THE RELATIONSHIP OF PALMER DROUGHT VARIABLES TO THE YIELD OF WINTER WHEAT IN WESTERN KANSAS

by

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B. S., Kansas State College, 1942

A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

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INTRODUCTION

The world's population is growing at a rapid pace and is expected to exceed six billion people by the year 2000 (29). It has been estimated that world food production must be trebled to meet the demand at that time. Therefore, it is important to search for new techniques to further our understanding of the effects of weather on crops.

Virtually every aspect of agricultural crop production involves a meteorological factor. Some of these factors have such a profound influence that they must be taken into consideration in farm management practices. To complicate the problem, some of the important weather factors are extremely variable, making it difficult or impossible for farmers to obtain satisfactory yields in every year of operation.

The relationships of weather factors to the yield of grain and other crops have been studied for a number of years. Temperatures and precipitation have been investigated most frequently although previous studies have not been limited to these two variables. Lack of precipitation is the most frequent limiting factor for crop yields on dryland farms in the Western Plains States. Thus, a priori, the best correlations with yield could be expected using that parameter. Other climatic factors, however, adversely affect production in some years. In addition to precipitation, Rainere (22) lists high temperature, hail, low temperature, and wind as "the most common and significant atmospheric elements that affect our food industry." With special reference to wheat, Nuttonson (19) mentions diseases and insects as being detrimental to production.

Literature references concerning the relation of weather factors to crop production are voluminous. Many man hours have been expended on this problem but research results have been only moderately successful. An ideal weather variable would account for all of the variation in yield due to variations in precipitation, temperature, wind, relative humidity, and all other weather factors affecting crop production. But a technique for measuring such a variable has never been developed.

In 1961, Palmer (21) developed a procedure for determining the duration and intensity of "meteorological" drought. That term was used since drought was evaluated as a meteorological anomaly, i.e., weather elements were the only variables used in the procedure. This is in contrast to agricultural drought which considers plant response to dry weather conditions. Palmer's approach to drought was new since it was the first system that provided both time and space comparisons of drought severity. Some of the factors derived in the procedure measured the cumulative effect of the antecedent weather conditions for an area or point. Palmer suggested that these variables could very likely be used in crop yield investigations, in arriving at dry and wet period expectancies, in land use capability investigations, and for other similar uses.

It would be advantageous if a single factor could be identified which would explain most of the yield variation for various crops. Thus, it seemed desirable to investigate the utility of the Palmer Drought Index procedure in accounting for yield variations. The purpose of this study, therefore, was to study the relationship of his drought variables to the yield of winter wheat at specific locations in western Kansas.

REVIEW OF LITERATURE

As early as 1907-1913 Call and Hallsted (4) studied the relation of moisture to the yield of winter wheat in western Kansas. Soil moisture measurements were taken on four plots representing three different management practices, i.e., late-fall-plowed, early-fall-plowed, and alternately cropped and fallowed. They reported that fallowed plots had the greatest moisture content at seeding time and plots that were late-fall-plowed had the least. They concluded that yields varied directly with the amount of available soil moisture at planting time.

Cole and Mathews (7) and later, Compton (9) studied the relation of soil moisture content at seeding time to spring and winter wheat yields, respectively, for the Great Plains. Their work indicated that soil moisture content at the time of planting could be used to predict the success or failure of the crop.

Mathews and Brown (18) dealt with winter wheat and sorghum production in the semiarid Southern Great Plains. They stated that the climatic factors most affecting winter wheat are precipitation, evaporation, relative humidity and temperature. Data were presented showing the probable yields of wheat and sorghum that could be expected in areas with approximately the same annual precipitation. In the 17.0- to 17.9-inch precipitation area, which includes part of western Kansas, they indicated that wheat may be expected to fail because of deficient precipitation in about 2 years in 5. In a later study Larson and Thompson (16), reporting on the variability of wheat yields in the Great Plains, pointed out that, with the exception of Billings County, North Dakota, the counties with the greatest production risks are located in southeastern Colorado, southwestern Kansas, and the Panhandles of Texas and Oklahoma. They ascribed this to a shortage of rainfall in those areas.

Hallsted and Mathews (12) suggested that if the initial soil moisture is deficient and if little precipitation falls between the time of seeding and April 1, it would be best to abandon the crop and summer fallow the land. Their paper, published in 1936, was especially appropriate during the dust bowl days of the middle and late thirties. At Hays, with less than 3 inches of available moisture in the soil at seeding time and a wheat after wheat management practice, satisfactory yields were dependent on subsequent rainfall after planting of the crop. If the soil moisture was below average at seeding time there was only one chance in six of obtaining an average yield in the crop year.

Hoover and McCoy (13) emphasized the economic importance of summer fallowing in western Kansas. Yields for 22 counties in southwestern Kansas during the period 1947-1953 averaged significantly higher on summer fallow than on continuously cropped land. Abandonment of wheat before harvest was also reduced by summer fallowing.

Laude et al (17) showed that at Colby and Garden City the yield from summer fallow land was about twice that from continuously cropped land. They also found that efficiency of moisture storage under fallow was only 15 to 16% of the precipitation. However, this additional moisture was often the difference between a crop failure and a satisfactory crop. Studies at Colby and Garden City showed that every inch of available moisture above a certain threshold value increased yield 2 bushels per acre.

Swanson (24) showed averages of precipitation, temperature and evaporation for 5-day intervals for the period 1921-1948 at Hays, Kansas. He concluded that these short periods were an improvement over the use of monthly intervals for providing information for the planning of cropping systems and for aiding in the development of varieties better adapted to existing climatic conditions at Hays.

Hallsted and Coles (11) stated that a moisture content of 20% or more in the upper 3 feet of soil at seeding time practically precluded a crop failure at Hays, Kansas. If the soil moisture content was only 15% at seeding time the crop was almost entirely dependent on rainfall after seeding. The smaller the moisture amount at planting time, the greater was the probability of crop failure.

Cole and Mathews (6) studied subsoil moisture conditions under semiarid conditions. They reported that with normal wheat root development all of the available water was removed by harvest time. After harvesting, precipitation usually builds up the quantity of available soil moisture until spring when the use by plants again exceeds the rate at which the soil is recharged by precipitation.

Pallesen and Laude (20) investigated the effect of seasonal rainfall on winter wheat yields. Rainfall in western Kansas was of greatest advantage to winter wheat during the period from seeding time to the semi-dormant stage. Precipitation also had a beneficial effect during the period between the initiation of rapid stem growth and heading. Precipitation during the winter was found to be of little consequence, while slightly less than average rain in early spring was associated with the best yields of wheat. This agreed with irrigation research at the Garden City Branch Experiment Station. Bieberly et al (2) stated that irrigation during March and April may be harmful to wheat. Irrigation at that time encouraged excessive growth and lodging without increasing yields.

Taylor (25) represented the seasonal soil moisture regime by a single value, mean soil moisture tension. Crop yields were reduced as the mean tension increased which indicated that moisture was not equally available to plants throughout the entire range from field capacity to permanent wilting percentage.

Chilcott (5) related crop yields to precipitation for a number of stations in the Great Plains area. His concluding statement was, "Notwithstanding the fact that annual precipitation is a vital factor in determining crop yield, it is seldom if ever the dominant factor; but the limitation of crop yield is more frequently due to the operation of one or of several inhibiting factors other than shortage of rainfall." He listed hail, inadequate seasonal distribution of precipitation, plant diseases, insect pests, soil blowing, strong winds, and frost damage as the principal factors decreasing yields.

In a recent study Thompson (26) evaluated some of the weather factors that affect wheat production in North Dakota, South Dakota, Nebraska, Kansas and Oklahoma. He used multiple regression equations containing the following weather variables in quadratic form: preseason precipitation, April rain, April mean temperature, May rain, May mean temperature, June rain, June mean temperature, July rain, and July mean temperature. In another study (27) Thompson reported that quadratic equations best described the relationship of weather variables to yield.

