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Weather in Relation to the Yield of Dry-Land Winter Wheat

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WEATHER IN RELATION TO THE YIELD OF DRY-LAND WINTER WHEAT

By

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INTRODUCTION

Agriculture first developed in the Middle East where, probably about 15,000-10,000 B. C., the earliest wheat crop was reaped from cultivated wild grasses (Mann, 1946). In Biblical times the Middle East acted as the granary of the western world and led the world in cereal production. Now, however, the situation is different. The Middle East is one of the lowest yielding areas in the world. This failure of the agriculture of the Middle East may be due to both climatic and cultural reasons. Many students of the Middle East report that the climate has changed and that there has been a gradual decline in the amount of rainfall, especially of the autumn rainfall on which the grower of winter wheat depends for the sowing and germination of his crop. Cultural practices have not changed appreciably in that region even though the whole area may have changed from sub-humid to semi-arid. Farmers still follow the same routine of thousands of years ago. Another reason for agricultural failure is the lack of knowledge about climate and crop relationships and the attempts of growing wheat in areas where the climatic pattern is not suited to wheat production.

Many areas having as much as 16 inches of annual rainfall fail to give an economic crop yield. For instance, during the 15 years 1920-1934 the average annual precipitation in Tripolitania was 14.8 inches and in Tunis 16.5 inches, while the yields per acre were 5.2 and 6.0 bushels, respectively. In South Australia, which enjoys similar climate and where the average precipitation for the same years was 16.0 inches, the average yield was 10.6 bushels, or double that of Tripolitania for the same amount of rainfall. This significant difference indicates that in developing arid regions it is necessary to estimate the capacity of climatic and soil conditions for the production of profitable wheat yields.

Purpose

The present problem is to investigate weather in relation to winter wheat production and to determine the extent to which yields are influenced by climatic factors at different periods of the growth cycle of the wheat plant. Knowledge of such relationships makes it possible to determine, to a certain degree of accuracy, the suitability of a region to winter wheat production.

Scope

The study consists of a review of literature on the subject and of a statistical analysis of wheat yields in relation to annual variation in climatic elements for typical dry-land winter-wheat areas.

Weather is characterized by a large number of variables such as rainfall, temperature, hours of sunshine, wind velocity and humidity, but only temperature and precipitation have been extensively measured. Therefore, these two weather elements have been given primary importance in this investigation.

Wheat has been chosen for this study because of its predominance in the farming of arid regions where topography, soil, location and rainfall are favorable for agriculture. Wheat survives dry spells better than oats or barley, and is considered the best representative of the small grains. Since it has a wide geographic distribution, it offers the widest possibilities for the analysis of yield under varied climatic conditions. Winter wheat predominates in semi-arid regions especially in the Middle East; for this reason the investigation is limited to this crop.

"Dry-land" referred to in this study is that land which receives, on the average, an annual precipitation of not more than 20 inches. Two dry-land areas which receive most of their precipitation during the winter and spring months and which have very limited rainfall during the summer have been studied.

The term "weather" is employed rather than "climate." The two are differentiated in that climate is an average of weather conditions and determines the degree to which an area is capable of crop production. Weather is the sum of day-to-day climatic elements and determines the yield of crops for any particular season.

THE WHEAT PLANT

Origin

Most investigators agree that the wheat plant originated somewhere in the Middle East, where civilization first started. *Triticum vulgare* or common wheat forms the basis of the greater part of the wheats cultivated at present. *Triticum vulgare aestivum* is the most popular species and includes many varieties of both winter and spring wheats (Wilson, 1948).

Growth cycle

Various investigators divide the growth cycle of wheat into separate stages. Azzi (1922) divided the cycle into four periods: the first, from germination and development of the plant until the beginning of tillering; the second, from the beginning of tillering until its completion; the third, from the completion of tillering until heading; and the fourth, from heading until harvest. Smith (1920) recognized six stages in the life cycle of wheat; namely, germination, tillering, jointing, heading, blossoming and ripening. Alsberg (1928) gave the best and most satisfactory division. He divided the wheat growth cycle according to the sensitiveness of the plant to weather and its reaction to weather factors. He recognized the following stages:

1. Germination and the formation of the first leaf: For germination, soil should be sufficiently warm and adequately moist. If wheat is sown too early in the fall while the ground is warm, plants may start well but soon decay or wither. If the seeding is done late, when the soil temperature is so low that germination is slow or does not

occur at all, the plant cannot get a proper start before winter sets in. So "a very late summer in warmer regions of wheat culture or a very early winter in the cooler regions may greatly diminish the yield of winter wheat."

2. From the formation of the first leaf until heading: In this period the average daytime temperature should be above 40.0° F., the critical point at which growth is suspended. The most critical period in this stage is that immediately before heading, when the wheat plant is very susceptible to weather changes.

3. Heading and flowering: During this period cool weather and plenty of moisture are favorable for good crop yields. High temperature and lack of moisture at the time of blooming tend to produce sterile, scorched or shrivelled heads.

4. Formation and maturing of grain: Cool, humid weather during the earlier stages and dry weather during the latter stages are favorable for good yields. Very hot, very dry and very windy weather at this period reduce yield by causing grain to be small and shrunken.

Alsberg's division of the growth cycle helps in understanding the description of the ideal climate for wheat as given by Abbe (1905, p. 316).

> The ideal climate is one with a long and rather wet winter, with little or no frost, prolonged into a cool and rather wet spring, which gradually fades into a warmer summer, with only comparatively light rains after the blossoming of the crop, just enough to bring the grain to maturity, with abundant sunshine and rather dry air towards the harvest but without dry and scorching wind until the grain is fully ripe, and then hot dry rainless weather until the harvest is gathered.

Water requirement

Water requirement or "the ratio of the weight of water absorbed by the plant during its growth to the weight of the dry matter produced exclusive of roots" is not a constant and definite ratio. It varies from season to season and in different localities. It is affected by such soil factors as type, moisture content, cultivation, fertility, temperature and cropping system, and by such climatic factors as temperature, humidity and wind velocity. Different investigators found different ratios ranging from 395 to 801 pounds of water per pound of dry-matter and from 1067 to 1280 pounds of water per pound of grain. In general, on dry-land farms, high yields are usually associated with a low water requirement and vice-versa (Bracken and Cardon, 1935). Hopkins (1935) found in Saskatchewan, Canada, that the water requirement of spring wheat was 489 pounds per pound of dry matter when wheat was grown on fallow land and 764 pounds per pound of dry matter when wheat followed wheat. Finnel (1929) reported that the water requirement of winter wheat is still greater than spring wheat because it is a long season crop.

Temperature requirement

To a limited degree, plants can adjust and protect themselves against severe weather. They can withstand freezing temperatures by making their sap more concentrated and can resist heat to a limited degree by transpiration. Although both soil and air temperatures are important factors in plant growth, most studies have been made only on air temperatures. The optimum temperature for wheat germination is given by Alsberg (1928) as 68-77° F., and the two extremes at which germination can occur as 41° F. and 100° F. Growth of the wheat plant was found to cease when the temperature dropped to 40.0° F. (Asai, 1922). Also at a temperature of 108.5° F. or more, growth ceased and the plants began to die. The optimum temperature for wheat growth was found by Rutter (1911) to be 83.6° F.

