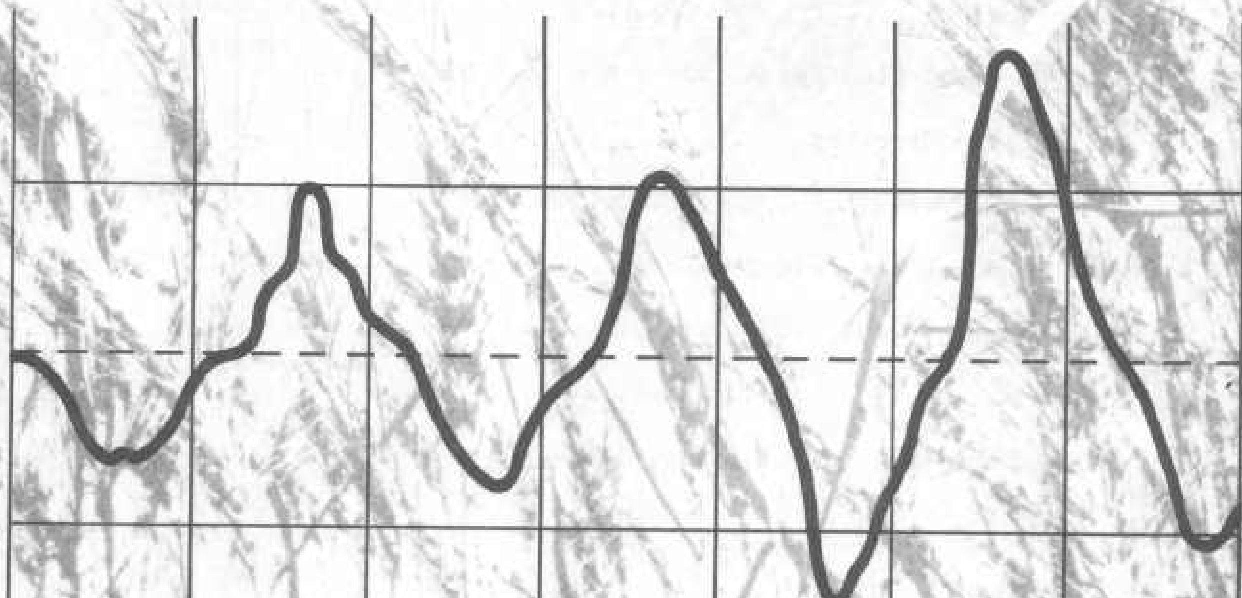
DO SUNSPOT CYCLES AFFECT CROP YIELDS?

by Virden L. Harrison

AGRICULTURAL ECONOMIC REPORT NO. 327
ECONOMIC RESEARCH SERVICE
U.S. DEPARTMENT OF AGRICULTURE



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ABSTRACT

Sunspot activity occurs on a regular cyclical basis. Temperature, precipitation, length of growing season, radiation levels, atmospheric pressure, and high-altitude wind speed in the United States and elsewhere may be related to the single or double sunspot cycle. This study tests the hypothesis that crop yields at the State level are related to various phases of the sunspot cycle. Crops and States included are wheat in Texas and Kansas, corn in Illinois and Nebraska, rice in Louisiana, and cotton in Texas. Statistical analysis was made of data for 1866-1973. Results indicate that (1) lower than average yields are associated with low sunspot activity, especially low activity following the high of the minor sunspot cycle (2) higher than average yields are associated with high sunspot activity, and (3) both the single and double sunspot cycles may give useful information in predictions of yield deviations.

Keywords: Sunspots, crop yields, projections, weather.

CONTENTS

Washington, D.C. 20250

April 1976

SUMMARY

Sunspot activity may affect crop yields and sunspot cycles may help us predict yield deviations. Preliminary studies were made for 1866 through 1973 of wheat in Texas and Kansas, corn in Illinois and Nebraska, rice in Louisiana (1895-1972), and cotton in Texas. Lower than average yields are associated with low sunspot activity, especially when it follows the high of the minor sunspot cycle. Higher than average yields appear to occur during high sunspot acitivity. A double sunspot cycle contains two single cycles. These alternate in intensity and are referred to as major and minor cycles.

What percentage changes in crop yields occurred that may be associated with sunspot activity? Texas wheat yields declined 7 percent in periods of low sunspot activity while output rose 4 percent during highly active periods. For Kansas wheat, results were not consistent enough to hypothesize a relationship. Corn yields in Illinois averaged a drop of about 8 percent in the year of lowest sunspot activity in each single cycle. Years of high sunspot activity were associated with higher than average yields. Nebraska corn responded the most during the double not the single sunspot cycles. Yields dropped 10.4 percent below average in years of low sunspot activity that followed the sunspot high in the minor cycle. They rose 10 percent in the 3 years of highest sunspot activity during the minor sunspot high. For Louisiana rice, yields declined in years of less sunspot activity and they rose when sunspot activity increased. No consistent relationship emerged for Texas cotton.

DEFINITIONS

Sunspots. Sunspots are cool areas on the surface of the sun that look dark in relation to the bright surface. They come in pairs, rotate like giant hurricanes, and have very strong magnetic fields. Sunspot numbers are indexes that take into account the number of spots and the number of groups of spots moving across the face of the sun. A continuous record has been kept of sunspot numbers since about 1610.

Sunspot cycles. Sunspot activity occurs on a regular cyclical basis. Figure 1 shows the sunspot numbers since 1755. Since 1750, the single sunspot cycle has averaged about 11 years in length (10.5 since 1900), ranging from 7.5 to 16.5 years between highs and 9.0 to 13.0 years between lows. On the average, about 6.4 years lapse between the high and low point and 4.6 years between the low and high point.

Double sunspot cycle. The double sunspot cycle contains two single cycles. Some authors plot each alternative cycle negatively (figs. 2 and 3) because recent cycles have alternated in magnitude and because magnetic polarity of the sun is believed to reverse each 10-11 years. Average length of the double cycle has been about 22 years since 1610 but closer to 21 years since 1900. Since 1750, about 10.75 years have elapsed between high positive years and 11.20 years between low negative years. Both the high positive and low negative points on the double cycle are high points on alternative single cycles.

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INTRODUCTION

In 1974, sunspot activity was nearing the low point of a cycle. That year, drought and other unusual weather conditions resulted in abnormally low yields for U.S. corn, barley, oats, sorghum, soybeans, and, to some extent, wheat. Some scientists have suggested that sunspot activity and crop yields are related. This paper discusses views on sunspot cycles, sets forth the hypothesis that sunspot cycles affect crop yields, and presents a preliminary study of the relation of crop yields to various stages of the sunspot cycle.

SOME PREVIOUS FINDINGS ON SUNSPOT ACTIVITY

Various authors have concluded that sunspot activity affects temperatures, precipitation, length of growing season, air circulation, atmospheric pressure, high-altitude wind speed, and other phenomena in various parts of the United States and the rest of the world.

According to J. Murray Mitchell, terrestrial climate may vary on a similar wave length to the 11-year sunspot cycle. But he concludes:

> And yet, although we know that solar activity is responsible for important events in the earth's ionosphere, I believe it is fair to say that no one has proved beyond a reasonable doubt that <u>surface climate</u> is also responsive to variable solar activity (<u>1</u>, p.211).<u>1</u>/

Mitchell does suggest a continued search for relationships between solar activity and weather.