Johnson (15) developed a mathematical procedure for evaluating relationships between climate and crop yields. This approach differed from the conventional regression method in that he estimated a frequency distribution over a period of years rather than obtaining a predicted yield for a particular year. Use of this procedure was suggested for estimating the frequency distribution of wheat yields from climatic data.

GENERAL CLIMATE-CROP RELATIONSHIPS IN WESTERN KANSAS

Western Kansas has a continental (land-controlled) climate which is characterized by abundant sunshine, dry atmospheric air, relatively low annual rainfall, moderate to occasionally strong surface winds, rather large daily and annual temperature variations, and a late spring-early summer precipitation maximum. Average annual precipitation ranges from about 16 inches along the western border of southwestern Kansas to approximately 24 inches along a north-south line through the middle of the State (1). Fortunately for agriculture, about three-fourths of the average annual precipitation occurs during the growing season, i.e., from April through September. Much of the precipitation falls in connection with showers or thundershowers during this period. The "effective" precipitation is significantly less than the average annual amount. Heavy downpours occur at times resulting in considerable runoff from cultivated fields. On the other hand, light showers, which account for a sizeable portion of the annual precipitation, wet only the top few inches of soil and provide little benefit to growing crops.

The peak in rainfall occurs in May and June, declining to a minimum during the winter months. Precipitation is very light in the winter season and there is usually only light snow.

The transition from the cold to the warm season, and vice versa, occurs rather rapidly. The spring and fall seasons are noted for changeable weather. Unseasonably warm days and nights during the spring, followed by an outbreak of cold air and freezing weather, can cause freeze damage in wheat fields not protected by a snow blanket.

The annual and daily temperature ranges in western Kansas are relatively large. Marked warming during the day and a rapid loss of heat at night are the rule in that area. Frequent cloudless skies and relatively dry atmospheric air both contribute to the large daily and annual temperature cycles. A daily temperature range of 30° is not uncommon, and variations of more than 40° are recorded at times, particularly in the fall season.

Winter wheat, one of the most important crops grown in the Western Plains States, has a wide range of adaptation, generally being grown between 20° and 40° latitude (3). This does not mean, of course, that it can withstand all of the vagaries of the climate where it is produced. Because of the intense solar radiation, dry atmospheric air, and moderate to strong surface winds during the warm season the potential evapotranspiration rate in western Kansas is quite high. Thus, if soil moisture is limiting, winter wheat and other crops may at times be subjected to stress conditions which are extremely detrimental. Lack of sufficient ground cover after a dry fall and winter is also a problem in fields of winter wheat. If sufficient precipitation is not forthcoming in the early spring, soil blowing during the windy months of March and April may completely wipe out a crop.

PROCEDURE

Development of Palmer Drought Index

Palmer (21) used data for western Kansas and central Iowa to develop his Drought Index procedure. It was first applied to geographic areas, but it was later used to obtain drought analyses at points. Assuming a certain available water holding capacity for the soil, Palmer used a hydrologic accounting system to determine the estimated amount of available moisture in the crop root zone at the end of given time periods. To do this he calculated evapotranspiration by Thornthwaite's formula (28). Then, by tabulating estimates of evapotranspiration, soil moisture recharge, runoff, and soil moisture loss for a particular area for a long period of record (usually 30 years), the average moisture climate for that area was established. The difference between the precipitation needed to maintain this average moisture climate and the actual precipitation for the time period under consideration was defined as the moisture departure 'd'. During wet periods these departures are positive; during dry periods they are negative. Palmer normalized these moisture anomalies by multiplying the 'd' values by an appropriate constant for each area and for each time period. Thus, the relative intensity of the dry or wet period for that area was determined. Using this moisture anomaly index, Palmer computed a dimensionless index, X, which gives an indication of the cumulative intensity of the dryness or wetness. This index can take on values ranging from about -8 for an extremely dry condition up to approximately +8 for a very wet one. In the very dry thirties in Kansas the lowest monthly Palmer Index value was -7.09 for the Northeastern Climatological Division. At the other extreme, the index climbed to +8.40 in the North Central Division during the very wet year of 1951.

The classes for wet and dry periods were defined as shown in Table 1.

Table 1. Classes for wet and dry periods.

Palmer Index	Class
$\geq$ 4.00	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.50 to -0.99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -2.99	Moderate drought
-3.00 to -3.99	Severe drought
$\leq$ -4.00	Extreme drought

Since the moisture departures are normalized for a particular area or locality, the system allows both time and space comparisons of drought intensity. Thus, with reference to average climatic conditions, a moderate drought in eastern Colorado is comparable to a moderate drought in Missouri.

As an example of drought comparisons over time, the lowest monthly Palmer Index value during the dry thirties in southwestern Kansas was -4.65. In the fifties, the lowest Index was -5.24. This indicates the drought of the fifties was the most severe of the two droughts although it was of shorter duration than the one in the thirties.

Data

Figure 1 is a map showing the locations of the Kansas State University Branch Agricultural Experiment stations and Experimental Fields over the western two-thirds of Kansas used in obtaining the correlations presented in this study. The yields of one particular variety of hard red winter wheat, Turkey Red, from the uniform variety trials were used. This variety was selected because a longer record of yield data is available for Turkey Red than for any other winter wheat variety in Kansas. The yield data are from summer fallow land, except at Mankato Experimental Field where continuous cropping was practiced.

Winter wheat yield data for the time trend analysis for the Northwestern, West Central, Southwestern and Central climatological divisions in Kansas were provided by the Statistical Reporting Service, U. S. Department of Agriculture, Topeka, Kansas.

All temperature and precipitation data were tabulated from records at the office of the State Climatologist, ESSA-Weather Bureau, Manhattan, Kansas.

The Palmer Drought Indices, moisture anomaly indices, estimated subsoil moisture, and precipitation values for the area-yield correlations were obtained from Mr. Wayne Palmer, Environmental Data Service, Environmental Science Services Administration, Washington, D. C. In addition, the drought analysis computations for Garden City were provided by Mr. Palmer.

Other parameters needed in the analyses were derived as described under "Statistical Procedure."

The crop year in this study was defined as the period from July of one year through June of the following year. Thus, wheat yield data for each harvest were correlated with monthly drought and weather variables for the preceding 12-month period.

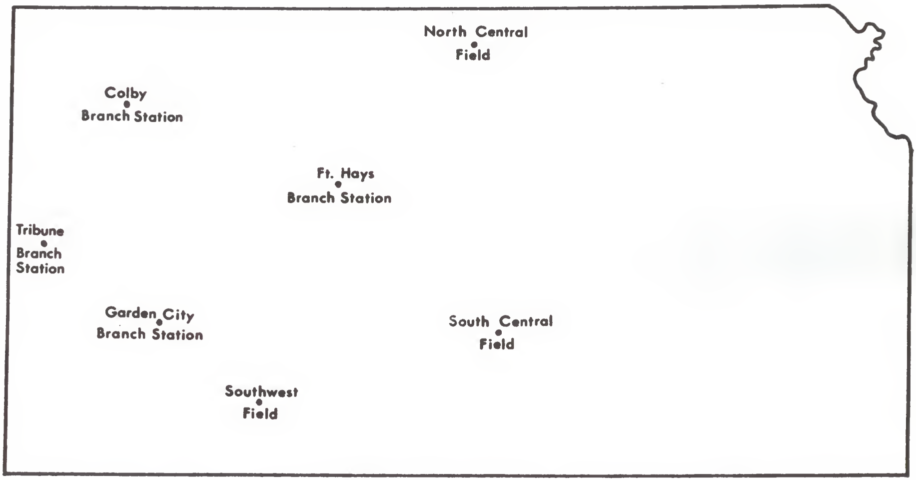

Fig. 1. Branch Experiment Stations and Experimental Fields in Kansas furnishing winter wheat yield data for regression analyses.