DISTRIBUTION OF WHEAT

Wheat has an almost world-wide distribution because it can be grown under very diverse conditions. Its range of growth reaches as far north as latitude 65° (in Europe) and as far south as latitude 45° (in Australia); it is also grown within the tropics in such countries as Egypt, India, Mexico and the Phillipines (Smith, 1920). This does not mean that every area within the above limits can produce wheat. Ability to produce economic yields depends on combinations of climatic factors; for example, in South Australia, West Australia and Victoria, excellent wheat crops have been produced with an annual rainfall of 10 inches because other factors were favorable. It has been stated that in the Sahara there are large areas having an annual precipitation of 31.5-35.4 inches, quite unfit for the production of any crop because of high evaporation and greatly raised moisture requirements of plants (Clayton, 1930).

Winter wheat is wider in its distribution than spring wheat. It occupies the great bulk of the world's wheat acreage. But in some areas such as the Columbia River Plateau Region and the Colorado-Nebraska-South Dakota-Minnesota Region of the United States, spring wheat and winter wheat belts overlap.

Bennett and Farnsworth (1937) gave the distribution of the world wheat acreage (average for 15 years, 1920-1934) by five-inch rainfall zones and indicated that 41 per cent of the wheat acreage lie in regions having an annual rainfall of less than 20 inches. This distribution is shown in table 1, which shows the heaviest concentration of the acreage in the 15-20 inch zone. This relatively heavy concentration is said to be recent, and to be due to the development of better dry farming methods and of drought-resistant varieties of wheat. Bennett and Farnsworth also gave a geographic distribution of wheat areas by size of yield. From their data table 2 was prepared to show the distribution of dry-land wheat regions according to the average yield levels for the 15 years, 1920-1934.

Table 2 shows that the distribution of dry-land areas according to yield is approximately symmetrical or normal with nearly as many low yielding areas as high yielding ones. The highest concentration is in the frequency interval 9-11 bushels per acre. The mean yield for the 39 regions was found to be 10.9 bushels per acre; the median 10.9 bushels per acre, and the mode 10.6 bushels per acre.

The five lowest yielding areas were Tripolitania (5.2 bushels per acre), Cyrenaica (5.4 bushels), Tunis (6.0), San Luis, Argentina (6.7) and Canary Islands (7.1). The five highest yielding areas were Alberta, Canada (18.0), Washington, U.S.A. (17.5), Manitoba, Canada (15.9), California, U.S.A. (14.7) and Saskatchewan, Canada (14.7).

Table 1. Distribution of world wheat acreage by five-inch rainfall zones. Average 1920-1934*

Annual rainfall in inches	Acres (millions)	Per cent of total
Below 10.0	9	2**
10.0 - 14.9	32	8**
15.0 - 19.9	119	31
20.0 - 24.9	83	22
25.0 - 29.9	45	12
30.0 - 34.9	38	10
35.0 - 39.9	29	8
40.0 - 44.9	11	3
45.0 - 49.9	11	3
Over 50.0	6	1
Total	383	100

* Bennett and Farnsworth (1937).
** Much of this is irrigated.

Table 2. Distribution of the major wheat areas of the world by size of yield. Average yield levels for 1920-1934*

Average yield per acre in bushels	Number of areas of indicated yields
5.00 - 6.99	4
7.00 - 8.99	7
9.00 - 10.99	10
11.00 - 12.99	8
13.00 - 14.99	7
15.00 - 16.99	1
17.00 - 18.99	2
Total	39

* Bennett and Farnsworth (1937).

REVIEW OF LITERATURE

Literature on the correlation of weather and crop yields is voluminous and extensive. Many writers in different countries have studied the influence of rainfall, temperature and other weather factors upon the yield of grain crops. Literature on the relation of weather to yield of winter wheat, however, is limited in amount and is much less extensive than literature on the relation of weather to yield of spring wheat, especially in the United States and Canada.

Barkley (1927) found in Northern Victoria, Australia, a very high positive correlation of 0.90 between yield and rainfall during August and September (correspond to February and March in the northern hemisphere). Clayton (1930) also found that in Australia the rainfall of August and September is the dominant factor for winter wheat which comes into head in early October. He pointed out that August and September are the months of maximum growth and increase in dry matter and that during this time lack of moisture is detrimental to yields.

Richardson (1925) related average seasonal April-October rainfall (corresponds to October-April rainfall in the northern hemisphere) and average wheat yields in Victoria, Australia, for thirty years and found that 0.89 bushels were produced for every inch of rainfall. He also reported that rain during September has the most pronounced effect on yield.

Hessling (1922) relating weather to yield of winter wheat in the Argentine Republic found no linear correlation between yield and rainfall but found an inverse relation between temperature and yield. The highest correlation was found between yield and the temperature for the four months August through November (correspond to February through May in the northern hemisphere).

Mattice (1926), using data from Akron, Colorado, correlated the yield of winter wheat under eight cropping systems with five weather elements over a period of 15 years. The correlation coefficients which he found for the summer fallow cropping system are: +0.52 ±.13 for yield and June rainfall; +0.38 ±.15 for yield and fall rainfall; -0.45 ±.14 for yield and December mean temperature; -0.49 ±.14 for yield and June evaporation; and -0.32 ±.16 for yield and seasonal evaporation. He concluded that the highest correlation was between June rain and yield because June is the critical period of heading.

Bracken and Cardon (1935) found at Nephi, Utah, a ratio of 0.962 between yield and rainfall for the years 1911-1918 and of 0.983 for 1927-1933. These ratios represent bushels per acre produced for every inch of precipitation.

Hensey (1935) found a high correlation between the amount of rainfall 60 days prior to seeding time and final yields. He was able to forecast the production of winter wheat by crop reporting districts seven months prior to harvest time with a fair degree of accuracy. He also studied rainfall and wheat yields in western Kansas and found in the northern district a correlation coefficient of +0.872 between yield and rainfall during the 12 months before the previous harvest. In the southern district, the August to October rainfall showed the highest correlation: +0.536. In the middle district the October to November precipitation showed the highest relation: +0.766.

Pallesen and Laude (1941) found in western Kansas that rainfall during the period from seeding time to December 1 had the greatest influence on yield.

Koeppe (1934) studied the relation between meteorological conditions and winter wheat yields in central and western Kansas. She reported that rainfall is the most critical and outstanding factor in the production of winter wheat. She found the most significant relationship to be that fairly moist Augusts, Septembers, Octobers, Januarys and Februarys, and distinctly dry Aprils were followed by good yields of wheat. She also found a correlation coefficient of +0.50 for yield and total yearly snowfall and of -0.60 for yield and minimum temperature in June. She reported that large yields seemed to be favored by large numbers of frost days in both October and April. Strong winds in December were perhaps favorable to yield showing a positive correlation coefficient of 0.44, but strong winds in September and March affected yields negatively showing a correlation of -0.77 and -0.74, respectively.