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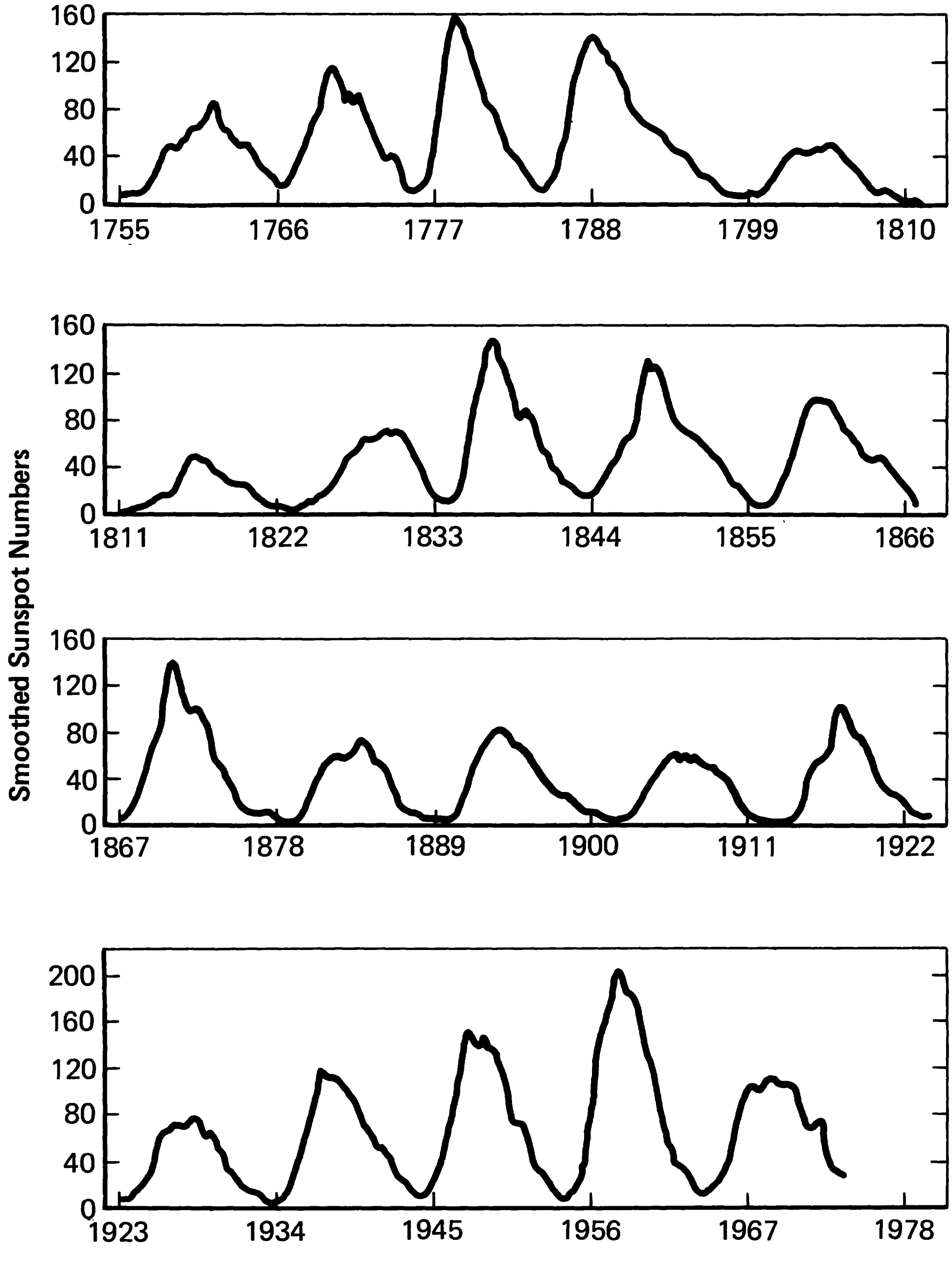
*Agricultural Economist with the Commodity Economics Division, Economic Research Service, stationed at Clay Center, Nebraska. Research reported herein was conducted while the author was with the Economic Projections and Analytical Systems Program, National Economic Analysis Division, ERS, Washington, D.C.

<u>1</u>/ Underscored numbers in parentheses refer to items in Bibliography at the end of this report.

ZURICH SUNSPOT NUMBERS, 1755-1974



Source: Miller, Viola. World Data Center for Solar-Terrestrial Physics, National Oceanic and Atmospheric Admin., Boulder, Colo.

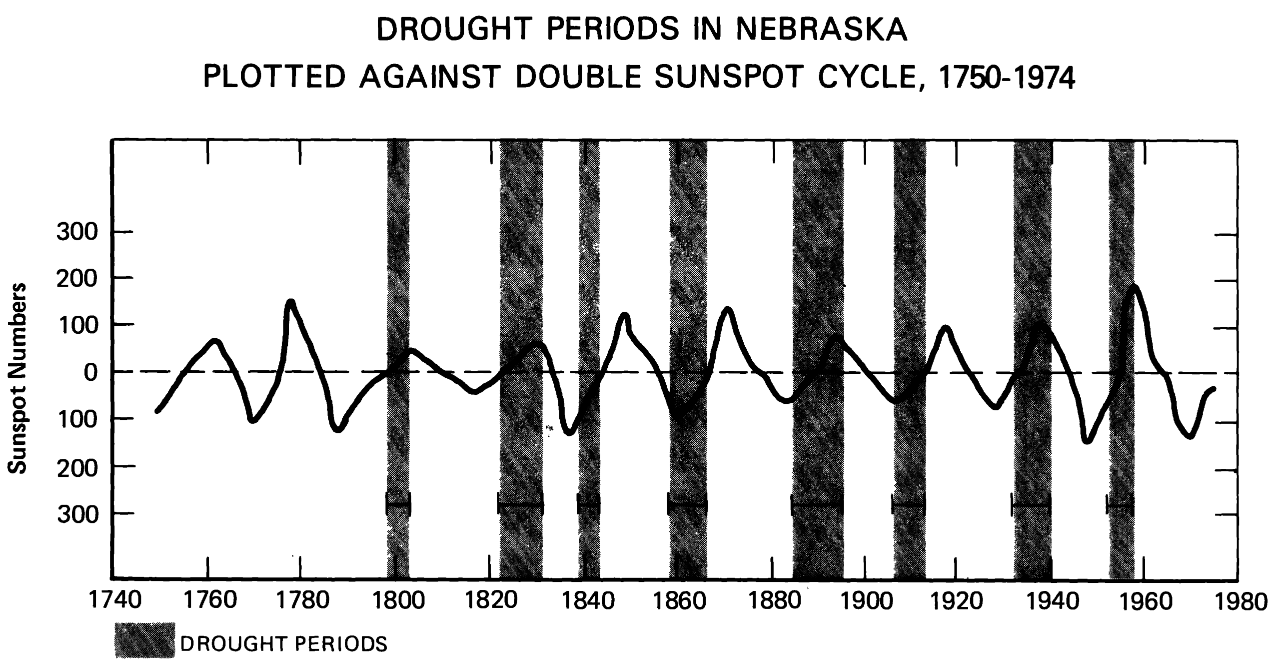
Figure 1

Louis M. Thompson noted a "remarkable" correlation between July-August temperature variability in the Corn Belt and the 20-22 year double sunspot cycle (2). But the relation is confused somewhat by what appears to be a 2-year cycle superimposed on the double sunspot cycle. Using drought data for Nebraska from tree ring studies by Weakly (3), Thompson also compared drought periods in Nebraska to the double sunspot cycle (fig. 2). He suggested:

> If one is interested in betting on the odds of severe drought occurring in the Corn and Wheat Belts in the mid-seventies, he has, to support his confidence, the occurrence of 8 drought periods in succession, all following the peak of the minor maximum and extending through the following quiet years toward the peak of the major cycle (2, p. 89).

Thompson also suggested that droughts spread or migrate northward gradually for several years, so that a drought beginning in Texas may reach Nebraska or Kansas 3 to 4 years hence.

Another author, J.W. King, suggests that "the apparently very strong connection between the solar cycle and the weather is not generally appreciated (4)." He presents evidence that important climatic features such as drought, rainfall, and length of the growing season depend on the solar cycle. He quotes Gloyne (5), who concluded from 1914-71 data at Eskdalemuir in the



Source: Roberts, Walter O., Relationships Between Solar Activity and Climate Change, Univ. Corp. for Atmospheric Res., Boulder, Colo., Nov. 1973.