Time Trends in Yield

Thompson (26) found a very definite time trend upward in yields of wheat and other crops for the period 1930-1962 in Central United States. He attributed this to more favorable weather during the second one-half of that period than during the first one-half, and to improved technology after the mid-thirties. It should be emphasized, however, that Thompson was dealing with areal yield averages and that production from a number of different varieties was used in obtaining the averages for a given year.

A time trend in yield of winter wheat was noted for several of the crop reporting districts of western Kansas. Figure 2 is a map of Kansas showing the nine climatological divisions in the State, and these divisions are conterminous with the crop reporting districts. A plot of winter wheat yields versus time for each of the Northwestern, West Central, Southwestern, and Central Divisions showed marked time trends for the period 1926-1965. These yields were for all varieties grown in the respective Divisions during this period. A plot of the data for the Northwestern Climatological Division is shown in Fig. 3.

There are several factors contributing to the yield increases. Removal of unproductive land from cultivation, availability of better farming implements, improved wheat varieties, and wiser management practices undoubtedly contributed to the higher production in recent years.

From a statistical analysis of the Turkey Red yield records for the Branch Experiment Stations at Colby, Garden City, Hays and Tribune for the period 1926-1965, it was apparent that the existence of a significant time trend in yield for that variety was unlikely. Three of the yield records showed a very slight upward trend while the fourth showed virtually no trend during that period. A plot of yield versus years for Hays is shown in Fig. 4. A t-test of the 'b' in

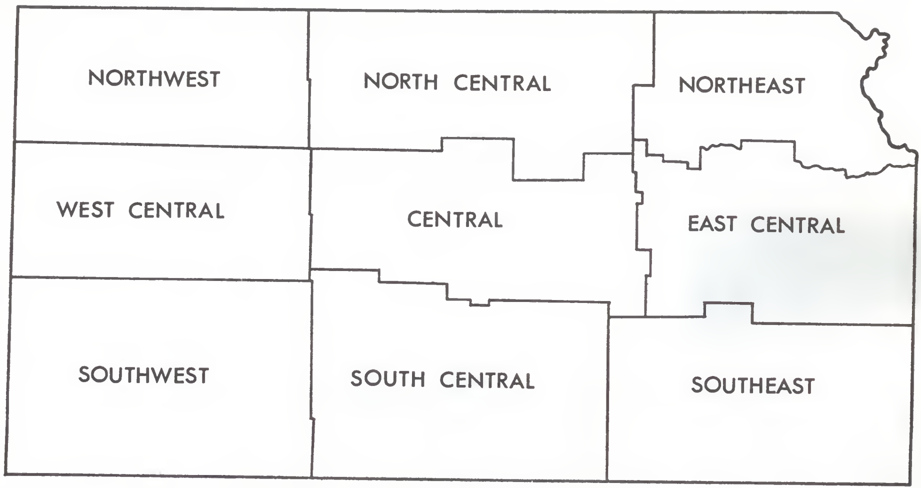

Fig. 2. Climatological Divisions of Kansas.

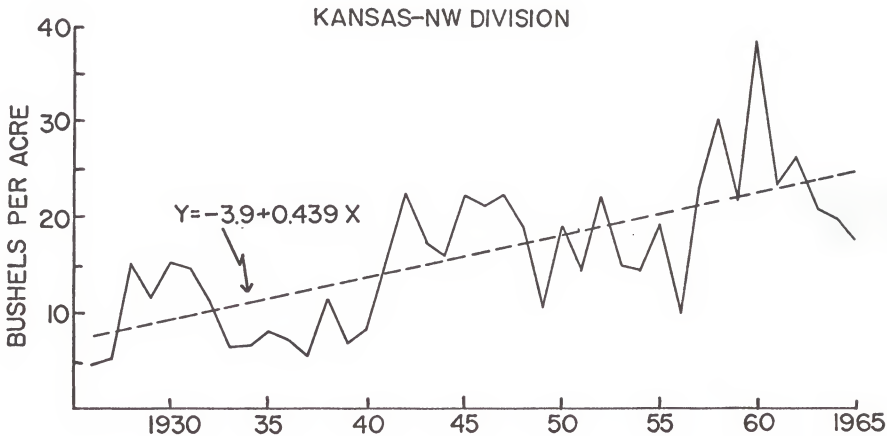

Fig. 3. Winter wheat yields for the Northwestern Climatological Division, Kansas, plotted against years for the period 1926–1965. The regression line is dashed.

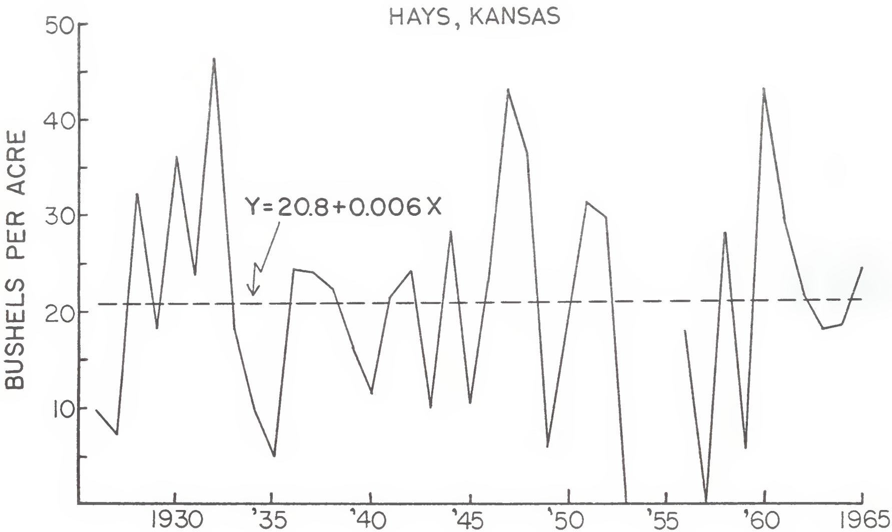

Fig. 4. Turkey Red wheat yields for the Hays Branch Experiment Station, Kansas, plotted against years for the period 1926-1965. The regression line is dashed.

each of the regression equations, Y = a + b X, indicated the slopes of the regression lines were not significantly different from zero at all four locations ('Y' refers to yield in bushels per acre and 'X' is the year in which that yield was produced). This was considered as justification for using the yield data for all of the locations without adjustment for trend.

Management practices on the experimental plots from which the data were taken have remained relatively unchanged through the years. Too, the genetic and ecological changes in Turkey Red wheat have been rather minor during the period covered by this investigation.

It was concluded that yield data for the crop reporting districts over western Kansas showed a marked time trend during the period 1926-1965. Since point yield data were used in this study no attempt was made to identify the amount of yield increase for those areas due to the various factors. For the experimental plot data, changes in technology and varietal changes were found to be minor. Thus, variations in the weather accounted for most of the year to year differences in the point yield data.

Statistical Procedure

A Fortran program for determining Palmer Drought analyses by IBM 1401-1410 electronic computer was written recently (William J. Plant and Merle J. Brown, 1965. A fortran program to perform Palmer drought analyses. Mimeographed. Kansas State University, Manhattan). However, before using that program to obtain drought analyses for the specific locations in western Kansas it was necessary to compute the various climatic constants for each month at each location in the manner described by Palmer (21). The IBM computer complex at Kansas State University was utilized in obtaining these constants as well as in determining the Palmer drought analyses, and for computing the multiple correlations. In obtaining the constants, weather data for nearby stations were used in some cases, i.e., McPherson data were used to obtain the constants for Hutchinson, Burr Oak data were used for Mankato, and Ashland data were used for Minneola. Palmer drought analyses were run for Colby, Hays, Garden City, Mankato, Minneola, Hutchinson, and Tribune. Then, point yield data of Turkey Red winter wheat for these locations were correlated with point drought variables. The record lengths ranged from 51 years at Hays to 23 years at Minneola (Table 2). The drought variables used were monthly moisture departure, d, and monthly Palmer Drought Index, X.