Zink (1940) studied the relation of weather factors to wheat yields on the Levan Ridge, Utah. She found the highest correlations to be between yield and evaporation, yield and length of drought period and yield and rainfall. Evaporation showed the highest and most consistent correlation because it is an integration of several climatic factors such as temperature, humidity and wind velocity. Some of the more important correlation coefficients which she found are the following: +0.113 between yield and rainfall during the year of harvest; +0.668 between yield and rainfall during April, May and June; +0.327 between yield and rainfall during the fallow period; -0.700 between yield and evaporation from April 1 to heading; -0.437 between yield and maximum temperature of the period April 1 to heading (June 4-June 30).

A number of investigators studied the relation between soil moisture at seeding time and yield of winter wheat.

Hallsted and Coles (1930) studied data from three dry-land experiment stations in Kansas and found a correlation of +0.85 between moisture in the upper three feet of soil at the time of seeding of winter wheat and the yield of wheat the following year.

Pallesen and Laude (1941) also made their studies in western Kansas and reported that the moisture stored during the fallow year increased the level but did not reduce the absolute variability of the yields.

RELATIONSHIPS BETWEEN RAINFALL AND YIELD

In regions having limited rainfall, growth of wheat and its final yield are primarily dependent upon moisture. Therefore, it seems that rainfall is the most important single factor influencing yield. There is a minimum requirement of rainfall for the production of a profitable crop. Any quantity of rain less than this minimum would result in failure of the crop. The magnitude of this minimum varies with many factors such as rainfall distribution, humidity, average wind velocity, air temperature, and soil type. Mathews and Brown (1938) investigated the relationship between the total water used and the yield of wheat at Colby and Garden City, Kansas, and found that 7.37 inches of water were required before any grain was produced and that each additional 0.51 inch of water produced a bushel of wheat. Watt (1948) gives 10 inches of seasonal (April-October) rainfall as the margin for safety of wheat growing in Australia.

Crop yields are related only in part to the quantity of available water. Moisture is not equally beneficial to wheat in all its stages of growth. This study was designed to investigate the importance of the seasonal distribution of rainfall by determining the relation between rainfall during different periods and yield. A study was made for two typical winter wheat dry-land areas, one in South Australia and the other in Juab County, Utah. For South Australia, data from five dry-land experimental farms (see appendix 1) were pooled and analyzed. This pooling was necessary to form a long series which is required to show the average relation of yield to precipitation. A precedent for this procedure is found in Hopkins' (1935) pooling of the results from several stations in Canada to give him a long series. For Juab County, Utah, the yield data for the Nephi Dry-land Experimental Farm have been correlated with rainfall data as recorded at Levan. Data for 42 years, 1908-1949, have been analyzed to show the relationships. For South Australia the yield figures are the average of all systems practised on the farms while those for Nephi are yields of the summer fallow cropping system.

Relationships for South Australia

The relationships studied for South Australia are those between yield and the following rainfall periods:

1. Monthly rainfall.

2. Total annual rainfall.

3. Seasonal rainfall, or that precipitation falling during the seven months of active growth of the wheat plant, namely April-October. This rainfall is termed 'useful' because of its direct assistance to the growing crop.

4. Autumn rainfall, or that precipitation falling during the months of April and May. This period covers the germination and formation-of-the-first-leaf stages in the wheat growth cycle.

5. Winter rainfall, or that precipitation falling during the months of June and July. This period includes the period of early vegetative growth and tillering.

6. Spring rainfall, or that precipitation falling during the months of August, September and October. This includes heading and flowering, the most critical periods in the growth cycle.

7. 'Fallow' rainfall or that precipitation falling during the eight months from August 1 of the year preceding harvest to March 31 of the harvest year. This could be termed 'pre-seasonal' rainfall and could be regarded as an indication of soil moisture at seeding time.

The correlation coefficients between yield and rainfall for monthly periods is shown in table 3. Table 4 presents the correlation

Table 3. Correlation coefficients between yield and monthly rainfall obtained from analysis of data from five dry-land experimental farms in South Australia for 89 crop years

Month	Average precipitation (inches)	Correlation coefficients (r)
January	0.50	+0.153
February	0.82	-0.292
March	0.72	-0.089
April	0.77	+0.121
May	1.72	+0.309*
June	2.02	+0.542**
July	1.72	+0.541**
August	1.90	+0.722**
September	1.88	+0.380*
October	1.43	+0.419**
November	0.90	+0.205
December	0.85	+0.092

* Significant at the 5% level.
** Significant at the 1% level.

Table 4. Simple relationships between yield and rainfall during periods longer than one month obtained from analysis of data from five dry-land experimental farms in South Australia for 89 crop years

Relation between yield and:	Correlation coefficients	Coefficients of determination in per cent	Simple regression equations: Y= yield, X= rainfall of the stated period
Annual rainfall	+0.662**	43.8	Y = 0.384 + 1.043 X
"Usefull" rainfall	+0.733**	53.7	Y = 1.615 + 1.299 X
Autumn rainfall	+0.309**	9.5	Y = 12.120 + 1.715 X
Winter rainfall	+0.648**	42.0	Y = 6.472 + 2.672 X
Spring rainfall	+0.666**	44.4	Y = 3.816 + 2.441 X
"Fallow" rainfall	+0.093	0.9	Y = 14.738 + 0.188 X

** Significant at the 1% level.

coefficients between yield and rainfall during the other above periods and gives the regression equations of yield on rainfall during the same periods.

In South Australia, winter wheat is seeded in April or May, the fall months. Table 3 indicates that precipitation in the summer month of January and the autumn month of March had no significant correlation with yield. However, precipitation in February showed a negative correlation which approached significance. Since this relationship was contrary to expectation, a search was made for the cause. It was found that rainfall in February had a highly significant negative correlation of -0.409 with winter rainfall and a significant negative correlation of -0.234 with spring rainfall. This seems to indicate that heavy rainfall in February is usually accompanied by low precipitation the following winter and spring, and that it is this low precipitation which causes the reduced yields rather than the high precipitation in February. April has no significant correlation while May, the month in which seeds germinate, has a higher and significant correlation. From May on, the wheat plant adds to its dry weight at an increasing rate for three to four months, reaching a maximum in early October when heads begin to appear. From October until harvest the rate of growth decreases. This trend is followed by the correlation coefficients which go up and down with the increase and decrease in the rate of growth. The correlation coefficients indicate the increasing importance of precipitation for the wheat plants as they grow bigger and transpire more.

Table 4 indicates that the "useful" rainfall or that falling during the months of April to October has the closest relationship with yield.