Figure 2

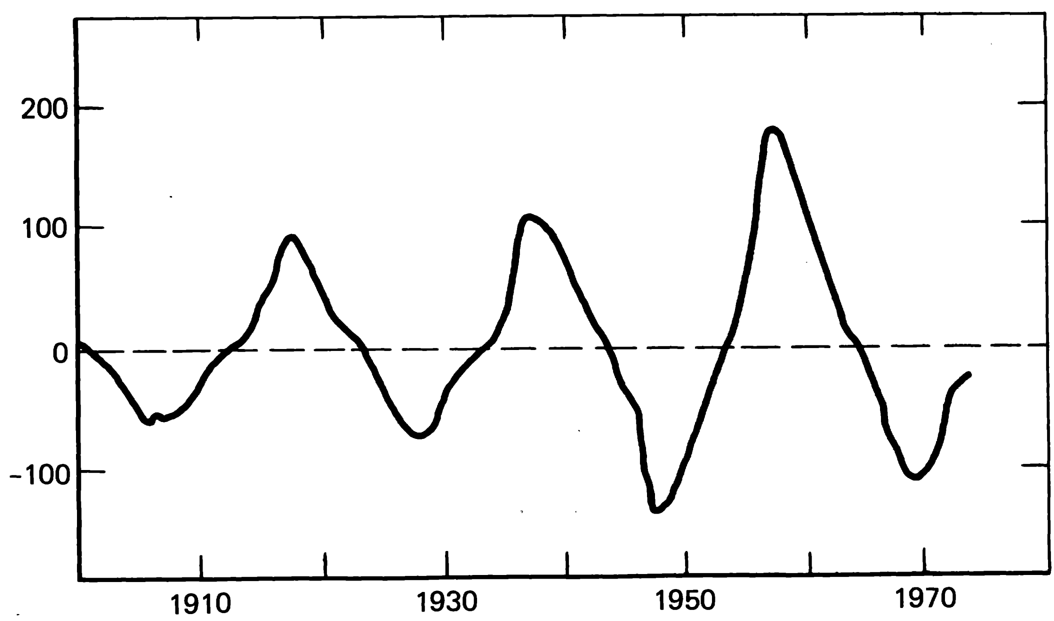
United Kingdom that the growing season is about 25 days longer near sunspot maximum than near sunspot minimum and it tends to be longest approximately a year after the maximum. From this conclusion, King inferred that the solar cycle influences temperatures in spring rather than in autumn.

King also cites other studies showing relationship between the sun and the weather. Winstanley's study of 1951-69 data concludes that rainfall at Beirut is highly negatively correlated with solar activity (6). The rainfall was low for several years, centered about a year after sunspot maximum. From a study of monthly rainfall in England for 1697-1970 done by Wales-Smith (7), King concluded that abnormal rainfall in spring occurs at the extremes of the solar cycle; the driest springs tend to occur near sunspot maximum, the wettest springs around sunspot minimum. And he notes Baur's study that in the North-eastern United States and North-Central Europe, severe winters are more likely to occur when sunspot activity is at a minimum or maximum (8).

According to King, it is well established that the density and temperature of the atmosphere above about 100 km vary markedly with solar activity during the 27-day solar rotation periods and the 11-year solar cycles. Though such effects in the upper atmosphere are well known, the physical mechanisms by which corresponding effects might be produced at lower levels are not clear. Some evidence suggests, however, that solar radiation in the form of energetic particles may influence the surface weather.

Double sunspot cycles also receive attention. Walter O. Roberts gives three reasons why we should consider the double sunspot cycle of 20-22 years

DOUBLE SUNSPOT CYCLE, 1900-1974



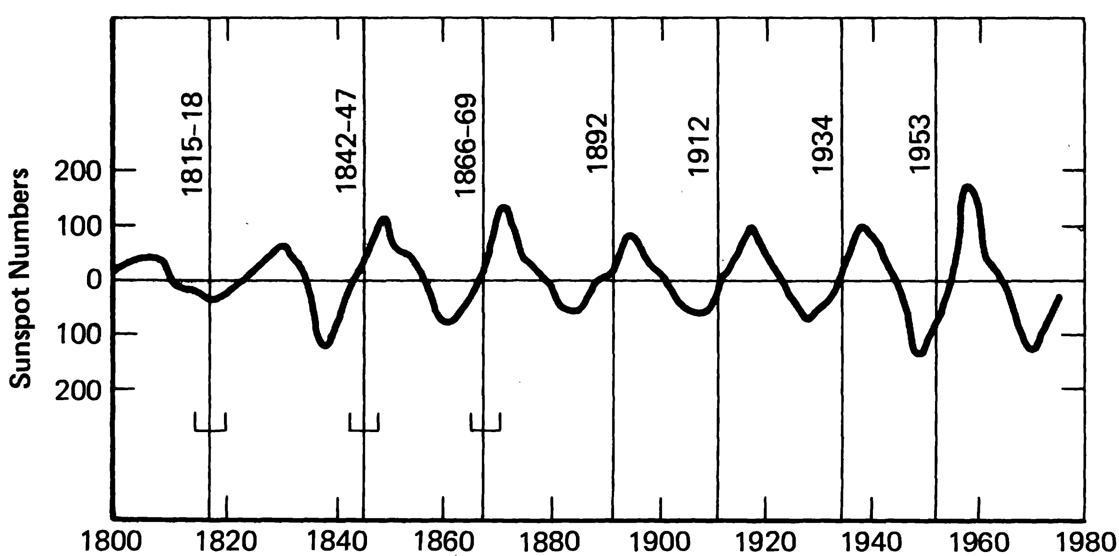
Source: Roberts, Walter O., Relationships Between Solar Activity and Climate Change, Univ. Corp. for Atmospheric Res., Boulder, Colo., Nov. 1973.

Figure 3

in addition to the 10-11 year cycle (9). First, the magnetic fields of the leader spots of sunspot pairs are opposite in opposite hemispheres of the sun during a given 10-year cycle, but both fields reverse at the start of a new cycle. Second, the polarity of the magnetic field of the sun near the poles is generally believed to reverse each 10 or 11 years (though there is some irregularity as to the exact time of reversal). Third, for recent 10-11 year sunspot cycles, every other one has tended to be larger in magnitude.

For Roberts, recent research findings of regularly recurring droughts in the high plains area of the United States rank among findings with the soundest empirical statistical evidence that solar activity influences climate. He notes a striking tendency for the droughts to recur about every 20-22 years. These droughts relate with reasonable constancy to the alternative minima of the solar activity cycle (fig. 2). According to Marshall, all the major droughts of the available time period (1800 to date) came remarkable close to the solar activity minima that followed the minor peaks (10 and fig. 4). In other words, a drought normally occurs just after the low point following the negatively plotted high of the double cycle. Figure 4 is adapted from Marshall's Ph.D. thesis (10). The vertical lines correspond to the center dates of all droughts cited by Marshall from rainfall data over the high plains region. The three earlier droughts are less reliably determined; for them, the horizontal bars show approximate beginning and ending dates. Note that every drought occurs near the sunspot minimum following the negatively plotted sunspot maximum.

HIGH PLAINS DROUGHTS
AND THE DOUBLE SUNSPOT CYCLE, 1800-1974



Source: Roberts, Walter O., Relationships Between Solar Activity and Climate Change, Univ. Corp. for Atmospheric Res., Boulder, Colo., Nov. 1973.

Figure 4

Roberts speculates that if drought in the high plains reoccurs according to its historical pattern, and if the double sunspot cycle is 21 years in length (as it has averaged recently), a high plains drought would begin in 1973. None occurred that year, but he suggests it might have been delayed a year or so because of an unusual flareup of sunspot activity in 1972. He speculates that if the drought is delayed the same length of time that the sunspot minimum is delayed, this development could strengthen the hypothesis that droughts are causally connected to solar activity. It is too early to tell if the rainfall shortage in Iowa, Kansas, and other States occurring in the summer and fall of 1975 will turn out to be a real drought.