For the locations with both yield and weather records dating back to 1932, other correlations were run in an attempt to determine which variables were best related to yields; these comparisons were all for the period 1932-1965. As an example, winter wheat yield at Colby was related to the monthly Palmer Drought Index at Colby and also to the monthly Palmer Drought Index for the Northwestern Climatological Division.

One of the disadvantages of using an areal value of the Palmer Drought Index is that it may be representative of only a very small portion of the area under consideration. It is possible, particularly when the Index is computed for large geographical areas, for a severe drought to be in progress in one part of the district while wet conditions may be the rule in another portion. Thus, the computed Index may indicate neither the very dry nor the wet condition. On the other hand, because of the variability in precipitation from one location to another, the Index for a point may be representative of conditions at that point only.

Table 2 summarizes the analyses that were made in this investigation. The subsoil moisture variables referred to in the Table are estimated values obtained as a by-product in the Palmer Drought Index computation procedure. It is the estimated amount of water available in the crop root zone, exclusive of the plow layer. In his hydrologic accounting procedure, Palmer (21) uses a value of one inch of available water for the plow layer at field capacity.

Table 2. Stations and periods for which multiple regression analyses were made.

Station	Period of record (point data)		1932-1965 (point and areal data)*			
	Monthly moisture departure 'd'	Monthly Palmer Drought Index 'X'	Monthly precipitation (In.)	Monthly moisture departure 'd'	Monthly Palmer Drought Index 'X'	Monthly subsoil moisture (In.)
Colby(46)[1]	x	x	x	x	x	x
Garden City(32)	x	x	x	x	x	x
Hays(51)	x	x	x	x	x	x
Hutchinson(28)	x	x				
Mankato(23)	x	x				
Minneola(27)	x	x				
Tribune(39)	x	x	x	x	x	x

*The four areas used were the Climatological Divisions for Northwestern, West Central, Southwestern, and Central Kansas.

[1]Number of years of yield data

The areal precipitation values used were the monthly precipitation amounts for the appropriate climatological divisions, i.e., in one part of the study point yield data at Colby were correlated with monthly precipitation for the Northwestern Climatological Division, yield data at Garden City were correlated with monthly precipitation for the Southwestern Division, etc.

Both multiple linear regression and multiple curvilinear regression were used in this investigation. Snedecor (23) listed the principal uses of these techniques as: 1) To measure the relationship, if any, between the independent variable, X, and the dependent variable, Y; 2) To determine the shape of the regression curve; 3) To test hypotheses about cause and effect; or 4) To predict 'Y' from 'X'. The goal of this study was to obtain some insight into the predictive power of certain drought and weather variables with regard to winter wheat yields at specific locations in western Kansas (item 4, above).

The general model for multiple linear regression is (10):

(1) $$Y = \alpha + \beta_1 X_1 + \ldots\ldots + \beta_s X_s + e$$

where:

$\alpha = \bar{Y} - \beta_1 \bar{X}_1 \ldots\ldots - \beta_s \bar{X}_s$ = constant

β_1 = the slope of the regression plane in the X_1 direction

β_s = the slope of the regression plane in the X_s direction

e = the amount by which a certain point is above or below the regression plane and is a measure of random error.

Y = dependent variable (in this study it is the annual yield in bu/acre of Turkey Red winter wheat and $\bar{Y}$ is the mean of the yield observations).

$X_1 \ldots\ldots X_s$ are independent variables (drought and weather variables).

The multiple curvilinear regression situation was restricted to the following model:

(2) $$Y = \alpha + \beta_{11} X_1 + \beta_{12} X_1^2 + \ldots\ldots \beta_{s1} X_s + \beta_{s2} X_s^2 + e$$

Analyses were run on the computer for the stations listed in Table 2. First, linear correlations between winter wheat yield, Y, and the various monthly drought and weather variables, X's, plus correlations for each of the quadratic terms were obtained. Second, sample data for the variables with the highest linear correlations were inserted in the appropriate equations (models 1 and 2, above) and estimates of the population parameters (β's) were obtained. If a squared term was put in the equation, the linear term for that variable was retained. Appropriate 'F' and 't' tests were made after this run in order to eliminate variables which did not account for significant variations in wheat yield (probability level 10%).

The process of obtaining population parameter estimates and eliminating variables was continued until all of the variables retained were shown to significantly affect yields. Finally, different combinations of variables were tried in an attempt to improve on the multiple correlation values and/or reduce the number of variables in each equation.

It was realized that a linear term, X, and the square of that term, X^2, may each be poorly correlated with the dependent variable, Y, and yet may produce an excellent multiple R^2 when both are put into the system together (14). To minimize this possibility most of the variables, plus the corresponding squared terms, were included in the first run in which a multiple R^2 was obtained.

RESULTS

Results of the multiple correlation analyses are contained in Tables 3-10 and Tables 12-13. The 10% level of significance applied throughout these tables, except no particular level of significance was required for the linear term when the corresponding quadratic term was included in the regression equation.

In general, the multiple correlation coefficients, R, were not high. The highest multiple R^2 was obtained for Tribune for the period 1924-1965, using monthly moisture departures, d, correlated with yield (Table 3). The R^2 in this

Table 3. Values of degrees of freedom (D/F), probability of F (P), standard error of estimates (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly moisture departure, d, for specific points and Turkey Red winter wheat yields*.

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	41	0.01	11.9	0.67	0.48	Aug., Jan., June, $Aug.^2$
Garden City	26	0.01	7.8	0.79	0.63	July, Aug., Feb., June, $Aug.^2$
Hays	48	0.01	9.4	0.59	0.35	Oct., Jan.
Hutchinson	24	0.05	8.5	0.54	0.29	July, Oct., $Oct.^2$
Mankato	19	0.01	8.2	0.73	0.53	Oct., Nov., Jan.
Minneola	25	0.10	9.3	0.36	0.13	Nov.
Tribune	30	0.01	8.0	0.89	0.80	Aug., Oct., Jan., Apr., June, $Oct.^2$, $Apr.^2$, $June^2$

*Crop year is July through following June.

Table 4. Values of degrees of freedom (D/F), probability of F (P), standard error of estimate (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly Palmer Drought Index, X, for specific points and Turkey Red winter wheat yields.

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	43	0.01	11.9	0.65	0.42	Sept., Apr.
Garden City	28	0.01	9.3	0.66	0.44	Nov., May, $Nov.^2$
Hays	49	0.01	10.2	0.46	0.21	Feb.
Hutchinson	25	0.05	8.5	0.51	0.26	Oct., $Oct.^2$
Mankato	19	0.01	8.3	0.72	0.52	Nov., Apr., $Nov.^2$
Minneola	25	0.10#	9.5	0.32	0.11	Jan.
Tribune	37	0.01	12.4	0.63	0.40	Nov.

#A 't' test indicated slope of regression line not significantly different from zero (10% level).

case was 0.80 and the standard error of estimate was 8.0 bu/acre. Other multiple R^2 values in the study were less than 0.65.

A comparison of the data in Tables 3 and 4 would seem to indicate that for Hutchinson, Mankato and Minneola there was little over-all difference between the multiple correlation coefficients and standard errors of estimate for the Palmer Drought Index, X, compared to those for the moisture departure, d. These data are for the entire period for which yield and weather data were available at the various stations. At Colby, Garden City, Hays, and Tribune the point 'd' terms accounted for more of the yield variation, although the R^2 values for Hays were quite low.