Changes in this rainfall seem to be, on the average, responsible for 53.7 per cent of the variation in wheat yields. When the period April to October was split into autumn, winter and spring, the closest relationship was found between yield and spring rain. This conforms with the concept developed with monthly precipitation-yield correlations. Spring rains are most effective because they fall at a period when transpiration is at a maximum and moisture is most needed. The coefficients of correlation also indicate a lack of relation between "fallow" or pre-seasonal rainfall and yield. This lack of relationship seems to indicate that "fallow" rains are not important for large yields as they account for less than one per cent of the variation in yield.

The simple regression coefficients (coefficients of the X's in the regression equations in table 4) represent the number of bushels of wheat produced for each inch of rain falling during the stated periods.

Coefficients of multiple regression were calculated to show the average influence in bushels per acre of one additional inch of rain above the average or a deficiency of one inch below the average during the stated periods. They show the net effect of rainfall in any one period independent of rainfall in any other period. The partial regression coefficient for yield on autumn rainfall independent of winter and spring rains is 0.105 bushels per acre. That for yield on winter rainfall, independent of autumn and spring rains is 1.670 bushels per acre; and that for yield on spring rainfall independent of both autumn and winter rains is 1.489 bushels per acre. The standard partial regression coefficients (b' - values) are 0.019, 0.405 and 0.444, respectively. These indicate that the maximum effect of rainfall is received during the spring and winter, with much less effect during the fall. The multiple regression equation for yield (Y) on the most influential factors, autumn rainfall (X_1), winter rainfall (X_2) and spring rainfall (X_3) is:

$$Y = 2.24 + 0.11\,X_1 + 1.67\,X_2 + 1.49\,X_3.$$

This equation shows that most of the yield, except 2.24 bushels per acre, is accounted for by rainfall during the period April to October. Such equations could be used to determine to some extent, from the precipitation of a certain region, the expected average yield of winter wheat and thus the suitability of that region for profitable production of winter wheat. The coefficient of multiple correlation (R) is 0.751 and the coefficient of multiple determination (R^2) is 0.564 or 56.4 per cent.

Relationships for Nhill

Table 5 shows the correlation coefficients between yield and monthly rainfall. Table 6 shows the correlation coefficients for periods longer than one month and gives the simple regression equations of yield on rainfall during the same periods. Autumn rainfall is that falling during the months of August, September and October. Winter rainfall is that falling from November 1 to March 31. Spring rainfall is that falling during April, May and June. "Fallow" rainfall is that falling during the 12 months from the beginning of August of one year until the end of July of the year of seeding. The crop year is from August 1 to July 31.

The correlation coefficients in table 5 indicate a trend of relationship between precipitation and yield similar to that indicated for South Australia. Precipitation during August and September (pre-seeding period) shows a negative but insignificant correlation with

Table 5. Correlation coefficients between yield and monthly rainfall obtained from analysis of data from the Nephi Dry-land Experimental Farm for the period 1908-1949. Months are arranged according to the crop year.

Month	Average precipitation recorded at Levan (inches)	Correlation coefficients (r)
August	1.06	-0.054
September	0.94	-0.101
October	1.40	+0.163
November	1.08	-0.247
December	1.29	+0.048
January	1.23	+0.146
February	1.27	+0.082
March	1.60	+0.119
April	1.41	+0.327*
May	1.42	+0.322*
June	0.71	+0.299*
July	0.85	+0.132

* Significant at the 5% level.

Table 6. Simple relationships between yield and rainfall during periods longer than one month obtained from analysis of data from the Nephi Dry-land Experimental Farm for the period 1908-1949.

Relationship between yield and:	Correlation coefficients	Coefficients of determination (r^2) in per cent	Simple regression equations: Y= yield, X= rainfall of the stated period
Annual rainfall	0.240	5.8	Y = 13.67 + 0.67 X
Crop year rainfall	0.366*	13.4	Y = 7.30 + 1.11 X
Autumn rainfall	0.018	-	Y = 22.89 + 0.09 X
Winter rainfall	0.099	1.0	Y = 19.53 + 0.56 X
Spring rainfall	0.556**	30.9	Y = 11.01 + 3.44 X
Fallow rainfall	0.134	1.8	Y = 17.44 + 0.40 X

* Significant at the 5% level.
** Significant at the 1% level.

yield. The closest relationship is shown to exist between yield and precipitation for April and May, the two months immediately preceding the month of heading.

Table 6 shows that only rainfall during the crop year and rainfall during the spring period had any significant correlation with yield. The regression equation for spring rainfall shows that each additional inch of spring precipitation is associated, on the average, with an extra 3.44 bushels of wheat per acre. Therefore, rainfall during spring is by far the most important single rainfall factor in the production of winter wheat at Nephi.

The multiple regression equation for yield on autumn rainfall (X_1), winter rainfall (X_2) and spring rainfall (X_3) is:

$$Y = 7.42 - 0.01 X_1 + 0.56 X_2 + 3.44 X_3.$$

The coefficient of multiple correlation is 0.550 and the coefficient of multiple determination is 0.303 or 30.3 per cent.

The standard partial regression coefficients are 0.003, 0.097 and 0.556 for yield on autumn, winter and spring precipitation, respectively. These indicate that spring precipitation is more than five times as effective on yields as winter precipitation and more than 200 times as effective as autumn precipitation.

RELATIONSHIPS BETWEEN TEMPERATURE AND YIELD

Since records of temperature for South Australia could not be obtained from available sources, these relationships were studied for Nephi only. Table 7 shows the relationships between yield and mean temperatures for each month and the whole year. The most striking point in connection with the correlations shown in table 7 is that temperature of all months except June and July had practically no influence on yield. High temperature during November and December showed a correlation with yield which approached significance indicating that warm Novembers and Decembers seem to favor large yields the following season. June and July which cover the critical period of flowering seem to be particularly important in determining the yield of wheat as far as temperature is concerned. High temperature over these two months involves a great risk. It increases the water requirement of the plants which, if they reach the flowering stage before the spring rains set in, would give a poor crop. In South Africa wheat which reaches the flowering stage during a period of drought is considered a failure and farmers are urged to use it for grazing.

The correlation between yield and the mean annual temperature was not significant.

Table 7. Correlation coefficients between mean temperatures and yield obtained from analysis of data from the Nephi Dry-land Experimental Farm for the period 1908-1949. Months are arranged according to crop year.

Period	Mean temperature (degrees Fahrenheit)	Correlation coefficients (r)
August	70.3	+0.027
September	61.6	+0.020
October	49.9	+0.009
November	37.4	+0.273
December	27.8	+0.250
January	24.7	+0.038
February	30.5	+0.139
March	38.9	+0.139
April	47.3	-0.126
May	55.3	+0.019
June	64.2	-0.350*
July	72.1	-0.368*
Calendar year	48.3	+0.039

* Significant at the 5% level.

PRECIPITATION EFFECTIVENESS AND YIELD

There is a general impression that the most critical factor in the production of crops in semi-arid areas is precipitation effectiveness. Some investigators say that the amount of precipitation effective in crop production is more important than either the total amount of rainfall or its distribution. To test the significance of such statements, yield was correlated with precipitation effectiveness as represented by index values calculated according to Thornthwaite's* formula:

$$\frac{P}{E} = 115 \left(\frac{P}{T-10}\right)^{\frac{10}{9}}$$

where $\frac{P}{E}$ = precipitation-evaporation ratio or precipitation effectiveness,

P = monthly precipitation in inches,

T = monthly temperature in degrees Fahrenheit.