On the subject of the relation of solar activity to temperature changes, Roberts quotes Lamb's opinion that warmer weather in most regions appears to have occurred significantly more often during the years of high solar activity (11, p. 443 ff.). Roberts also quotes Bray:

> 75-80 percent of all known glacier advance events and other indicators of cold climate in late glacial and post-glacial time occurred during intervals of weak solar activity, and a similar percentage of glacier recession and warm climate indicators occurred with high solar activity (12).

Concerning atmospheric pressure and its relation to solar activity, Roberts reports that Wexler confirmed others' findings that high latitudes show higher average pressures at sunspot maximum than at minimum (13). H.C. Willett, using several indicators of solar activity, concluded that at high solar activity there is a mass displacement of air toward high latitudes (14).

The possible relation of crop yields and sunspots has been studied to some extent already. Using data on aggregate U.S. corn yields from 1866 to 1973, Jerry A. Sharples tested the hypothesis that yields during the increasing half of the double sunspot cycle did not differ significantly from those in the remainder of the cycle (15). After dividing the data into three sections based on apparent linear yield trends--1866-1940, 1941-60, and 1961-73--he computed the deviations from the linear regression line. The mean corn yield was 0.81 bushel per acre lower in the increasing phase than in other years of the cycle. He also compared yields for the first half of the increasing phase of the double sunspot cycle with remaining years in the cycle. Yields were 0.87 bushel per acre lower in the first half of the increasing phase than in the remainder of the cycle. Neither of these differences, however, differed significantly from zero.

TESTING THE HYPOTHESIS

Methodology

This study examines the relation of crop yields to sunspot activity for wheat in Texas and Kansas, corn in Illinois and Nebraska, rice in Louisiana, and cotton in Texas. Data used were from 1866-1973 for wheat, corn and cotton, and 1895-1972 for rice.

Yield data were plotted, observed, and divided into periods based on apparent linear trends. Linear regressions were applied to each period and the deviations from the regression line computed. Table 1 shows the periods, average yields, and slopes for the crops and States involved. These deviations were compared with various stages of the sunspot cycle. The following data--number of negative deviations, sum, mean, s^2, and t value--were calculated for the years associated with the phases of the sunspot cycle listed below:

Year of single cycle low point and each of the 9 years following.

Year of single cycle high point and each of the 9 years following.

Year of double cycle low point and each of the 9 years following.

Year of double cycle high point and each of the 9 years following.

Three consecutive years beginning with the year of the single cycle low point.

Three consecutive years beginning with the year of the single cycle high point.

Three consecutive years beginning with the year of the double cycle low point.

Three consecutive years beginning with the year of the double cycle high point.

Three lowest years of the single cycle.

Three highest years of the single cycle.

Three lowest years of the double cycle.

Three highest years of the double cycle.

T-values were used to compare the mean value of years corresponding to a given stage of the sunspot cycle with zero, the mean;2/ and also with the mean values for other stages of the cycle.

Results for each crop in each State are discussed, followed by some observations common to several crops or States.

Findings for Selected Crops

Texas Wheat

Between 1866 and 1973, 10 single sunspot cycles of about 11 years each occurred. If these cycles are averaged, the mean wheat yield deviation

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2/ The mean of all observations is zero by definition, since the observations are deviations around a linear regression line.

Table 1.--Yields, slopes, and variances, selected States and crops, 1866-1973

State and crop	Period	Number of years	Average yield per acre		Yield increase per year (slope)	Yield variance	Yield standard deviation
Texas wheat	1866-1951	86	11.19	12.69 bu.	0.007	8.7	2.95
	1952-1973	22	18.55		.691	29.8	5.46
		108					
Kansas wheat	1866-1926	61	13.77	15.78 bu.	-.031	8.9	2.98
	1927-1953	27	14.06		.185	11.0	3.31
	1954-1973	20	24.21		.897	48.1	6.93
		108					
Illinois corn	1866-1932	67	33.71	44.84 bu.	.128	34.5	5.87
	1933-1955	23	47.04		1.133	112.1	10.59
	1956-1973 1/	17	85.76		2.707	238.1	15.43
		107					
Nebraska corn	1866-1932	67	28.50	33.45 bu.	-.175	57.6	7.59
	1933-1955	23	23.97		.956	87.5	9.36
	1956-1973 1/	17	65.76		3.723	440.7	20.99
		107					
Louisiana rice	1895-1951	57	1,615	2,003 lb.	10.40	53,002	230
	1952-1972 2/	20	3,110		94.80	368,381	607
		77					
Texas cotton	1866-1922	57	186.1	208.3 lb.	-1.50	1,871	43.3
	1923-1947	25	153.8		1.90	745	29.3
	1948-1961	14	265.3		14.15	4,807	69.3
	1962-1973	12	361.3		.15	2,589	50.9
		108					

1/ Excludes 1970, the corn blight year.

2/ Excludes 1969 and 1973, years of hurricane damage.

SOURCE: See appendix.

associated with certain stages of the cycle differs significantly both from zero and from certain years associated with other parts of the cycle. For example, the yield in SL1, the year following the single sunspot cycle low, was 1.81 bushels per acre less than the mean of all observations and 2.53 bushels less than the yield in SH1, the year following the single cycle high (table 2). And yields in the first 3 years beginning with the single cycle low (SL0-SL2) were 1.31 bushels per acre lower than those in the first 3 years beginning with the single cycle high (SH0-SH2). These differences are significant at the 90-percent level.

There have been only five double sunspot cycles since 1866. When groups of years associated with the rising portion of the double cycle 3/ are compared with groups of years associated with the falling portion, negative yield deviations are associated with the rising portion and positive yield deviations with the falling portion (table 2). Yield in the first 3 years of the rising and falling stages differed little. But in the first 5 years of the rising stage (DL0-DL4), they averaged 1.22 bushels less than in the first 5 years of the falling stage (DH0-DH4). And yields in the first 9 years of the rising stage averaged 1.47 bushels less than in the corresponding years of the falling stage. About 64 percent of the yield deviations in the first 5 years and 62 percent in the first 9 years of the rising portion were negative. But 72 percent of the yield observations in the 4th through 8th year of the rising stage (DL3-DL7) were negative, compared with only 44 percent in the 4th through 8th year of the falling stage (DH3-DH7).

The variance of the observations in most cases is high, indicating that factors other than sunspots have a strong yearly effect on yields. But over time sunspots could be a factor.

In summary, lower than normal yields appear during low sunspot activity, and higher than average yields are associated with high sunspot activity. Both the single and double sunspot cycles may give useful information for predicting yield deviations.

Kansas Wheat

Though the difference is not statistically significant, Kansas wheat yields associated with 10 single sunspot cycles averaged 0.83 bushel per acre lower in the 3 years of lowest sunspot activity (RSL3) than in the 3 years of highest activity (RSH3) (table 3). About 59 percent of observations were negative during the 3 lowest sunspot years while only 40 percent were negative during the 3 highest sunspot years. Yields in the 5 years beginning with the sunspot low (SL0-SL4) are 0.58 bushel lower than in the corresponding 5 years beginning with the sunspot high. But again, this difference is not significant.

3/ Recall that the double cycle is plotted such that each alternative single cycle is plotted negatively (figures 2 and 3) so that the low point of the double cycle is the high point of alternative single cycles.

