GRAIN YIELDS AND WEATHER FLUCTUATIONS

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Within recent years there have been considerable questions raised regarding the relative effects of weather and technology upon our present high levels of production. When yield levels are extrapolated for five, 10 or more years into the future, a small error in the trend line can become greatly magnified. We must be sure what recent years represent before predictions for future years are made.

Because of the continually changing levels of technology determining the relationship between weather and yield under present-day agricultural conditions is not simple. In its simplest form, one could say that yields are a result of weather, of technology and of a weather technology interaction. Favorable weather alone will not produce high yields unless adequate technology is used. Improved technology alone will not produce high yields without adequate weather. Favorable weather conditions allow technology to express itself to its fullest potential. Probably much of the effect on yields is due to the interaction between technology and weather, which is difficult to evaluate under our continually changing level of technology. In many ways it is comparable to an experiment without a control or check plot.

In examining the relationship between grain yields and weather fluctuations in light of this conference, it seems that three questions are of considerable importance.

1. Are there periodic fluctuations in the weather, and are any of these predictable?

2. How closely is the weather at two locations related?

3. What effect has weather had upon our present high levels of grain production?

To gain some appreciation of variation in crop production as it might be related to weather let us first examine corn yields for Missouri shown in Figure 1. Severe drought conditions occurred in 1894 and again in 1901. For a period of several years after this, yields were generally above average. During the period 1910-1914, production declined. There were irregular fluctuations in yields to the mid-20's, then a general decline in yields until the mid-30's. The decline in yields from 1925 to 1935 was usually attributed to soil deterioration. The years 1934 and 1936 were also very severe drought years. Hybrid corn was introduced on a commercial scale in 1934 and was

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rapidly adopted so that by 1945 about 90 percent of the corn in the Corn Belt was hybrid corn. Yields in the late 30's and early 40's showed a gradual increase. A slight decrease in yields occurred in the early 50's, which was due to cool and wet weather in 1950 and 1951 and dry years in the mid-50's. Recent years have shown high yields with an upward trend. A similar pattern is shown for Illinois and Iowa in Figure 1, with the general decline from 1925 to 1935 particularly noticeable.

Periodicity of Weather Fluctuations

Yields have shown certain patterns of periodic fluctuation. This raises the question of periodic fluctuations in weather. We use the term "periodic fluctuations" here rather than cycles because they do not have the rhythm associated with a true cycle. But if weather shows any degree of rhythmic pattern or just grouping into "good weather" and "bad weather" years, it is important to take this fact into consideration in agricultural planning. Any extrapolation of yields from the present situation must consider the effects of both weather and technology. If a physical explanation can be obtained for any grouping of the data or for any long-range forecast, even of a general nature, it would be extremely valuable. Even if all grouping of these years is due only to random factors, it cannot be completely ignored in agricultural planning. As will be brought out later we are enjoying a run of favorable years preceded by a run of unfavorable years. To project our recent trends of corn yields could lead to serious problems of food supply should we find ourselves with no reserve of feed grains at the end of favorable years and in a severe drought year.

Statistical techniques can be used to examine the periodicity and persistence of weather. One approach is to see if the runs of years depart from a random model. For example, let us use red, white and blue balls drawn from a fishbowl. The red can be dry, the white average, and the blue wet years, each occurring one third of the time. Probability theory can be used to show how often a dry year will follow another dry year, or any other choice you may select.

During the mid-50's the climatology group at Iowa State had been frequently asked the question, "Does weather persist?" The climatologists were not considering day to day persistence but only long-range persistence of say, year to year, or growing season to growing season. A random study was made for Iowa, both for individual stations and for the state average for a long series of years, for the total rainfall for the growing season, April through September. The data for Iowa were not significantly different from a random model. Dry years followed dry years as frequently as the random data model predicted. This would indicate that no real weather persistence occurred in the total precipitation, April through September.
Figure 1. Fluctuations and trends in corn yields in Missouri, Illinois, and Iowa from 1890 to 1962.
The relationship between spring and fall weather was also examined, with no significant departure from the random model. The random model indicates that dry weather follows dry weather; in fact, it predicts it will occur with a certain probability. Once we have had a dry year (using the three groups above), there is a 1/3 chance of the next year being dry, and a 1/9 chance of the next two years being dry. When this technique was applied to Kansas data, dry years did seem to persist. More recently the question of randomness of weather has again been raised for Iowa conditions because of the occurrence of a run of favorable years from 1957 to 1963. The run of favorable years from 1937 to 1943 might have been regarded as a random occurrence, but to experience another run of favorable years with peak years nearly 20 years apart causes one to raise questions about randomness of weather in Iowa or in the midwest.