This is the most widely accepted formula for measuring the effectiveness of precipitation because it is suppose to evaluate the effectiveness of precipitation in terms of the temperature at which it fell.

The $\frac{P}{E}$ ratios were computed for Nephi for each month of the entire period January 1908 to December 1949. These indices of precipitation effectiveness were correlated with yield to show the relationships between combined rainfall and temperature and yield. To obtain the precipitation effectiveness indices for periods longer than one calendar month, the accumulated sum of the monthly indices was

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* C. W. Thornthwaite, "The Climates of North America".

taken.

Table 8 gives the correlation coefficients between precipitation effectiveness indices and yield. A column showing the correlation coefficients between precipitation alone and yield is also given in the same table for comparison. Figure 1 shows the relationships graphically.

Table 8 and figure 1 show that the two sets of correlation coefficients run approximately parallel. This seems to indicate, contrary to common belief, that precipitation-effectiveness indices do not show a closer relation to yield than does precipitation alone. Precipitation effectiveness, therefore, revealed nothing more than did precipitation and as it is much more difficult to calculate, it has nothing to commend it over precipitation alone for determining the relationships with yield.

Table 8. Correlation coefficients between precipitation effectiveness indices* and yield compared with correlation coefficients between precipitation alone and yield obtained from analysis of data from the Nephi Dry-land Experimental Farm for the period 1908-1949. Months are arranged according to crop year.

Period	Correlation coefficients between yield and precipitation effectiveness indices	Correlation coefficients between yield and precipitation alone
August	-0.058	-0.054
September	-0.129	-0.101
October	+0.120	+0.163
November	-0.289	-0.247
December	+0.098	+0.048
January	+0.151	+0.146
February	+0.024	+0.082
March	+0.058	+0.119
April	+0.305*	+0.327*
May	+0.307*	+0.322*
June	+0.300*	+0.299*
July	-0.128	+0.132
Autumn season	+0.014	+0.018
Winter season	+0.063	+0.099
Spring season	+0.513**	+0.556**
Fallow period	+0.203	+0.134
Crop year	+0.219	+0.366*
Calendar year	+0.139	+0.240

* Calculated according to Thornthwaite's formula.
* Significant at the 5% level.
** Significant at the 1% level.

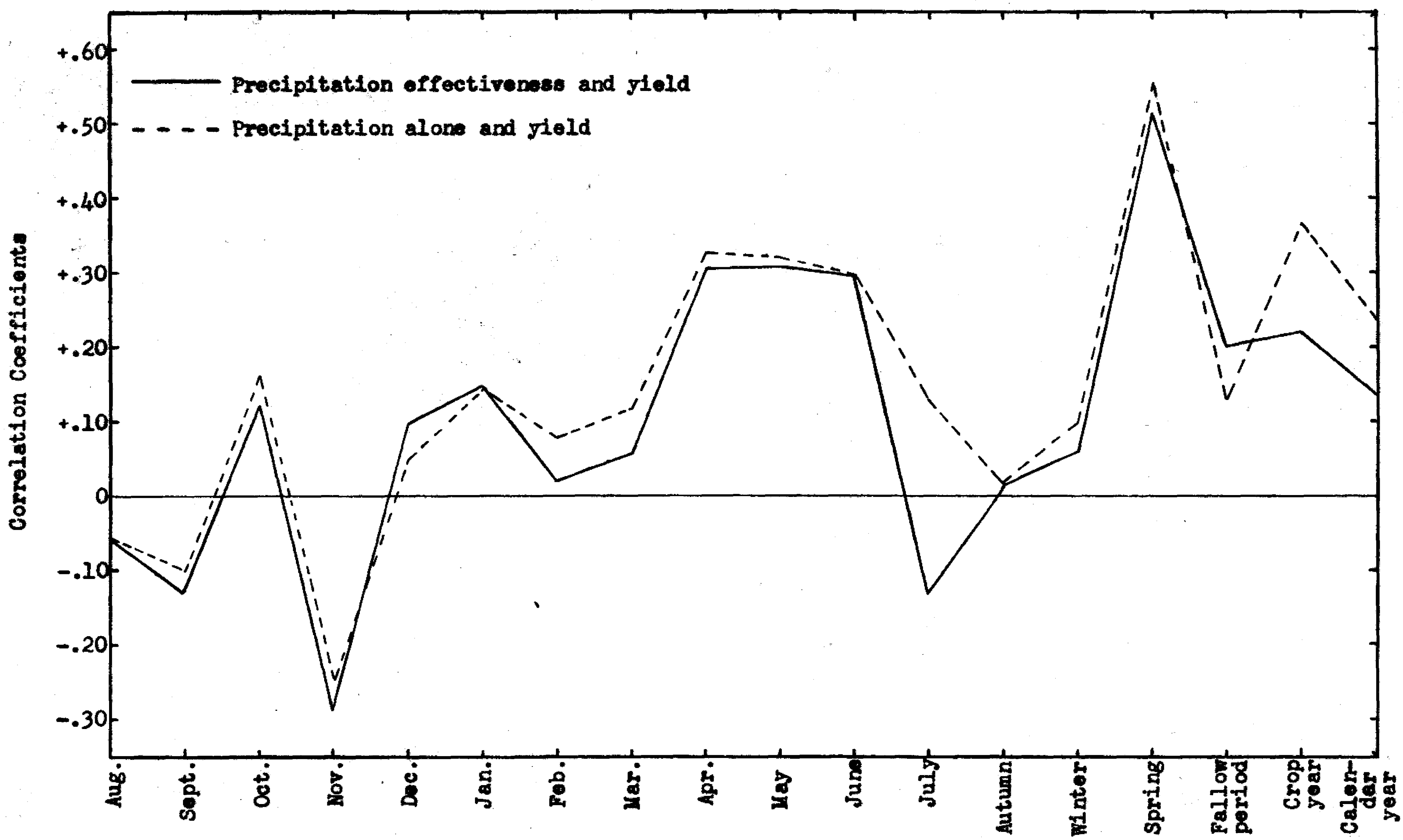

Figure 1. The correlation coefficients between yield of dry-land winter wheat and precipitation effectiveness compared with the correlation coefficients between yield and precipitation alone for Nephi Dry-land Experimental Farm, 1908-1949.

DISCUSSION

In the two areas studied, South Australia and Juab County, Utah, precipitation during the fallow period previous to the sowing of the crop had practically no influence on wheat yield the following season. The coefficients of correlation found were 0.093 and 0.134 for South Australia and Juab County, respectively. This lack of apparent benefit of moisture during the fallow period is contrary to expectation based on popular opinion.