Table 2.--Crop yield-sunspot relationships for Texas wheat, 1866-1973

Stage of sunspot cycle 1/	Observations 2/	Negative observations	Sum	Mean	s^2	T-value 3/
All observations	108	60	0	0	8.78	0
SL0	10	5	-1.81	-.18	12.65	-.16
SL1	10	7	-18.14	-1.81	9.90	-1.82
SL2	10	6	-5.48	-.55	9.30	-.57
SL3	10	6	3.17	.32	13.67	.27
SL4	10	6	2.96	.30	5.19	.41
SL0-SL2	30	18	-25.43	-.85	10.39	-1.44
SL0-SL4	50	30	-19.30	-.64		
SH0	10	8	.75	.08	3.10	.13
SH1	10	3	7.19	.72	7.79	.81
SH2	10	4	5.87	.59	7.69	.67
SH3	10	5	4.83	.48	8.27	.53
SH4	10	8	-6.12	-.61	10.10	-.61
SH0-SH2	30	15	13.81	.46	5.84	1.04
SH0-SH4	50	28	12.52	.25		
DL0	5	4	2.02	.40	5.76	.38
DL1	5	1	4.79	.96	2.56	1.34
DL2	5	2	.38	.08	5.56	.07
DL3	5	4	-3.44	-.69	9.75	-.49
DL4	5	5	-12.77	-2.55	.81	-6.35
DL5	5	1	3.42	.68	8.81	.52
DL6	5	4	-7.79	-1.56	2.98	-2.02
DL7	5	4	-12.22	-2.44	8.97	-1.82
DL8	5	3	-5.75	-1.15	17.13	-.62
DL0-DL2	15	7	7.19	.48	4.11	.92
DL0-DL4	25	16	-9.02	-.36		
DL0-DL8	45	28	-31.36	-.70		
DH0	5	4	-1.27	-.25	.94	-.59
DHL	5	2	2.40	.48	14.83	.28
DH2	5	2	5.49	1.10	11.09	.74
DH3	5	1	8.27	1.65	5.44	1.59
DH4	5	3	6.65	1.33	12.49	.84
DH5	5	2	5.53	1.11	13.80	.67
DH6	5	4	-2.78	-.56	.96	-1.27
DH7	5	1	18.00	3.60	15.64	2.04
DH8	5	3	-7.62	-1.52	7.80	-1.22
DH0-DH2	15	8	6.62	.44	8.00	.60
DH0-DH4	25	12	21.54	.86		
DH0-DH8	45	22	34.67	.77		
RSL3	29	19	-19.29	-.67	10.58	-1.10
RSH3	30	14	16.97	.57	5.58	1.31
RDL3	15	7	5.33	.36	4.31	.66
RDH3	15	7	11.64	.78	7.15	1.12

1/ The 3-digit code refers to stage of the sunspot cycle. S means single cycle, D means double cycle, L means low point of the cycle, H means high point, 0 is the year of the low or high, 1 is the first year following the low or high, 2 is the 2nd year following the low or high, and so on. For example, SL0 is the single cycle low year and DH4 is the 4th year following the double cycle high year. The 4-digit code has the following meaning: RSL3 is the 3 lowest years of the single cycle, RSH3 is the 3 highest years of the single cycle, RDL3 is the 3 lowest years of the double cycle, and RDH3 is the 3 highest years of the double cycle.
2/ Observations are deviations from a linear regression of yield data in 2 segments: 1866-1951 and 1952-73.
3/ T-values are for comparisons of the mean of all observations (zero by definition) with a cycle year.
SOURCE: See appendix.

Table 3.--Crop yield-sunspot relationships for Kansas wheat, 1866-1973

Stage of sunspot cycle 1/	Observations 2/	Negative observations	Sum	Mean	s^2	T-value 3/
			Bushels			
All observations	108	54	0	0	10.09	0
SL0	10	5	.13	.01	9.33	.01
SL1	10	6	-4.16	-.42	11.99	-.38
SL2	10	6	-15.74	-1.57	10.64	-1.53
SL3	10	5	-5.61	-.56	13.62	-.48
SL4	10	5	7.07	.71	16.42	.55
SL0-SL2	30	17	-19.77	-.66	10.38	-1.12
SL0-SL4	50	27	-18.31	-.37		
SH0	10	4	2.37	.24	9.08	.25
SH1	10	2	12.48	1.25	11.89	1.14
SH2	10	7	-17.21	-1.72	7.68	-1.96
SH3	10	4	14.30	1.43	10.15	1.42
SH4	10	6	-1.30	-.13	6.83	-.16
SH0-SH2	30	13	-2.36	-.08	10.46	-.13
SH0-SH4	50	23	10.64	.21		
DL0	5	1	9.36	1.87	8.76	1.41
DL1	5	0	8.45	1.69	1.81	2.81
DL2	5	3	-6.45	-1.29	10.94	-.87
DL3	5	3	4.14	.83	13.02	.51
DL4	5	4	-7.96	-1.59	5.24	-1.56
DL5	5	2	4.73	.95	11.86	.61
DL6	5	3	.92	.18	17.57	.10
DL7	5	2	-2.47	-.49	5.84	-.46
DL8	5	4	-3.25	-.65	2.90	-.85
DL0-DL2	15	4	11.36	.76	8.40	1.01
DL0-DL4	25	11	7.54	.30		
DL0-DL8	45	22	7.47	.17		
HD0	5	3	-6.99	-1.40	4.98	-1.40
DH1	5	2	4.03	.81	24.45	.36
DH3	5	4	-10.76	-2.15	5.87	-1.99
DH3	5	1	10.16	2.03	8.90	1.52
DH4	5	2	6.66	1.33	4.79	1.36
DH5	5	1	8.67	1.73	4.05	1.93
DH6	5	4	-9.42	-1.88	2.50	-2.67
DH7	5	2	5.30	1.06	9.45	.77
DH8	5	2	-.70	-.14	8.53	-.11
DH0-DH2	15	9	-13.72	-.91	11.77	-1.03
HD0-DH4	25	12	3.10	.12		
DH0-DH8	45	21	6.95	.15		
RSL3	29	17	-10.27	-.35	7.48	-.70
RSH3	30	12	14.51	.48	10.24	.83
RDL3	15	4	18.32	1.22	8.65	1.61
RDH3	15	8	-3.81	-.25	11.40	-.29

1/ The 3-digit code refers to stage of the sunspot cycle. S means single cycle, D means double cycle, L means low point of the cycle, H means high point, 0 is the year of the low or high, 1 is the first year following the low or high, 2 is the 2nd year following the low or high, and so on. For example, SL0 is the single cycle low year and DH4 is the 4th year following the double cycle high year. The 4-digit code has the following meaning: RSL3 is the 3 lowest years of the single cycle, RSH3 is the 3 highest years of the single cycle, RDL3 is the 3 lowest years of the double yccle, and RDH3 is the 3 highest years of the double cycle.
2/ Observations are deviations from a linear regression of yield data in 3 segments: 1866-1926, 1927-53, and 1953-73.
3/ T-values are for comparisons of the mean of all observations (zero by definition) with a cycle year.
SOURCE: See appendix.

Comparisons with increasing and decreasing stages of the double cycle show little differences. While for some individual years, yields differed significantly from the overall average, behavior in these years is usually interspersed, and inconsistent with behavior in adjacent years.

As with Texas wheat, low sunspot activity may be associated with lower than average yields and high activity may be associated with higher than average yields. But the high yield variability and limited numbers of observations make any conclusion tentative.

Illinois Corn

As shown in table 4, low yields appear in the year of the lowest sunspot activity (SL0) and the 2 to 4 years immediately following. The lowest average yield occurs in the year of lowest sunspot activity (8 of the 10 observations were negative in that year). Conversely, higher than average yields come during years of high sunspot activity, and the highest yield occurs in the 2 years following the highest sunspot activity (SH1) and (SH2).

Specifically, Illinois corn yield deviations for the year of the sunspot low were 3.89 bushels per acre below the average, a figure significantly different from zero. And the yields in the year following the sunspot high were 2.10 bushels above the average; this finding also differed significantly from zero. Furthermore, the yields for the 3 years beginning with the year of the sunspot low were 2.69 bushels below and significantly different from the yield for the 3 years beginning with the year of the sunspot high (compare SH0-SH2 with SH0-SH2 in table 4).

As for the double sunspot cycle, corn yields were lower during the increasing phase than in the decreasing phase. Yields were especially high during the year of the double sunspot high and the 2 years following. At 2.69 bushels above the average, they were statistically different from zero at the 90-percent confidence level (DH0-DH2). And yields were also rather low in the 4-year period (DL6-DL9) 4/ associated with low sunspot activity that occurs after the negatively plotted double cycle high.