The importance of available moisture at or near seeding time was borne out by the data in Table 3. Every regression equation had a term for 'd' for one of the fall or late summer months. The months of October and November were particularly important in this regard. This is also evident from an examination of the standard partial regression coefficients, b', in appendix Table 1 (b' values for this study are in Tables 1-6 in the appendix). In general, the absolute values of the standard partial regression coefficients were largest for the fall and late summer months which indicates those months accounted for a greater percentage of the yield variation than others listed in this table.

Tables 5-10 and Tables 12-13 can be used for comparison of the multiple correlations between point and areal drought and weather variables. For example, Colby yield data were correlated with monthly Palmer Index values, X, for the Northwestern Climatological Division as well as with the Palmer Index at Colby. All of the data in these tables are for the period 1932-1965.

A study of Tables 5 and 6 reveals that the multiple correlation coefficients and standard errors of estimate were essentially the same for the corresponding sets of data for Colby, Garden City and Hays. The multiple R^2 for

Table 5. Values of degrees of freedom (D/F), probability of F (P), standard error of estimate (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly Palmer Index, X, for specific points and Turkey Red winter wheat yields (1932-1965).

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	24	0.01	10.2	0.78	0.61	Aug., Mar., Mar.^{2}
Garden City*	28	0.01	9.3	0.66	0.44	Nov., May, Nov.^{2}
Hays	32	0.01	10.6	0.52	0.27	Feb.
Tribune	29	0.01	12.2	0.69	0.48	July, Oct.

*Data for this station are same as in Table 4.

Table 6. Values of degrees of freedom (D/F), probability of F (P), standard error of estimate (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly Palmer Index, X, for areas# and Turkey Red winter wheat yield at specific locations in western Kansas (1932-1965).

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	25	0.01	10.3	0.76	0.58	Sept., May
Garden City	28	0.01	9.3	0.66	0.43	Oct., May, Oct.^{2}
Hays	31	0.01	10.5	0.55	0.30	Feb., Feb.^{2}
Tribune	30	0.01	13.2	0.61	0.37	Nov.

#Northwestern, Southwestern, Central, and West Central, respectively.

Tribune yields versus monthly Palmer Indices at that location was 0.48 compared to 0.37 for Tribune yields versus Palmer Indices for the West Central Climatological Division. Since the variables used in obtaining each of the multiple R^2 values were not the same, there was no appropriate test for deciding whether the point Drought Index was statistically better than the area Drought Index for this location.

With regard to point yields versus point rain and point yields versus area precipitation, one produced as good results as the other (Tables 7 and 8). Two of the multiple R^2 values were the same. The R^2 for Colby yields versus area precipitation was higher than the R^2 for Colby yields versus point precipitation, while for Tribune the opposite was the case. The importance of precipitation in October and November was again clearly shown in these two tables. This is also substantiated by the b' values in appendix Table 4.

Point subsoil moisture (estimated) seemed to be slightly better correlated with yields than was area subsoil moisture, but this did not hold true for all locations, e.g., at Colby and at Garden City (Tables 9 and 10). The R^2 value for monthly point subsoil moisture at Colby was the same as the monthly area subsoil moisture R^2. At Garden City the area subsoil moisture variables accounted for more of the yield variation than did corresponding point data.

There is a striking resemblance in the multiple R^2 values in Table 9 to those in Table 5. This was investigated further by computing the linear correlations for each of the twelve months for point Palmer Drought Indices at Colby versus estimated subsoil moisture for that location. The results are shown in Table 11. The linear correlations ranged from 0.953 for May down to 0.742 for November. This suggests that in certain months at Colby the estimated amount of subsoil moisture is a good indicator of the Palmer Index value for those months.

Table 7. Values of degrees of freedom (D/F), probability of F (P), standard error of estimate (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly point precipitation and Turkey Red winter wheat yields (1932-1965).

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	25	0.05	13.6	0.51	0.26	Apr., June
Garden City	28	0.01	9.9	0.60	0.36	Oct., Feb., June
Hays	28	0.01	8.6	0.76	0.58	Sept., Oct., Nov., Jan., Mar.
Tribune	28	0.01	10.3	0.80	0.64	Aug., Oct., Jan.

Table 8. Values of degrees of freedom (D/F), probability of F (P), standard error of estimate (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly precipitation for areas# and Turkey Red winter wheat yields at specific locations in western Kansas (1932-1965).

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	23	0.05	13.2	0.60	0.36	Oct., Feb., Oct.^{2}, Feb.^{2}
Garden City	29	0.01	9.8	0.60	0.35	Oct., Feb.
Hays	28	0.01	8.7	0.75	0.57	Oct., Nov., Feb., Nov.^{2}, Feb.^{2}
Tribune	28	0.01	13.0	0.65	0.43	Oct., Nov., Nov.^{2}

#Northwestern, Southwestern, Central, and West Central, respectively.

Table 9. Values of degrees of freedom (D/F), probability of F (P), standard error of estimate (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly estimated subsoil moisture for specific points and Turkey Red winter wheat yields (1932-1965).

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	24	0.01	10.1	0.78	0.61	Sept., May, May^2
Garden City	28	0.01	9.2	0.67	0.44	July, May, $July^2$
Hays	32	0.01	10.6	0.52	0.27	Apr.
Tribune	30	0.01	12.5	0.66	0.43	Feb.

Table 10. Values of degrees of freedom (D/F), probability of F (P), standard error of estimate (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly estimated subsoil moisture for areas# and Turkey Red winter wheat yields at specific locations in western Kansas (1932-1965).

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	24	0.01	10.1	0.78	0.61	Dec., Apr., $Dec.^2$
Garden City	28	0.01	8.5	0.73	0.53	Oct., Feb., $Oct.^2$
Hays	32	0.01	11.1	0.44	0.19	Mar.
Tribune	30	0.01	13.8	0.56	0.31	Feb.

#Northwestern, Southwestern, Central, and West Central, respectively.

Table 11. Simple linear correlation coefficients between Palmer Drought Index, X, and estimated subsoil moisture for Colby, Kansas, (1932-1965).

Jan.	Feb.	Mar.	Apr.	May	June
0.844	0.898	0.941	0.952	0.953	0.942
July	**Aug.**	**Sept.**	**Oct.**	**Nov.**	**Dec.**
0.907	0.879	0.896	0.828	0.742	0.767

At least one other point is worthy of note with regard to Tables 9 and 10. Six of the eight regression equations retained a term for subsoil moisture in February, March or April. This suggested that soil moisture was important during those months and lends support to the conclusion of Hallsted and Mathews (12). However, the R^2 values for Hays and Tribune in each of these tables are quite low so most of the variation in 'Y' was unexplained.

A consideration of the standard partial regression coefficients in appendix Table 5 indicates that at Garden City the quadratic term for area subsoil moisture in October is an important factor accounting for yield variation. For the point subsoil moisture variable at Garden City one of the chief contributors is the quadratic term for July. The high correlation of the variables from month to month must be considered when analyzing the data in these two tables.

Over-all, the best R^2 values were obtained by correlating point yields with moisture departure, d, values for Colby, Garden City, Hays, and Tribune for the period 1932-1965 (Table 12). The results shown in Table 3 for these locations were obtained from point 'd' values versus yields for the entire period of yield records. In general, the results were not as good as for the shorter period given in Table 12.

Table 12. Values of degrees of freedom (D/F), probability of F (P), standard error of estimate (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly moisture departure, d, for specific points and Turkey Red winter wheat yields (1932-1965).

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	24	0.01	10.8	0.75	0.56	Aug., Jan., June
Garden City*	26	0.01	7.8	0.79	0.63	July, Aug., Feb., June, Aug.^{2}
Hays	29	0.01	8.7	0.74	0.55	Oct., Nov., Feb., Nov.^{2}
Tribune	29	0.01	10.1	0.80	0.64	Aug., Oct.