Rainfall during both autumn and winter did not show any significant correlation with yield at Nephi, but showed a highly significant correlation in South Australia. This difference may be caused by the warmer autumns and winters enjoyed by South Australia which enables some growth to take place. The concept is further indicated by a positive correlation which approaches significance found between temperature of the late autumn and yield for Nephi. Warm Novembers and Decembers favored higher yields.

Spring is found to be the most critical period in the growth cycle of winter wheat in regard to both precipitation and temperature. Wet, cool springs are found to favor large yields.

The trend of the results of this study agrees with most of the literature cited, but the coefficients of correlation are, in most cases, numerically lower. This may be caused by the longer series studied for this paper. The only outstanding differences between the results found by this investigation and those reported in the literature cited are the relations between yield and autumn rainfall.

Hennay (1935) found for western Kansas high positive correlations between yield and precipitation during the 60 days prior to seeding and between yield and precipitation during September, October and December. Similar relationships were not found for Nephi.

Precipitation effectiveness as represented by Thornthwaite's indices did not show any advantage over precipitation alone for determining the relationships of weather conditions and yield for the two areas. Precipitation in this study showed a closer relationship to yield than did precipitation effectiveness. Koeppe (1934) correlated precipitation effectiveness indices, calculated according to the same formula, with winter wheat yields for Ford County, Kansas, and found that these correlations revealed nothing more than did either temperature or precipitation alone. The writer feels that this inferiority of precipitation effectiveness indices may be due to a defect in the formula. Thornthwaite's formula does not consider the length of the period during which precipitation falls which seems to be important. Precipitation falling in small showers quickly evaporates, and a smaller percentage of the total soaks into the ground than if it all fell in one prolonged shower. Therefore, it is felt that to measure precipitation effectiveness the formula should also provide for the duration of the precipitation showers and may be the form in which precipitation falls.

This study could have been more complete if the temperature data for South Australia could have been obtained, and it also would have been more complete if data for precipitation and temperature could have been obtained for periods shorter than the monthly intervals. However, this study represents the relationships involved with a fair degree of accuracy because long series of data have been used consistently. For practical purposes, the relationships found in this study are more useful than relationships for shorter periods for determining the suitability of a region for winter wheat production because usually only monthly and annual records of precipitation and temperature can be obtained.

This study has shown some relationships which can be used in determining the suitability, for the production of winter wheat, of a dry-land region having climatic patterns similar to those studied. The regression or prediction equations enable a reasonable estimate of the size of forthcoming crops to be expected from a knowledge of weather conditions affecting plant development. Such estimates should be regarded with caution since the influence of weather elements on yield depends not only on variations in any one of them separately, but also on their coincidence in time with each other as well as with certain stages in the growth of the wheat plant. This circumstance leaves to chance a large part of the responsibility for fluctuations in yield. The relationships found relate to the average; consequently, the capacity of an area for winter wheat production could be determined only on an average basis which does not account for exceptionally scanty or boom years.

This study indicated that, on the average, in dry-land areas having mild winters similar to those in South Australia, good yields of wheat could be expected if the following conditions prevail: low rainfall in the autumns but enough to germinate the seed and keep it alive till winter sets in; high precipitation in winters and springs; cool protracted springs gradually fading into warm summers. A sudden and early onslaught of summer would reduce the growing period of the crop causing small shrivelled grain and consequently light yields. Spring precipitation falling in short showers seems to be less beneficial to the crop than that falling in prolonged showers.

In areas having cold winters similar to those in Juab County, good yields of winter wheat could be expected if the following conditions prevail: low precipitation in the fall but enough, especially in October, for germination of the seed and the growth of the plant into dormancy for the cold winter; low winter precipitation but more than that of the autumn; a snow cover in winter to keep the warmth in the soil since warm winters are favorable for large yields; high spring precipitation through April, May and June, and cool temperatures during June and July.

The relationships indicate that profitable wheat production in areas of low rainfall is possible where the distribution of rainfall during the year is favorable. This led the writer to believe that crop failures in the Middle East are due to the dry springs experienced and to the early onslaught of summer; in other words, to the bad distribution of annual precipitation, most of which falls during the late autumn and winter months. The best way of combating such failures seems to be the development of early maturing varieties and the early sowing of the crop.

Suggestions for further study

Further study of the relation between yield and weather conditions, especially during the periods of autumn and winter, seem to be needed because the findings of investigators differ. Also, further study of the relationships between precipitation effectiveness and yield should be made in order to obtain more evidence before precipitation effectiveness is discarded as being inferior to precipitation alone for the study of weather-crop relationships.

SUMMARY

1. Weather data and wheat yields were obtained for five dry-land wheat experimental stations in South Australia and for the Nephi Dry-land Experimental Farm in Juab County, Utah. These data were statistically analysed to determine the relationships of weather to wheat yields.

2. For South Australia, data from the five dry-land experimental farms were pooled together and analysed. Only relationships between precipitation and yield were studied as temperature data could not be obtained.

3. For Juab County, wheat yields at the Nephi Dry-land Experimental Farm were related to precipitation and temperature as recorded at Levan.

4. In South Australia precipitation in spring and winter were equally influential on yields. Precipitation during August (a winter month) was the most influential monthly period on yields. Rainfall during the fallow period previous to seeding did not show any significant correlation with yield.

5. At Nephi, April and May were the most critical months for wheat as far as precipitation is concerned. June and July were the most critical months with regard to temperature. The only highly significant correlation found was that between spring rainfall and yield.

6. Precipitation effectiveness did not show any closer relationship to yield than did precipitation alone.

APPENDIX I

The five dry-land experimental farms from which data have been analyzed for South Australia are all situated within the radius of 200 miles from Adelaide. These farms are:

1. Booborowie Experimental Farm: mean annual precipitation for 31 years is 17.36 inches; extremes being 9.76 and 26.78 inches. Total area is 1,344 acres. Soil is red, brown earth class.

2. Eyre Peninsula Experimental Farm: mean annual precipitation for 16 years is 12.89 inches; extremes being 8.93 and 21.69. Total area is 3,000 acres. Soil is of a calcarious nature and of good working character.

3. Roseworthy Agricultural College Experimental Farm: mean annual precipitation for 32 years is 17.40 inches; extremes being 9.36 and 27.46 inches. Total area equals 122 acres. Soil is uniform in character consisting of fairly heavy loam.

4. Turretfield Experimental Farm: mean annual precipitation for nine years is 16.65; extremes being 9.97 and 22.82 inches. Total area equals 1,573 acres. Soils are of red loam nature with some calcarious patches and silty flats.

5. Veitch's Well Experimental Farm: mean annual precipitation for 22 years equals 11.86 inches; extremes being 5.94 and 16.69 inches. Total area is 3,800 acres. The soil is on the main of a sandy nature with some areas of light loam.

Appendix table 1 gives the average monthly precipitation and average annual yield of winter wheat at each of the above five stations.

Appendix table 2 gives the monthly precipitation for Levan, Utah.

Appendix table 3 gives the monthly mean temperature for Levan, Utah.