Nebraska Corn

Nebraska corn yield data give somewhat different results from the Illinois data. Since Nebraska yields were highly variable and inconsistent from one phase of the single sunspot cycle to another, they apparently do not relate to phases of the single sunspot cycle. The yield deviations associated with the year following the lowest sunspot activity (SL1) were 4.14 bushels per acre less than those associated with the year following the highest sunspot activity (SH1). But due to their high variability, yields did not differ significantly from zero nor each other (table 5). Also, the average yields associated with years adjacent to SL1 and SH1 have opposite signs; the results are therefore inconsistent.

4/ The period DL6-DL9 is not shown in the table.

Table 4.--Crop yield-sunspot relationships for Illinois corn, 1866-1973

Stage of sunspot cycle 1/	Observations 2/	Negative observations	Sum	Mean	s^2	T-value 3/
			Bushels			
All observations	107	51	0	0	33.26	0
SL0	10	8	-38.90	-3.89	19.73	-2.77
SL1	10	6	-9.55	-.95	41.86	-.47
SL2	10	3	10.17	1.02	24.80	.65
SL3	10	7	-24.28	-2.43	73.63	-.89
SL4	10	5	7.76	.78	44.30	.37
SL0-SL2	30	17	-38.28	-1.28	31.02	-1.25
SL0-SL4	50	29	-54.80	-1.10		
SH0	10	5	.30	.03	53.50	.01
SH1	10	3	21.04	2.10	11.82	1.94
SH2	9	3	19.41	2.16	45.69	.96
SH3	10	6	-14.04	-1.40	24.18	-.90
SH4	10	3	4.51	.45	34.26	.24
SH0-SH2	29	11	40.75	1.41	35.08	1.28
SH0-SH4	49	20	31.22	.64		
DL0	5	3	-13.30	-2.66	49.39	-.85
DL1	5	1	16.17	3.23	17.89	1.71
DL2	4	1	-2.54	-.63	46.25	-.19
DL3	5	3	-5.97	-1.19	5.69	-1.12
DL4	5	1	.80	.16	43.58	.05
DL5	5	2	1.75	.35	47.82	.11
DL6	5	3	-12.21	-2.44	46.46	-.80
DL7	5	3	-8.78	-1.76	24.62	-.79
DL8	5	3	-15.23	-3.05	66.40	-.84
DL0-DL2	14	5	.33	.02	38.24	.01
DL0-DL4	24	9	-4.84	-.20		
DL0-DL8	44	20	-39.31	-.89		
DH0	5	2	13.60	2.72	52.90	.84
DH1	5	2	4.87	.97	5.51	.93
DH2	5	2	21.95	4.39	42.67	1.50
DH3	5	3	-8.07	-1.61	48.60	-.52
DH4	5	2	3.71	.74	33.30	.29
DH5	5	2	14.28	2.86	22.98	1.33
DH6	5	1	13.55	2.71	6.64	2.35
DH7	5	4	-8.57	-1.71	21.09	-.83
DH8	5	3	-3.67	-.73	38.81	-.26
DH0-DH2	15	6	40.42	2.69	30.96	1.88
DH0-DH4	25	11	36.06	1.44		
DH0-DH8	45	21	51.65	1.15		
RSL3	29	17	-24.22	-.84	30.79	-.81
RSH3	29	13	23.40	.81	33.71	.75
RDL3	14	6	-3.41	-.24	34.36	-.16
RDH3	15	7	26.81	1.79	33.39	1.20

1/ The 3-digit code refers to stage of the sunspot cycle. S means single cycle, D means double cycle, L means low point of the cycle, H means high point, 0 is the year of the low or high, 1 is the first year following the low or high, 2 is the 2nd year following the low or high, and so on. For example, SL0 is the single cycle low year and DH4 is the 4th year following the double cycle high year. The 4-digit code has the following meaning: RSL3 is the 3 lowest years of the single cycle, RSH3 is the 3 highest years of the single cycle, RDL3 is the 3 lowest years of the double cycle, and RDH3 is the 3 highest years of the double cycle.

2/ Observations are deviations from a linear regression of yield data in 3 segments: 1866-1932, 1933-55, and 1956-73.

3/ T-values are for comparisons of the mean of all observations (zero by definition) with a cycle year

SOURCE: See appendix.

Table 5.--Crop yield-sunspot relationships for Nebraska corn, 1866-1973

Stage of sunspot cycle 1/	Observations 2/	Negative observations	Sum	Mean	s^2	T-value 3/
			Bushels			
All observations	107	50	0	0	45.39	0
SL0	10	4	7.11	.71	96.21	.23
SL1	10	6	-24.84	-2.48	51.65	-1.09
SL2	10	4	14.95	1.49	33.31	.82
SL3	10	6	-13.87	-1.39	34.99	-.74
SL4	10	3	28.93	2.89	32.31	1.61
SL0-SL2	30	14	-2.78	-.09	59.29	-.07
SL0-SL4	50	23	12.28	.25		
SH0	10	6	-.81	-.08	29.07	-.05
SH1	10	3	16.57	1.66	102.81	.52
SH2	9	4	-2.68	-.30	38.18	-.14
SH3	10	3	1.46	.15	41.91	.07
SH4	10	5	-9.75	-.97	48.63	-.44
SH0-SH2	29	13	13.08	.45	54.10	.33
SH0-SH4	49	21	4.79	.10		
DL0	5	3	-1.51	-.30	41.42	-.10
DL1	5	0	36.03	7.21	11.10	4.84
DL2	4	1	10.23	2.56	24.87	1.03
DL3	5	2	-5.48	-1.10	26.65	-.47
DL4	5	3	3.67	.73	26.45	.32
DL5	5	2	16.80	3.36	38.83	1.21
DL6	5	4	-11.81	-2.36	44.88	-.79
DL7	5	3	-11.80	-2.36	28.37	-.99
DL8	5	4	-34.69	-6.94	75.33	-1.79
DL0-DL2	14	4	44.75	3.20	32.92	2.08
DL0-DL4	24	9	42.94	1.79		
DL0-DL8	44	22	1.44	.03		
DH0	5	3	.70	.14	23.87	.06
DH1	5	3	-19.46	-3.89	143.23	-.73
DH2	5	3	-12.91	-2.58	43.03	-.88
DH3	5	1	6.94	1.39	63.80	.39
DH4	5	2	-13.42	-2.68	75.67	-.69
DH5	5	3	2.93	.59	41.81	.20
DH6	5	2	7.08	1.42	21.19	.69
DH7	5	3	-5.08	-1.02	55.08	-.31
DH8	5	1	.96	.19	74.22	.05
DH0-DH2	15	9	-31.67	-2.11	63.06	-1.03
DH0-DH4	25	12	-38.15	-1.53		
DH0-DH8	45	21	-32.26	-.72		
RSL3	29	14	-14.09	-.49	54.16	-.36
RSH3	29	12	32.09	1.11	48.50	.86
RDL3	14	4	48.79	3.48	33.08	2.27
RDH3	15	8	-16.70	-1.11	55.35	-.58

1/ The 3-digit code refers to stage of the sunspot cycle. S means single cycle, D means double cycle, L means low point of the cycle, H means high point, 0 is the year of the low or high, 1 is the first year following the low or high, 2 is the 2nd year following the low or high, and so on. For example, SL0 is the single cycle low year and DH4 is the 4th year following the double cycle high year. The 4-digit code has the following meaning: RSL3 is the 3 lowest years of the single cycle, RSH3 is the 3 highest years of the single cycle, RDL3 is the 3 lowest years of the double cycle, and RDH3 is the 3 highest years of the double cycle.

2/ Observations are deviations from a linear regression of yield data in 3 segments: 1866-1932, 1933-55, and 1956-73.

3/ T-values are for comparisons of the mean of all observation (zero by definition) with a cycle year.

SOURCE: See appendix.

However, an observation or two can be drawn from calculations associated with the double cycle. For example, the first 2 years following the double sunspot low (high sunspot activity) are associated with significant yield increases (positive observation in 8 of 9 years) (DL1-DL2). But high sunspot activity near the high point of the double cycle is asssociated with negative observations.

