964.

17. Shaw, L. H., ESTIMATION OF SOIL MOISTURE UNDER CORN, Iowa Agricultural Station Research Bulletin 520, 1963.

18. Shaw, Lawrence H. and Durost, Donald D., MEASURING THE EFFECT OF WEATHER ON AGRICULTURAL OUTPUT, USDA, Economic Research Service, Washington, D. C., October 1962.

19. Slutzky, Eugen, "The Summation of Random Causes as the Source of Cyclical Processed", Vol 5, Econometrica, 1937.

20. Smith, Warren J., "The Effect of Weather upon the Yield of Corn", Monthly Weather Review, U.S.D.C., Weather Bureau, Washington, D.C., February 1914.

21. Stalling, J. L., "Weather Indexes", Journal of Farm Economics, Vol. XIII February 1960.

22. Thompson. Louis M., WEATHER AND TECHNOLOGY IN THE PRODUCTION OF CORN AND SOYBEANS, CAED Report 17, Iowa State University of Science and Technology, Ames, Iowa. 1963.

23. Wallace, H. A., "Mathematical Inquiry into the Effect of Weather on Corn Yield in the Eight Corn Belt States", Monthly Weather Review, U.S.D.C., August, 1920, Vol. 48.

24. Weakly, H. E., "A Tree Record of Precipitation in Western Nebraska", Journal of Forestry, Vol. 41.

25. Yule, G. U., "Why Do We Sometimes Get Nonsense-correlations Between Time Series -- A Study in Sampling and The Nature of Time Series", Journal of Statistics, Vol. 89.

Unpublished Materials

1. Lin, Wuu-long, THE INFLUENCE OF WEATHER ON CROP YIELDS AND FARM INCOME IN NORTHWESTERN KANSAS, Master's Thesis, Kansas State University, June 1968.

THE EFFECTS OF WEATHER ON CROP YIELDS
AND FARM INCOME IN NORTHEASTERN KANSAS

by

STEPHEN HSIEN-CHANG CHOU

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The objective of this study was to estimate the effect of weather on crop yield and farm income during the period 1932 through 1966 in northeastern Kansas. Four small grain crops, grain sorghum, corn, soybean, and wheat, and farm income from field crops were studied. Two different measurements of weather were used as variables in regression equations. One was the difference between actual monthly evapotranspiration and CAFEC evapotranspiration, and the second was actual monthly evapotranspiration. Multiple regression analysis was used to estimate the influence of weather on crop production and farm income.

Weather variables for months of the growing season were related to per acre yield of each crop separately. Due to multicollinearity among independent variables, only variables of few months were statistically significant. The relationship of per acre yield of crops to monthly weather variables used were: grain sorghum yield=f(August); corn yield=f(August); soybean yield=f(June, July, August); and wheat yield=f(September_{t-1}, November_{t-1}, December_{t-1}, April, May, June).

Results show that August weather had the most effect on per acre yield of grain sorghum, corn, and soybean, while September weather in year previous to harvest had most effect on wheat yield.

The fluctuation of farm income due to weather was estimated after removing from farm income the effect of changing price level and technology. A multiple curvilinear regression model was used to estimate the effect of weather on farm income. Weather variables significant in the weather-crop yield studies and their square terms were used as independent variables in the weather-farm income study. The relationship studied was farm income=f (August, December_{t-1}, $\text{Decmeber}_{t-1}^{2}$).

Results of the weather-farm income study showed August and December weather variables more statistically significant than variables of other months. Fluctuation of farm income was directly related to the fluctuation of crop yield with price level held constant. Farm income in 1934, 1951, and 1956 was much lower, due to poor crop yield, than that would be expected with normal weather.

Average December weather, of period studied, had the effect of decreasing farm income whereas on the average weather during the growing season, measured by August weather variable, was favorable and increased farm income.

The effect of weather variability during August on farm income, as measured by one standard deviation from the mean of the weather variable was ± $3,581,220, which was 6.7% of the average received from field crops during the period. The relationship reported between December weather and farm income was quadratic. The minimum point of the function was at evapotranspiration value of 0.088 inch. December evapotranspiration values larger or smaller than 0.088 inch resulted in increasing farm income. The quadratic relationship does not seem to give logical estimates of the influence of December weather on farm income when low variable values are used.