Appendix table 4 gives the average yield of winter wheat by the summer fallow cropping system at the Nephi Dry-land Experimental Farm.

Appendix table 1. Average monthly and annual precipitation and average yields of winter wheat at the five dry-land experimental farms in South Australia

Farm	No. of yrs. for which average is taken	Precipitation													Average annual yield
		Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual	
Booborowie	31	.53	.70	.69	.91	1.86	2.39	2.09	2.17	2.21	1.74	1.00	1.07	17.36	23.83
Eyre Peninsula	16	.60	.79	.53	.54	1.41	1.95	1.76	1.86	1.13	1.16	.50	.66	12.89	15.93
Roseworthy	32	.66	.69	.87	1.14	2.11	2.20	1.92	2.06	2.06	1.77	1.04	.88	17.40	16.62
Turretfield	9	.29	.91	.73	.87	1.80	2.31	1.79	2.11	2.39	1.43	1.24	.78	16.65	16.68
Veitch's Well.	22	.43	1.00	.79	.39	1.43	1.26	1.06	1.28	1.60	1.02	.73	.87	11.86	10.18
All stations	-	.50	.82	.72	.77	1.72	2.02	1.72	1.90	1.88	1.43	.90	.85	15.23	16.65

Appendix table 2. Monthly precipitation for Levan, Juab County, Utah for the period August 1, 1907 to July 30, 1949

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Total
1907-08	3.57	.91	1.11	.36	1.89	.82	1.19	1.00	.31	4.35	1.15	1.06	17.72
1908-09	1.55	2.89	1.87	.63	1.40	2.53	1.89	1.19	2.13	.42	.06	1.14	17.70
1909-10	2.18	.81	.52	1.90	3.17	.95	.89	.73	.52	1.05	T	.26	12.98
1910-11	.18	2.28	1.55	.78	1.35	2.08	1.38	1.28	1.17	.45	.34	.70	13.54
1911-12	.10	1.12	.75	.95	1.72	.46	.68	4.16	1.32	1.14	.18	.39	12.97
1912-13	.26	.94	3.37	1.44	0.78	1.08	2.17	1.06	1.22	.27	1.18	.40	14.17
1913-14	1.64	1.41	1.44	2.08	1.68	3.32	.84	1.09	4.23	.55	1.84	1.90	22.02
1914-15	.22	.02	1.81	.08	.40	1.14	2.34	1.42	1.50	3.21	1.04	.02	13.20
1915-16	.25	1.93	.36	1.11	1.14	5.01	.99	3.51	.45	.45	-	1.23	16.43
1916-17	1.20	.45	2.38	.88	2.24	1.08	1.52	.42	1.83	3.56	.01	.46	16.03
1917-18	.65	.94	.09	1.77	.50	2.53	1.18	1.06	1.20	1.16	.44	1.10	12.62
1918-19	.30	1.32	1.07	1.86	.90	T	1.12	1.35	1.21	.98	-	.42	10.53
1919-20	1.51	2.98	1.19	2.17	.74	1.13	1.68	3.08	1.59	1.26	.45	.60	18.38
1920-21	3.60	.95	3.63	.76	1.59	1.50	.92	.69	2.59	2.69	.77	1.96	21.65
1921-22	1.26	.33	.94	.31	2.03	1.59	1.11	1.18	1.27	1.02	.56	.60	12.20
1922-23	1.39	T	1.03	1.21	2.38	.84	1.18	1.16	2.55	1.62	.51	2.25	16.12
1923-24	.93	1.79	1.42	.25	.81	.30	.33	2.12	.15	2.68	.07	.35	11.20
1924-25	.66	1.31	1.55	.72	2.38	.40	1.49	1.65	1.53	.55	1.31	.98	14.53
1925-26	1.08	.96	1.43	.78	1.00	.51	1.37	1.01	1.42	1.74	T	1.37	12.67
1926-27	.66	.79	.23	1.32	1.50	1.15	2.15	1.93	1.18	.64	.36	.96	12.87
1927-28	.65	.77	1.70	1.20	.55	.39	.71	1.67	.60	1.57	.47	1.32	11.60
1928-29	.16	.27	.85	2.13	.44	.49	1.21	1.70	2.57	.71	.74	2.48	13.75
1929-30	1.19	1.32	.80	.05	.51	2.48	1.24	2.05	.86	2.74	T	1.40	14.64
1930-31	3.92	2.48	1.23	1.28	.10	.24	.76	.79	.99	.52	T	.30	12.61
1931-32	.37	.15	T	2.01	1.07	1.25	1.21	1.78	.92	.62	1.00	.92	11.30
1932-33	1.35	T	1.37	.40	1.62	.79	.46	1.08	1.67	2.89	.11	.60	12.34
1933-34	.76	.16	.30	.71	.98	.81	1.70	.18	.53	.05	.38	.15	6.71
1934-35	.41	.17	.65	2.17	1.04	.64	.65	1.49	1.86	2.82	T	.67	12.57
1935-36	.97	T	.03	.48	1.10	1.43	3.51	1.80	.71	.26	2.32	3.30	15.91
1936-37	.96	.35	1.54	T	2.04	.89	1.11	1.46	1.23	1.62	.04	1.05	12.29
1937-38	.33	.93	1.27	.33	1.85	.44	1.63	2.49	1.34	2.02	.71	.15	13.49
1938-39	.28	1.43	1.43	1.51	.92	1.07	1.06	.70	.86	1.18	.53	.34	11.31
1939-40	.26	2.76	2.24	.07	.24	2.72	2.78	1.76	1.98	T	.22	.17	15.20
1940-41	.18	1.58	1.26	1.09	.92	1.90	1.65	2.49	2.64	1.63	2.17	1.05	18.56
1941-42	1.36	.87	3.89	.78	2.31	.39	.99	1.79	.97	1.81	T	.52	15.68
1942-43	T	.17	1.10	1.44	.45	.51	.79	1.17	.33	1.36	2.83	.80	10.95
1943-44	.81	.31	2.06	.42	1.03	2.08	1.16	3.15	3.65	1.09	1.92	.06	17.74
1944-45	-	.07	.42	2.04	.53	.43	1.79	2.84	1.38	1.05	2.00	.88	13.43
1945-46	2.20	.59	1.06	.88	1.65	1.03	.32	1.01	1.55	2.23	T	.62	13.14
1946-47	2.85	.08	5.00	2.45	1.70	1.36	1.13	.82	1.90	.70	1.63	.40	20.02
1947-48	1.59	.60	2.31	1.73	.92	.19	.97	2.47	.76	.18	1.52	.20	13.44
1948-49	.74	.16	.50	.84	2.58	1.85	.34	1.42	.44	2.88	.83	.35	12.93
Average	1.06	.94	1.40	1.08	1.29	1.23	1.27	1.60	1.41	1.42	.71	.85	14.26

T = Trace

Appendix table 3. Monthly mean temperature for Levan, Juab County, Utah, for the period August 1907 to July 1949