Interestingly, large negative yields occur in 4 consecutive years beginning 6 years after the low point of the double sunspot cycle. This phenomenon also occurred with Illinois corn and Texas wheat. During these years, sunspot activity is low, since sunspot minima are reached approximately 6.4 years after sunspot maxima. Thus, though low sunspot activity is apparently connected with low yields, low activity following the negatively plotted double sunspot cycle high may be <u>especially</u> conducive to low yields. For Nebraska corn, negative yield deviations occurred in 15 of 20 observations for the 6th through the 9th year after the double sunspot minimum. Yields for these 4 years average 3.49 bushels, or 10.4 percent below normal. For Illinois corn, negative deviations occurred in 12 of 20 observations for the 6th through 9th year, averaging 1.99 bushels, or 4.4 percent below normal. And for Texas wheat, negative deviations occurred in 14 of 20 observations for years 6-9 and they averaged 1.34 bushels, or 10.6 percent below normal. If this phenomenon has occurred other than by chance, it lends support to other studies which claim that regular drought periods in Nebraska and other Plains States occur in precisely the same phase of the double sunspot cycle (2, 9, 10; figures 2 and 4).

Louisiana Rice

In table 6, which summarizes the data on rice in Louisiana, some relationship exists between sunspot cycle and rice yields though not a very strong one.5/ The historical period (77 years) is about three single cycles shorter than for the other crops discussed in this report.

Years 3 through 6 (SH3-SH6) following the single cycle high are associated with slightly lower than normal yields. During this 4-year period, 17 of 30 observations were negative. The average yield deviation was -52.9 pounds per acre. These years are associated with declining and low sunspot activity.

Conversely, years associated with increasing and high sunspot activity (notably years 1 through 6 (SL1-SL6) following the single cycle low year) appear to result in higher than normal yields. During this 6-year period, 24 of 42 observations were positive. The average yield deviation was 38.4 pounds per acre.

There is a slight indication that the declining phase of the <u>double</u> sunspot cycle is associated with lower yields, as contrasted to the increasing phase. In the declining phase, about 66 percent of the observations were negative; in the incresing phase, only about 32 percent were negative. The average yield deviations were -55.2 and 35.0 pounds for the decreasing and increasing phase, respectively--a difference of 90.2 pounds per acre.

5/ Since rice acreage is totally irrigated, we cannot expect much effect on yields due to sunspot activity. But rice was included to test for factors other than moisture which may be related to solar activity.

Table 6.--Crop yield-sunspot relationships for Louisiana rice, 1895-1972

Stage of sunspot cycle 1/	Observations 2/	Negative observations	Sum	Mean	s^2	T-value 3/
			----------	Pounds	----------	
All observations	77	38	0	0	24,819	0
SL0	7	5	-192	-27.4	8,018	-.81
SL1	7	3	152	21.7	44,836	.27
SL2	7	3	433	61.9	19,613	1.17
SL3	7	3	620	88.6	73,806	.86
SL4	7	3	15	2.1	9,071	.06
SL0-SL2	21	11	393	18.7	23,140	.56
SL0-SL4	35	17	1,028	29.4		
SH0	7	2	-21	-3.0	15,052	-.06
SH1	6	3	21	3.5	16,261	.07
SH2	8	4	261	32.6	8,480	1.00
SH3	8	4	-575	-71.9	42,238	-.99
SH4	8	5	-599	-74.9	15,636	-1.69
SH0-SH2	21	9	261	12.4	11,819	.52
SH0-SH4	37	18	-913	-24.7		
DL0	4	1	0	0	28,083	0
DL1	3	1	139	46.3	16,326	.63
DL2	4	2	132	33.0	6,622	.81
DL3	4	2	-82	-20.5	29,423	-.24
DL4	4	1	-88	-22.0	26,581	-.27
DL5	3	1	142	47.3	36,325	.43
DL6	3	1	-108	-36.0	25,291	-.39
DL7	3	1	211	70.3	8,997	1.28
DL8	3	1	479	159.7	41,930	1.35
DL0-DL2	11	4	271	24.6	14,089	.69
DL0-LD4	19	7	101	5.3		
DL0-DL8	31	11	825	26.6		
DH0	3	1	-21	-7.0	2,989	-.22
DH1	3	2	-118	-39.3	18,822	-.50
DH2	4	2	129	32.3	13,165	.56
DH3	4	2	-493	-123.3	62,094	-.99
DH4	4	4	-511	-127.8	2,448	-5.16
DH5	4	4	-283	-70.8	992	-4.49
DH6	4	2	-205	-51.3	16,938	-.79
DH7	4	3	-142	-35.5	5,924	-.92
DH8	4	2	12	3.0	10,554	.06
DH0-DH2	10	5	-10	-1.0	10,228	-.03
DH0-DH4	18	11	-1,014	-56.3		
DH0-DH8	34	22	-1,632	-48.0		
RSL3	21	11	-260	-12.4	21,385	-.39
RSH3	20	8	315	15.8	12,083	.64
RDL3	11	4	262	23.8	14,020	.67
RDH3	9	4	53	5.9	10,973	.17

1/ The 3-digit code refers to stage of the sunspot cycle. S means single cycle, D means double cycle, L means low point of the cycle, H means high point, 0 is the year of the low or high, 1 is the first year following the low or high, 2 is the 2nd year following the low or high, and so on. For example, SL0 is the single cycle low year and DH4 is the 4th year following the double cycle high year. The 4-digit code has the following meaning: RSL3 is the 3 lowest years of the single cycle, RSH3 is the 3 highest years of the single cycle, RDL3 is the 3 lowest years of the double cycle, and RDH3 is the 3 highest years of the double cycle.

2/ Observations are deviations from a linear regression of yield data in 2 segments: 1895-1951 and 1952-72.

3/ T-values are for comparisons of the mean of all observations (zero by definition) with a cycle year.

SOURCE: See appendix.

Two years are especially interesting--years 4 and 5 following the high point of the double sunspot cycle (DH4 and DH5). Since, on average, the sunspot low occurs about 6.4 years after the high, years 4 and 5 would be associated with low, declining sunspot activity. All 8 observations for years 4 and 5 were negative, averaging 99.3 pounds per acre, or 5. 0 percent below normal. Yield deviations in both years are highly significantly different from zero. And yield deviations also tend to be negative in years 3, 6, and 7.

If any stage of the double cycle might be associated with higher than average yields, years 7, 8, and 9 following the low point on the double cycle are candidates. These are years of increasing sunspot activity, with year 9 near the maximum in most cases. Seven of the 9 observations in the 3 years were positive. The average yield deviation was 117.1 pounds per acre, or 5.8 percent above normal yields. For year 9 following the double sunspot low, yields differed significantly from zero. High yields during this period conflict with the observations of low yields during approximately the same period reported for Texas wheat and Illinois and Nebraska corn.

Texas Cotton

Table 7 summarizes Texas cotton yield data associated with phases of the sunspot cycle. Negative and positive observations seem to be clustered in alternative periods of 3 to 4 years each. These clusters apparently have no consistent relation to the stage of the sunspot cycle. If one exists, it may be masked by what could be a smaller yield cycle imposed on a larger one as well as by other forces affecting yields.

CONCLUSIONS

What of the hypothesis that crop yields are somehow related to either the single or double sunspot cycle? In the presentation, no speculations were made on any mechanism by which sunspots could directly or indirectly affect yields. But the studies cited report that length of growing season, temperature, precipitation, radiation levels, atmospheric pressure, and high-altitude wind speed may be related to either the single or double sunspot cycle, or both.

For the current study, 108 years of data (77 years for rice) were used, which incorporated about 10 single and 5 double sunspot cycles; and yields were analyzed for various phases of these cycles. Statistical tests were used in some cases to compare the average yields for a given stage of the cycle with the overall mean or with some other stage. High variability and lack of enough observations in some instances make any conclusions tentative.

Some observations are consistent for several crops.

First, lower than average yields are associated with low sunspot activity (Texas wheat, Kansas wheat, Illinois corn, Nebraska corn, and Louisiana rice).