*Data for this location are same as in Table 3.

Table 13. Values of degrees of freedom (D/F), probability of F (P), standard error of estimate (S.E.), multiple correlation coefficient (R), and R^2 for multiple regression between monthly moisture departure, d, for areas# and Turkey Red winter wheat yields for specific locations in western Kansas (1932-1965).

Location	D/F	P	S.E. (bu)	R	R^2	Factors
Colby	24	0.01	10.1	0.78	0.61	Aug., Jan., June
Garden City	29	0.01	9.2	0.66	0.43	Oct., Feb.
Hays	30	0.05	10.9	0.52	0.27	Jan., Feb., Jan.^{2}
Tribune	27	0.01	12.2	0.72	0.52	Oct., Dec., May, May^2

#Northwestern, Southwestern, Central, and West Central, respectively.

A comparison of the data in Tables 12 and 13 indicates generally poorer R^2 values and larger standard errors of estimate for the area 'd' values compared to the point 'd' values. An exception to this was the data for Colby which had R^2 values and standard errors of estimate which were very similar.

A comparison of the data in Tables 5 through 10 and Table 13 did not indicate any marked superiority of the variables in one table over those in any other table. In general, point 'd' values for the period 1932-1965 (Table 12) produced higher R^2 values and lower standard errors of estimate than any of the other variables.

As was mentioned above, the highest multiple R^2 for any location was obtained by relating point yield data at Tribune to the monthly 'd' variable (Table 3). The resulting regression equation was:

$$\hat{Y} = 24.84 + 1.563\ X_3 + 10.300\ X_5 + 15.085\ X_8 + 0.195\ X_{11} + 0.014\ X_{13} - 2.005\ X_{17} - 0.958\ X_{23} - 0.424\ X_{25}$$

where:

$\hat{Y}$ = predicted yield in bu/acre

X_3, X_5, X_8, X_{11}, X_{13} are monthly departure, d, values for August, October, January, April, and June, respectively.

$X_{17} = (X_5)^2$

$X_{23} = (X_{11})^2$

$X_{25} = (X_{13})^2$

The predicted yields, $\hat{Y}$, obtained from this equation were plotted against actual yields (Fig. 5). The dashed line in this figure is the perfect prediction line, i.e., for points on the line actual yield equalled the estimated yield. For harvested yields below 20 bu/acre the predicted yields were generally

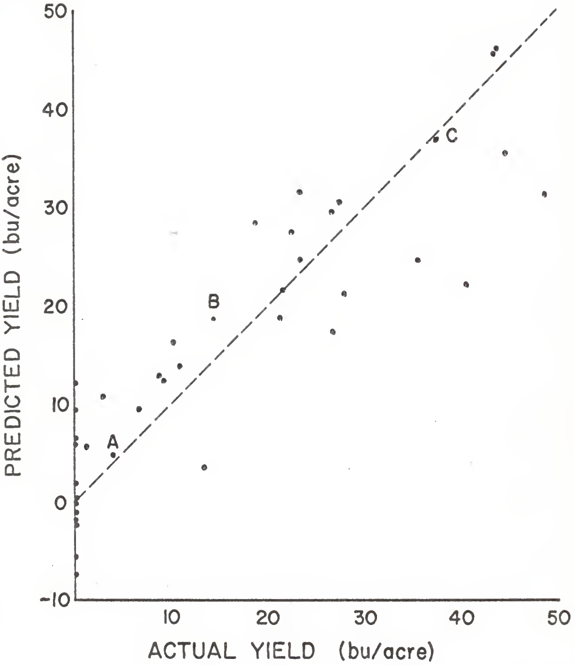

Fig. 5. Actual winter wheat yield at Tribune Branch Experiment Station plotted against predicted yield for the period 1924-1965. For points on the dashed line, actual yield eoualled predicted yield.

too high; but for yields above 30 bu/acre the opposite was true. The average absolute deviation of predicted yields minus actual yields for the period 1924-1965 at Tribune was 5.4 bu/acre.

Snedecor (23) gives the formula for the variance of $\hat{Y}$ for a specific set of 'X' values. The standard error of $\hat{Y}$ was computed from that formula, using observation and regression data corresponding to each of the points A, B and C in Fig. 5. The results are given in Table 14.

Table 14. Standard error of estimate of predicted yield ($s_{\hat{Y}}$) at points A, B and C in Fig. 5.

Point	$s_{\hat{Y}}$ (bu/acre)
A	3.72
B	2.15
C	3.21

Some indication of the efficiency of regression in explaining variations in the point yield data can be obtained by comparing the standard errors of estimate before regression to those resulting from a use of regression (Table 15). The greatest change was at Tribune where the standard error of estimate was lowered from 15.8 to 8.0 bu/acre.

Table 15. Standard error of estimate (S.E.) of winter wheat yield at various western Kansas locations before and after using regression.

Location	S.E. before regression (bu/acre)	Lowest S.E. using regression (bu/acre)
Colby	15.2	10.1
Garden City	11.7	7.8
Hays	12.2	8.6
Hutchinson	9.5	8.5
Mankato	11.1	8.2
Minneola	9.8	9.3
Tribune	15.8	8.0

DISCUSSION

The method of computing monthly Palmer Drought Indices insures a high correlation of the values from one month to the succeeding month. In fact, the Index for a particular month was generally highly correlated with the value 3 or 4 months later. Thus, in attempting to account for variation in crop yields for a specific location, two or three monthly Indices in the correlation analysis, with the corresponding squared terms, usually provided just as good results as those utilizing four or more. The same would apply to estimated subsoil moisture values which were also highly correlated from month to month. This is the reason for the small number of factors in Table 4 compared to Table 3. Too, very few of the variables in Table 3 are included in Table 4. This was due in part to the high correlations of the variables from month to month, e.g., the chance that the monthly Palmer Index, X, for February would be retained in the regression analysis for Hays (Table 4) was very nearly the same as for the November Index.

Monthly moisture departure values were not highly correlated for successive months so as many as twenty-four of these values (a 'd' term for each month and the square of each 'd' term) could conceivably have been used in the analysis. This was also true for monthly precipitation, another factor which was correlated with yields.

The correlation of point yield with the area data used in this study gave almost as good results as did point yield correlated with point data. The precipitation data for the various locations were not observed on the experimental plots from which the yield data were taken. In some cases it was necessary to use data for a weather station several miles away. Table 16 contains information about the locations of the weather stations pertinent to this investigation. Precipitation data for the Branch Experiment Stations at Hays and Tribune were available for the entire period of yield records. Other data used were from a number of different locations, e.g., published weather data for Hutchinson were from four different locations during the period 1938-1966.

The problem of obtaining representative precipitation data for crop yield investigations has plagued researchers for some time. The generally low correlations in this study may have been due in part to the inadequacy of the precipitation data rather than to the limitations of the Palmer drought variables.

The estimates of soil moisture by the Palmer accounting system (21) may not be indicative of the actual amount of soil moisture on summer fallow. With that management practice the land is kept out of production in alternate years. During the idle years the soil is cultivated to control weeds and to maintain an adequate surface for the infiltration of precipitation. The existence of good soil moisture reserves at and subsequent to planting increases the probability of satisfactory yields in the year that crops are grown. This is the

Table 16. Station history information for stations providing weather data for multiple regression analyses.