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July	Annual
1907-08	67.0	59.0	52.0	36.1	30.5	27.7	31.5	39.1	48.4	50.0	59.1	71.0	46.3
1908-09	66.8	58.4	44.0	35.6	24.5	32.6	30.2	37.5	43.6	51.4	66.2	71.0	47.2
1909-10	70.1	59.2	49.7	37.9	17.2	26.0	27.4	46.4	50.4	56.6	67.8	73.8	50.1
1910-11	71.0	62.8	48.6	41.7	29.2	29.4	26.2	41.2	45.0	55.3	65.3	70.6	47.1
1911-12	70.6	61.7	45.8	31.8	22.0	26.3	32.2	37.0	42.6	52.2	64.4	69.6	46.1
1912-13	69.2	53.8	45.4	36.8	23.3	21.2	26.8	34.0	47.8	56.8	63.8	70.0	46.5
1913-14	70.2	58.3	45.0	39.4	25.0	30.0	28.9	41.8	48.0	57.0	61.6	69.7	48.9
1914-15	71.8	61.2	50.2	39.2	27.5	22.5	31.0	37.9	42.6	49.8	63.0	70.8	47.1
1915-16	69.7	58.8	51.0	39.3	28.8	23.9	32.5	42.4	48.8	51.0	62.6	70.0	46.5
1916-17	67.0	60.2	46.1	31.6	22.3	12.9	25.0	30.4	43.2	49.6	61.8	73.6	45.8
1917-18	68.6	61.8	49.5	38.0	35.5	24.7	27.3	42.0	44.0	53.2	70.2	70.1	47.2
1918-19	68.8	61.2	50.4	31.8	23.0	22.9	30.7	37.1	48.8	59.6	68.2	75.6	48.0
1919-20	71.8	63.0	41.9	35.6	20.4	24.6	32.5	36.0	41.2	55.2	65.9	72.2	47.1
1920-21	68.2	59.6	46.6	37.1	25.7	28.8	33.2	42.3	43.4	53.9	65.2	71.1	49.5
1921-22	68.0	58.4	54.6	40.2	35.4	17.2	31.6	33.6	42.0	53.7	67.4	71.4	46.6
1922-23	71.3	65.2	50.3	34.8	30.3	30.2	21.8	33.2	45.6	56.2	60.2	71.6	46.4
1923-24	67.8	58.0	44.5	41.3	26.2	18.3	35.8	32.7	46.1	57.6	66.6	73.0	47.6
1924-25	71.2	61.6	49.2	38.8	20.0	20.4	33.6	41.8	49.5	59.5	61.6	73.0	48.8
1925-26	69.2	61.2	48.2	37.0	30.2	24.4	34.7	41.1	51.0	58.8	68.0	71.3	50.0
1926-27	71.0	61.0	52.2	42.4	24.4	28.6	32.8	39.2	47.6	52.8	65.0	72.9	49.3
1927-28	69.5	62.4	53.0	43.2	25.2	28.4	32.6	43.2	45.3	58.8	63.0	73.0	49.3
1928-29	70.4	63.7	52.8	37.7	22.8	24.0	23.9	37.3	43.9	54.3	62.6	72.2	47.4
1929-30	70.6	60.3	50.9	35.1	33.4	20.5	34.8	39.8	53.3	51.8	64.4	72.9	46.9
1930-31	68.8	60.3	46.8	31.2	18.6	24.4	34.8	39.2	50.6	55.2	68.6	76.7	49.9
1931-32	72.9	63.9	54.6	35.2	22.0	19.7	30.9	39.0	47.6	55.7	63.0	72.1	47.8
1932-33	72.0	63.2	49.4	41.8	19.8	24.0	17.4	38.1	44.2	49.8	67.8	74.8	48.3
1933-34	69.3	65.6	55.2	39.4	34.2	31.4	40.8	48.0	54.2	63.2	65.2	76.8	53.2
1934-35	74.1	61.4	53.0	41.8	28.7	31.1	36.0	37.5	47.1	52.0	65.0	72.0	49.1
1935-36	71.6	64.6	49.4	35.6	27.8	27.2	31.2	39.2	50.7	58.8	65.8	70.8	49.2
1936-37	69.6	59.8	50.4	36.4	31.0	11.2	28.9	40.4	45.5	59.0	62.4	71.8	48.7
1937-38	73.2	64.6	51.6	41.5	33.9	32.9	34.0	39.5	49.2	54.1	65.6	69.4	49.2
1938-39	71.2	64.6	50.5	29.4	30.6	26.4	20.6	40.2	51.2	57.9	63.2	72.9	49.6
1939-40	73.1	62.6	49.1	42.1	36.2	27.8	34.0	42.9	48.8	60.4	67.8	72.6	50.7
1940-41	72.4	62.8	52.2	35.3	31.2	29.5	35.8	41.2	43.6	56.0	60.6	68.6	48.3
1941-42	67.8	57.0	47.3	39.4	32.8	24.5	25.4	35.2	48.6	51.6	63.8	71.8	48.0
1942-43	70.4	62.4	51.0	37.6	33.5	28.8	35.6	39.2	55.2	54.6	60.8	72.6	50.7
1943-44	71.7	65.7	53.3	39.2	31.6	21.3	27.4	34.0	43.6	56.5	59.6	70.8	47.4
1944-45	70.0	64.4	53.9	37.4	30.0	30.2	34.6	37.7	44.4	56.8	58.0	71.0	48.9
1945-46	69.8	59.6	53.6	40.2	30.8	23.4	30.6	43.1	53.2	54.4	66.8	73.6	49.8
1946-47	72.4	62.7	45.4	36.8	34.8	19.2	33.8	42.7	46.8	59.0	61.4	72.0	48.9
1947-48	70.6	64.3	53.6	32.3	30.8	29.5	30.9	31.7	49.0	51.4	65.4	73.8	49.0
1948-49	72.8	67.0	52.2	33.5	24.7	11.0	21.2	39.3	52.5	56.3	63.2	72.1	47.6
Average	70.3	61.6	49.9	37.4	27.8	24.7	30.5	38.9	47.3	55.3	64.2	72.1	48.3

Appendix table 4. Yield of winter wheat by the summer fallow cropping system at the Nephi Dry-land Experimental Farm for the period 1908 to 1949.

Harvest year	Yield (bushels/acre)	Harvest year	Yield (bushels/acre)
1908	27.5	1929	15.2
1909	4.6	1930	23.5
1910	13.7	1931	6.5
1911	30.0	1932	22.3
1912	14.7	1933	18.8
1913	2.0	1934	12.3
1914	39.3	1935	18.2
1915	44.8	1936	20.8
1916	23.5	1937	24.5
1917	28.2	1938	32.2
1918	16.3	1939	15.5
1919	12.8	1940	32.3
1920	20.8	1941	38.5
1921	34.9	1942	21.5
1922	16.5	1943	22.3
1923	25.7	1944	28.0
1924	21.5	1945	24.3
1925	32.7	1946	21.8
1926	38.2	1947	24.7
1927	19.3	1948	26.2
1928	33.3	1949	23.7

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