One additional point should be made here. There may be a difference between persistence in the weather and persistence in crop yields. In many areas producing grain, a low rainfall year may tend to create a "dry" crop year the next year, due to little carryover of soil moisture. Even with average rainfall the next year, it may seem like a dry crop year. In 1963 we had an excellent crop year in Iowa, partially because we had a good carryover of soil moisture from August, 1962. There definitely may be persistence from year to year in crop yields because of this carryover of soil moisture, which has helped carry the crop through dry periods and produce our high yields.

Figures 2 and 3 show relationships between July rainfall, July temperature and solar activity, where sunspots numbers have been shown with the minor maximum data plotted negatively. Only July rainfall and July temperature are shown, because they are so important in corn production and because they reflect the summer weather conditions. The year-to-year variation in July weather is rather striking in Figure 2. The three-year moving average shown in Figure 3 indicates some correlation with solar activity.

Willett (6) has stated that severe droughts in the midwest tend to occur during the period leading up to each major sunspot maximum. These major maxima have occurred in 1895, 1917, 1937 and 1957. Although a period may be very dry, a very wet year might occur within the dry period. The relations of this type, that is weather and solar activity, should only be used for general periods, not for individual years. But if any relationships can be found which allow us to predict that a period will be generally dry, or wet, this prediction could have important implications in farm program planning. In Figure 3 dry July's are shown near each of these years of sunspot maxima: 1891 and 1894, 1913 and 1916, 1934, 1935 and 1936, and 1954 and 1955. However, not all dry years were near the major maxima, and within some of these periods wet years occurred, for example 1896 and 1915.
Figure 2. Average July precipitation and July temperature for Kansas and yearly solar activity, 1892-1963.

Figure 3. 3-year averages of July precipitation and July temperature for Kansas and yearly solar activity, 1892-1963.
Figures 2 and 3 also show the strong negative relation frequently found between temperature and precipitation at a station. This is evident in several of the extreme years, but not always present. Figure 4 shows the fluctuations in summer weather in the six-state area including Nebraska, Kansas, Oklahoma, Iowa, Missouri and Arkansas. The correlation with solar activity is less apparent but the correlation with crop yield fluctuations shown in Figure 1 is rather striking. The low yields of 1894 and 1901 coincided with low summer precipitation. The 1910-1914 period showed decreasing summer rainfall; so did the early thirties, and generally favorable summer rainfall has occurred in recent years. And perhaps just as important is the fact that summer temperatures have been favorable in recent years.

The "areawise" relationship of weather is of importance in considering any farm program, particularly as it relates to the concentration of a crop within a smaller area. The more the acreage is concentrated the more susceptible the total production is to weather variability. If spread over a large area, good and bad weather may tend to average out in each year. When the acreage is concentrated, the entire area may be either "good" or "bad." This is something we know relatively little about at the present time--primarily because little effort has been expended on this problem. For example, is there an inverse relation between weather in the midwest and the east coast? The relationship between North Carolina and Nebraska is shown in Figure 5. An inverse relationship for July precipitation is indicated over much of the period. In the next figure, 6, the relationship appears quite evident when we look at cool season precipitation for 1963-1964. This shows considerable areas with the same pattern. This factor should definitely be considered in planning any concentration of the crop within an area if we want to stabilize production.

**Yields and Weather Fluctuations**

Now, the third question which was proposed, "What is the relationship between yields and weather fluctuations and what have crop yields been like in recent years?" Since we have looked at corn, let us examine soybeans and grain sorghums. (Figures 7 and 8.)

If we examine the soybean yields we see a frequent grouping of years above or below the trend line for average weather (5). One point of interest in this figure is that a line connecting the higher yields would be almost parallel to the trend line shown. Sorghum yields show a much more rapid increase due to newer hybrids introduced, greater use of fertilizers, and other factors along with a change to more favorable weather (4). Again there is a grouping of years above and below the trend line. A trend line greatly in error could easily have been projected from these data had the period 1934 to 1944 been used for projection. Certainly a trend line established for the period 1950 to 1960 would be just as misleading.
Figure 4. Average monthly precipitation and monthly temperature, June - August for 6 midwest states and yearly solar activity, 1892-1963.

Figure 5. Average July precipitation for North Carolina and Nebraska, 1892-1963.
Figure 6. Soil moisture accumulation in the U.S. (September 1963-March 1964) based on precipitation data.
Fig. 7. Actual and Calculated Yields of Soybeans in Illinois.
Fig. 8. Actual and Calculated Yields of Grain Sorghums for Kansas.
After looking at state and regional data it might be desirable to look at Story County, Iowa, which is just about in the center of the Corn Belt.