Name of weather station	Period of record	Distance from P.O.	Remarks
Colby	1914-1935	½ mi. WSW	
Colby	1935-1941	½ mi. NE	
Colby 1 SW	1941-1966	1 mi. SW	At Branch Exp. Sta.
Garden City	1932-1942	3 blocks E	
Garden City	1942-1949	3 mi. E.	
Garden City FAA	1949-1956	9 mi. SE	
Garden City Exp. Sta.	1956-1966	4½ mi. NE	At Branch Exp. Sta.
Hays 1 S	1912-1966	1 mi. S	At Branch Exp. Sta.
Hutchinson	1938-1949	3/4 mi. N	
Hutchinson	1949-1951	4 mi. E	
Hutchinson	1951-1953	--	1.3 mi. NE city lim.
Hutchinson Exp. Fld.	1953-1966	4 mi. E. Partridge	At Exp. Fld.
Mankato*	1961-1966	600 ft. NNW	
Minneola	1937-1946	Near P.O.	In town
Minneola	1946-1957	7 mi. NE Fowler	Moved from Minneola
Minneola	1957-1966	0.3 mi. WSW	
Tribune 1 W	1923-1966	1¼ mi. W	At Branch Exp. Sta.

*Smith Center weather data were used for 1943-1949 since the Experimental Field was located there prior to 1950. Burr Oak weather data were used for the period 1950-1961.

rationale of correlating crop yields with estimated soil moisture data, as determined by the Palmer accounting procedure. In that system, however, soil moisture losses by evapotranspiration are assumed. In summer fallowing, vegetative growth is controlled in the idle year and loss of moisture by evapotranspiration is reduced considerably. This is another possible explanation for the relatively poor correlations of point yield with subsoil moisture in this study.

This work provides a basis for further research in relating Palmer drought variables to crop yield data. Several additional areas need to be investigated, e.g., no attempt was made to include data for the Palmer Drought Index, moisture departure, estimated soil moisture, and precipitation in the same regression analysis. This could possibly yield an adequate equation for predicting yields. Too, accumulated moisture departure values for short periods could be used as one of the variables in the regression equation or the accumulated 'd' values could be included in combination with precipitation and/or Palmer Drought Indices. Further work in this regard should probably be restricted to locations which have precipitation data available for the experimental plots or in close proximity to the plots.

The relationship of yields for crop reporting districts to area Palmer Drought parameters and the development of a predictive yield equation for areas should also be investigated.

Weekly Palmer Drought Indices are currently being run by the National Weather Records Center for much of the United States east of the Rocky Mountains. These analyses are for Climatological Divisions but it would be possible to obtain weekly drought analyses for a point. The drought variables, if obtained for critical stages of growth of wheat, might correlate better with wheat yields than do monthly values.

Use of the computer program developed by Carmer (8) should simplify future regression analyses regarding the relationships of Palmer drought variables and crop yields.

SUMMARY AND CONCLUSIONS

A study was conducted to investigate the utility of Palmer drought variables in accounting for variations in winter wheat yield at specific locations in western Kansas. The locations used were Colby, Garden City, Hays, Hutchinson, Mankato, Minneola, and Tribune.

The variables obtained from the Palmer Drought procedure were monthly values of Palmer Drought Index, X, moisture departure, d, and estimated subsoil moisture. Turkey Red winter wheat yield data from uniform variety trials were available for each location for varying lengths of record and these data were correlated with the drought and weather variables.

Multiple linear and multiple curvilinear regression models were employed in making the statistical analyses. The regression and Palmer drought analyses were run on the IBM computer at Kansas State University.

In the first part of the study monthly Palmer Drought Index values and monthly moisture departure values were correlated with winter wheat yields. This part of the investigation was undertaken to determine the relationship of point yield with drought variables at specific points.

In the second part of the study both point and areal drought and weather variables were correlated with point wheat yield for the period 1932-1965. Use of data for the same period made it possible to identify the variables that were best correlated with point yields. The areal and point variables used were monthly precipitation, estimated monthly subsoil moisture, monthly Palmer Drought Index, X, and monthly moisture departure, d. The areal drought and weather data were for the Northwestern, West Central, Southwestern, and Central Climatological Divisions in Kansas.

The multiple correlation coefficients were rather low. The highest multiple R^2 for any location was obtained using monthly moisture departure, d, correlated with point yield. The R^2 in this case was 0.80 but other multiple R^2 values were less than 0.65.

Considering the entire period of yield records for Hutchinson, Mankato, and Minneola there was little difference between the multiple correlation coefficients and standard errors of estimate for the Palmer Drought Index, X, compared to those for the moisture departure, d. At Tribune, Garden City, Colby and Hays the point 'd' terms accounted for more of the yield variation than did the point 'X' values, but the multiple R^2 values were mostly low.

In general the highest multiple R^2 values were obtained for 1932-1965 using monthly moisture departure, d, values for specific locations correlated with point wheat yield. This 'd' variable gave better results than did any of the other point and area variables, i.e., monthly precipitation, monthly Palmer Drought Indices, or monthly estimated subsoil moisture.

Except for the point 'd' values, there was little difference in the point and area variables with regard to explaining variations in point yield.

In the regression analyses relating point moisture departures to point yields, the equation for every location had a 'd' term for one of the fall or late summer months. This suggested the importance of available moisture at or near seeding time in the production of winter wheat.

In the analyses of estimated subsoil moisture for points and areas versus point yield, six of the eight regression equations had at least one term for February, March or April subsoil moisture in the equation.

Based on these results, it was concluded that:

1) monthly point moisture departure, d, accounted for more of the variation in point wheat yield than did other drought and weather variables used in this study, namely, point and area Palmer Drought Index, point and area estimated subsoil moisture, point and area precipitation, and area moisture departure,

2) except for the point 'd' values, there was little difference in the drought and weather variables with regard to explaining variations in point wheat yield (see item 1 for a list of the variables),

3) adequate moisture at or near seeding time, and sufficient subsoil moisture during February, March, and April are especially important in the production of winter wheat in western Kansas.

ACKNOWLEDGMENTS

The author wishes to express his appreciation to Dr. Richard Vanderlip, major professor, and Dr. L. Dean Bark for their help and guidance in planning and carrying out this investigation. Their help in preparing the manuscript is also gratefully acknowledged.

Appreciation is expressed to Dr. Arlin Feyerherm for his aid in the statistical aspect of the study.

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APPENDIX

Table 1. Constants (a) for regression equations, partial regression coefficients (b) and standard partial regression coefficients (b') for monthly moisture departure (d).

Station	Period of record	a	Point data d	b	b'
Colby	1915-1966	28.5	Aug.	4.475	0.534
			Jan.	5.235	0.162
			June	2.184	0.335
			$Aug.^2$	-1.240	-0.336
Garden City	1932-1965	23.0	July	1.389	0.265
			Aug.	0.116	0.018
			Feb.	9.611	0.470
			June	1.626	0.344
			$Aug.^2$	-1.762	-0.396
Hays	1913-1966	20.8	Oct.	3.326	0.408
			Jan.	8.944	0.342
Hutchinson	1939-1966	28.5	July	0.967	0.300
			Oct.	2.343	0.467
			$Oct.^2$	-0.987	-0.538
Mankato	1943-1966	16.5	Oct.	4.005	0.629
			Nov.	7.445	0.647
			Jan.	-9.666	-0.435
Minneola	1938-1966	21.0	Nov.	4.452	0.365
Tribune	1924-1965	24.8	Aug.	1.563	0.198
			Oct.	10.300	0.885
			Jan.	15.085	0.381
			Apr.	0.195	0.019
			June	0.014	0.002
			$Oct.^2$	-2.005	-0.568
			$Apr.^2$	-0.958	-0.386
			$June^2$	-0.424	-0.300

Table 2. Constants (a) for regression equations, partial regression coefficients (b) and standard partial regression coefficients (b') for Palmer Drought Index variable (X).