Second, lower than average yields are especially connected with low sunspot activity following the high of the negatively plotted double sunspot cycle (Texas wheat, Illinois corn, and Nebraska corn).

Table 7.--Crop yield-sunspot relationships for Texas cotton, 1866-1973.

Stage of sunspot cycle 1/	Observations 2/	Negative observations	Sum	Mean	s^2	T-value 3/
			Pounds			
All observations	108	55	0	0	1,201	
SL0	10	6	-12.3	-1.23	581	-.16
SL1	10	5	-42.9	-4.29	960	-.44
SL2	10	7	-56.3	-5.63	765	-.64
SL3	10	3	51.1	5.11	893	.54
SL4	10	4	134.0	13.40	1,170	1.24
SL0-SL2	30	18	-111.5	-3.72	719	-.76
SL0-SL4	50	25	73.6	1.47		
SH0	10	4	95.9	9.59	606	1.23
SH1	10	5	7.6	.76	2,799	.05
SH2	10	8	-79.1	-7.91	1,145	-.74
SH3	10	4	-30.8	-3.08	1,496	-.25
SH4	10	6	-116.6	-11.66	1,132	-1.10
SH0-SH2	30	17	24.4	.81	1,465	.12
SH0-SH4	50	27	-123.0	-2.46		
DL0	5	2	44.4	8.88	727	.74
DL1	5	3	-87.4	-17.48	2,000	-.87
DL2	5	4	-46.5	-9.30	2,504	-.42
DL3	5	1	-19.7	-3.94	2,889	-.16
DL4	5	2	-20.9	-4.18	1,661	-.23
DL5	5	2	36.9	7.38	2,458	.33
DL6	5	3	53.8	10.76	2,751	.46
DL7	5	3	19.3	3.86	1,320	.24
DL8	5	3	-18.3	-3.66	913	-.27
DL0-DL2	15	9	-89.5	-5.97	1,625	-.57
DL0-DL4	25	12	-130.1	-5.20		
DL0-DL8	45	23	-38.4	-.85		
DH0	5	2	51.5	10.30	634	.91
DH1	5	2	95.0	19.00	3,465	.72
DH2	5	4	-32.6	-6.52	69	-1.76
dH3	5	3	-11.1	-2.22	474	-.23
DH4	5	4	-95.7	-19.14	747	-1.57
DH5	5	2	62.7	12.54	795	.99
DH6	5	1	-0.4	-.08	101	-.02
DH7	5	2	-8.3	-1.66	1,528	-.09
DH8	5	3	-1.3	-.26	1,053	-.02
DH0-DH2	15	8	113.9	7.59	1,311	.81
DH0-DH4	25	15	7.1	.28		
DH0-DH8	45	23	59.8	1.33		
RSL3	29	13	101.6	3.50	1,106	.57
RSH3	30	15	145.1	4.84	1,565	.67
RDL3	15	8	-24.3	-1,62	1,764	-.15
RDH3	15	7	169.4	11.29	1,388	1.17

1/ The 3-digit code refers to stage of the sunspot cycle. S means single cycle, D means double cycle, L means low point of the cycle, H means high point, 0 is the year of the low or high, 2 is the 2nd year following the low or high, and so on. For example, SL0 is the single cycle low year and DH4 is the 4th year following the double cycle high year. The 4-digit code has the following meaning: RSL3 is the 3 lowest years of the single cycle, RSH3 is the 3 highest years of the single cycle, RDL3 is the 3 lowest years of double cycle, and RDH3 is the 3 highest years of the double cycle.

2/ Observations are deviations from a linear regression of yield data in 4 segments: 1866-1922, 1923-47, 1948-61, and 1962-73.

3/ T-values are for comparisons of the mean of all observations (zero by definition) with a cycle year.

SOURCE: See appendix.

Third, higher than average yields are associated with high sunspot activity (Texas wheat, Kansas wheat, Illinois corn, and Louisiana rice).

Finally, both the single and double sunspot cycle may give useful information in predicting yield deviations (Texas wheat--both cycles, Kansas wheat--single cycle, Illinois corn--both, Nebraska corn--double cycle, Louisiana rice--both, but Texas cotton--neither).

If crop yields are in fact affected by sunspot activity, of what magnitude is the effect?

Over 1866-1973, Texas wheat yields averaged 12.69 bushels per acre. When the averaging is over 10 single cycles, low sunspot activity has been associated with a yield decline of about 0.85 bushel, or 7 percent of the overall average; and with high activity has come a yield increase of about 0.50 bushel, or 4 percent. Yields during low sunspot activity following the negatively plotted double-sunspot-cycle high were 1.34 bushels below the overall average, or 10.6 percent below normal. Texas wheat yields in recent years have averaged between 20 and 25 bushels per acre, reaching 29 in 1973. Whether these alleged effects due to sunspot activity may be greater or lesser as yields increase over time is beyond the scope of this report. One point to note: the magnitude of variability of crop yields (wheat included) has not diminished as yields have increased.

Kansas wheat yields have averaged 15.78 bushels per acre since 1866, but more recently they have averaged 30-35 bushels reaching 37 in 1973. Yields in the 3 lowest sunspot activity years averaged 0.83 bushel per acre lower than in the 3 highest years. But the results are not very consistent, so it is difficult to assign a yield effect due to the high and low sunspot activity.

Illinois corn yields averaged 44.84 bushels per acre in 1866-1973, but they have been in the 90's in recent years and reached 110 in 1972. The year of the lowest sunspot activity in each cycle resulted in a yield drop which averaged 3.89 bushels, which is about 9 percent of the overall average. But the average drop for the 3 lowest sunspot years was only 0.84 bushel. The 3 years in each cycle of highest sunspot activity were associated with yields of 0.81 bushel above the overall average. Yields associated with the 3 double sunspot high years were 2.69 bushels above the overall average. And yields during 4 sunspot low years following the negatively plotted sunspot high averaged 1.99 bushels below the overall figures.

For Nebraska corn, little relation emerged from a study of single cycles, but the double cycle proved a different matter. In the years of low sunspot activity following the negatively plotted sunspot high, corn yields decreased significantly for several years in a row. Yields in the 6th thru 9th year averaged 3.49 bushels per acre below normal, or 10.4 percent below the overall 1866-1973 average of 33.45 bushels per acre. And yields for the 3 years of highest sunspot activity following the negatively plotted sunspot high averaged 3.48 bushels above normal.

Louisiana rice yields averaged 2,003 pounds per acre in 1895-1972 but they have ranged between 3,500 and 4,000 pounds in recent years. Certain years of declining sunspot activity are associated with yields which were about 50-60 pounds per acre below the overall average. Conversely, years of increasing sunspot activity are associated with yields above normal by about 40 pounds. For the double sunspot cycle, the average yield deviations were -55 and 35 for the decreasing and increasing activity phases, respectively. Certain years and groups of years in the double cycle are considerably more dramatic, reaching 5 to 6 percent on the plus and minus side of the average, as reported earlier.

For Texas cotton, no consistent relation between yields and sunspot activity was apparent.

APPENDIX

Data Sources for Historical Yields

Crop	Years	Source
Cotton, Upland	1866-1948	(16) and (26)
	1930-1967	(17)
	1964-1969	(19)
	1969-1973	(18)
Wheat, all	1866-1943	(20)
	1944-1949	(21)
	1950-1954	(22)
	1955-1959	(23)
	1960-1963	(18)
	1964-1969	(19)
	1970-1973	(18)
Corn, for grain	1866-1943	(24)
	1944-1949	(21)
	1950-1954	(22)
	1955-1959	(23)
	1960-1963	(18)
	1964-1969	(19)
	1970-1973	(18)
Rice	1895-1953	(26)
	1950-1954	(23)
	1955-1959	(24)
	1960-1963	(18)
	1964-1969	(19)
	1970-1973	(18)

Data Source for Historical Sunspot Numbers

Mrs. Viola Miller
World Data Center A for Solar-Terrestrial Physics
National Oceanic and Atmospheric Administration
Boulder, Colorado 80302

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