Station	Period of record	a	Point data X	b	b'
Colby	1915–1966	23.0	Sept.	1.816	0.373
			Apr.	2.322	0.369
Garden City	1932–1965	21.2	Nov.	1.545	0.395
			May	1.970	0.411
			$Nov.^2$	-0.398	-0.303
Hays	1913–1966	20.7	Feb.	2.384	0.460
Hutchinson	1939–1966	29.1	Oct.	0.535	0.182
			$Oct.^2$	-0.373	-0.496
Mankato	1943–1966	19.5	Nov.	4.814	1.292
			Apr.	-1.670	-0.401
			$Apr.^2$	-0.454	-0.570
Minneola	1938–1966	20.4	Jan.	1.167	0.319
Tribune	1924–1965	16.4	Nov.	3.403	0.633

Table 3. Constants (a) for regression equations, partial regression coefficients (b) and standard partial regression coefficients (b') for monthly Palmer Drought Index variable (X). 1932-1965.

	Point data				Areal data*			
Station	a	X	b	b'	a	X	b	b'
Colby	28.9	Aug. Mar. $Mar.^2$	0.921 3.701 -0.610	0.202 0.601 -0.269	24.5	Sept. May	1.328 3.095	0.311 0.538
Garden City	21.2	Nov. May $Nov.^2$	1.545 1.970 -0.398	0.393 0.411 -0.303	23.8	Oct. May $Oct.^2$	1.346 1.552 -0.481	0.389 0.340 -0.362
Hays	20.2	Feb.	2.545	0.522	25.5	Feb. $Feb.^2$	1.950 -0.654	0.472 -0.377
Tribune	16.8	July Oct.	-3.415 6.423	-0.667 1.242	16.9	Nov.	3.231	0.604

*Point yield data at stations shown in left hand column were correlated with variables for Northwestern, Southwestern, Central, and West Central Divisions, respectively.

Table 4. Constants (a) for regression equations, partial regression coefficients (b) and standard partial regression coefficients (b') for monthly rainfall variable (PP). 1932-1965.

	Point data				Areal data*			
Station	a	PP	b	b'	a	PP	b	b'
Colby	11.4	Apr.	3.466	0.344	1.9	Oct.	17.611	1.449
		June	2.397	0.317		Feb.	31.114	1.027
						Oct.^{2}	- 2.444	-1.285
						Feb.^{2}	-12.475	-0.966
Garden City	4.9	Oct.	3.101	0.352	6.9	Oct.	3.655	0.394
		Feb.	8.387	0.368		Feb.	11.689	0.461
		June	1.562	0.262				
Hays	- 2.0	Sept.	1.599	0.280	24.8	Oct.	3.871	0.456
		Oct.	5.879	0.506		Nov.	-12.909	-1.113
		Nov.	3.274	0.267		Feb.	-25.399	-1.112
		Jan.	6.754	0.249		Nov.^{2}	5.033	1.434
		Mar.	4.651	0.329		Feb.^{2}	12.928	1.401
Tribune	- 3.1	Aug.	2.530	0.288	- 2.0	Oct.	12.451	0.993
		Oct.	11.722	0.715		Nov.	20.066	0.900
		Jan.	8.019	0.197		Nov.^{2}	-10.074	-1.267

*Point yield data at stations shown in left hand column were correlated with variables for Northwestern, Southwestern, Central, and West Central Divisions, respectively

Table 5. Constants (a) for regression equations, partial regression coefficients (b) and standard partial regression coefficients (b') for estimated monthly subsoil moisture variable (S). 1932-1965.

	Point data				Areal data*			
Station	a	S	b	b'	a	S	b	b'
Colby	4.0	Sept.	0.861	0.090	5.2	Dec.	5.924	0.813
		May	9.692	1.800		Apr.	3.680	0.722
		May^2	-0.715	-1.215		$Dec.^2$	-0.978	-0.932
Garden City	4.6	July	9.894	1.587	7.2	Oct.	17.125	1.298
		May	2.547	0.525		Feb.	4.924	0.607
		$July^2$	-1.562	-1.477		$Oct.^2$	-7.325	-1.475
Hays	9.3	Apr.	2.319	0.531	10.6	Mar.	2.241	0.435
Tribune	5.8	Feb.	6.484	0.655	6.0	Feb.	5.031	0.558

*Point yield data at stations shown in left hand column were correlated with variables for Northwestern, Southwestern, Central, and West Central Divisions, respectively.

Table 6. Constants (a) for regression equations, partial regression coefficients (b) and standard partial regression coefficients (b') for monthly moisture departure (d). 1932-1965.

	Point data				Areal data*			
Station	a	d	b	b'	a	d	b	b'
Colby	25.1	Aug.	3.426	0.419	24.3	Aug.	4.222	0.446
		Jan.	8.212	0.291		Jan.	13.184	0.429
		June	2.373	0.407		June	2.043	0.335
Garden City	23.0	July	1.389	0.265	18.2	Oct.	3.120	0.360
		Aug.	0.116	0.018		Feb.	11.567	0.529
		Feb.	9.611	0.470				
		June	1.626	0.344				
		$Aug.^2$	-1.762	-0.396				
Hays	17.0	Oct.	3.960	0.404	22.3	Jan.	6.167	0.369
		Nov.	-0.439	-0.036		Feb.	4.534	0.261
		Feb.	9.470	0.408		$Jan.^2$	-4.618	-0.412
		$Nov.^2$	3.217	0.424				
Tribune	16.9	Aug.	2.084	0.272	22.1	Oct.	7.771	0.662
		Oct.	11.112	0.725		Dec.	6.081	0.140
						May	-1.415	-0.138
						May^2	-2.397	-0.359

*Point yield data at stations shown in left hand column were correlated with areal variables for Northwestern, Southwestern, Central, and West Central Divisions, respectively.

THE RELATIONSHIP OF PALMER DROUGHT VARIABLES TO
THE YIELD OF WINTER WHEAT IN WESTERN KANSAS

by

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B. S., Kansas State College, 1942

AN ABSTRACT OF A MASTER'S THESIS

submitted in partial fulfillment of the

requirements for the degree

MASTER OF SCIENCE

Department of Agronomy

KANSAS STATE UNIVERSITY
Manhattan, Kansas

1967

The relationship of weather variables to crop yields in the Great Plains area has received considerable attention. This investigation was conducted to determine the utility of Palmer drought variables in accounting for winter wheat yield variation at specific locations over western Kansas.

Multiple linear regression and multiple curvilinear regression models were used. Palmer Drought analyses were run on the IBM 1401-1410 computer for seven stations in western Kansas. In the first part of the study point yield data at the seven locations were correlated with monthly Palmer Drought Index, X, and monthly moisture departure, d. Point drought and point yield data for the entire period of yield records were used in this part of the investigation.

In the second part of the study point yield data were correlated with weather and drought variables for points and areas for the period 1932-1965. This permitted an identification of the variables which were best correlated with winter wheat yields. A comparison of the utility of area and point variables in accounting for yield variation was also possible. Monthly precipitation, monthly Palmer Drought Index, monthly moisture departure, and estimated monthly subsoil moisture were the weather and drought variables used in this part of the study.

In general, the highest multiple correlation coefficients were obtained for 1932-1965 using monthly moisture departure for specific points and winter wheat point yield. This variable gave better over-all results than did monthly precipitation, monthly Palmer Drought Index or monthly estimated subsoil moisture values.

Except for monthly moisture departure values, there was little difference in the point and area variables with regard to accounting for point yield variations.

The importance of available moisture at a near seeding time and in the late winter and early spring was indicated by the drought and weather data. Rainfall in October and sufficient subsoil moisture in the February through April period were found to be especially important.

The high correlation of monthly Palmer Drought Index with monthly estimated subsoil moisture at Colby was demonstrated. It was shown that during certain months subsoil moisture is a good indicator of the Palmer Drought Index values for those months.

Additional research relating Palmer drought parameters to point and area yield data was recommended.