If we examine yields of corn in Story County in detail, several interesting facts appear. Figure 9 shows that through 1935 there appeared to be a gradual upward trend in yields. This was probably due to a number of miscellaneous management factors. The trend line shown for the period 1881 to 1945 was computed by Barger (1). In only two years of that period were yields over 10 bushels above the trend line. In six years yields were 10 bushels or more lower than the trend line. With the relatively low yields obtained, weather could fluctuate over a considerable range with relatively small effects on yield, although it is believed to have had a definite effect on yield patterns. With good weather, yields were limited by the relatively low level of technology. Extremely bad weather did depress yields. However, yields fluctuated around the trend line with little grouping of years—the longest consecutive period above or below normal was three years. Studies such as those made by Rose (3) showed low correlation between weather and corn yields in the heart of the Corn Belt, but much higher correlations in the climatically marginal areas of the Corn Belt. This was probably a very realistic picture for that period.

From 1936 to 1940 in Iowa the percent of hybrid corn grown increased from 10 percent to more than 90 percent. From 1937 through 1943 there were seven consecutive years with yields above this trend line. Is the trend line wrong? We don't think so. This series of favorable years is also shown by Dale (2) in a study of moisture stress days. The method for determining moisture stress days was developed on experimental plot yields where fertility—technology was held constant. The years 1937 and 1938 were not particularly favorable or unfavorable years. There may have been higher yields in 1937 because of a carryover effect of fertility from 1936, a very dry year. The years 1939 through 1943 were all increasingly better weather years, with a large number of non-stress days. Multiple regression studies for Iowa also confirm the idea of a run of favorable years from 1939 to 1943 (5). Ten of the next 13 years, from 1944 through 1956, were below a trend line extended at the same slope as that prior to 1935, but taking into account the effect of hybrid corn. The three high yielding years 1946, 1948 and 1952 all had a large number of non-stress days. For the other years with a large number of non-stress days certain weather factors depressed yields. In 1945, severe frost damage occurred; 1951 had a cool spring and early frost. The years 1944 and 1950 had low numbers of stress days but both years had late cool springs, which were detrimental to corn yields. The years 1947, 1949, 1953, 1954, 1955 and 1956 all had large numbers of stress days.

In 1956, Story County yields for corn harvested were 43 bushels per acre. Actually, this is a biased yield. About 1/3 of the corn in the county went into the "Soil Bank" after the dry weather occurred—and nearly all of this was the poorest corn. If this would have averaged 10 bushels (and much of it would have produced nothing), the Story County yield would have been 32 bushels per acre.
Using Dale's stress day index, certain years are compared below.

<table>
<thead>
<tr>
<th>Year</th>
<th>Story County Yield</th>
<th>Non stress Days</th>
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<tbody>
<tr>
<td>1934</td>
<td>22 bu/acre</td>
<td>10</td>
</tr>
<tr>
<td>1936</td>
<td>26</td>
<td>15</td>
</tr>
<tr>
<td>1947</td>
<td>30</td>
<td>25 Low index</td>
</tr>
<tr>
<td>1956</td>
<td>32 (as revised)</td>
<td>17</td>
</tr>
<tr>
<td>1942</td>
<td>65</td>
<td>55 High index</td>
</tr>
<tr>
<td>1962</td>
<td>83</td>
<td>55</td>
</tr>
</tbody>
</table>

Low yields were associated with few non-stress days or a low weather index. In 1947, distribution of moisture was particularly bad--13.5 inches in June, then practically no rain during the remainder of the summer. In unfavorable weather years good management has not allowed us to produce much more than just ordinary management. In moderate weather years we may have done better, because of deeper rooting from fertilizers. However, if this moisture is removed from the lower subsoil one year, it may not be replenished by the beginning of the next growing season. In favorable weather years we have improved yields considerably by good management. Starting in 1957, all years have had a medium to high weather index and yields have been high.

Comparing 1942 with 1962 shows a yield increase in Story County of 18 bushels, an average increase of 0.90 bushels per year between these two favorable weather years. Thompson (5) has shown an average increase, using a linear trend adjusted for weather of 0.70 bushels per year for the state. This seems like very good agreement when one considers that Thompson's study was for the entire period from 1930 to 1962.

Figure 9 shows a trend line from 1941 to 1962 fitted by the least squares method. This line is too steep because of the fact that weather was generally more favorable in the last half than in the first half of the period. Nevertheless, it is significant that a line drawn from the peak yield of 1942 to the peak yield of 1962 would result in a line about parallel with the least squares trend line. Certainly a trend line fitted to the period 1950 to 1960 would result in a very steep slope because of the unfavorable years in the early and mid-50's followed by a run of favorable years after 1956.

In summary, the data presented in this paper show (1) great variation from year to year in weather and crop production (2) a close resemblance of crop and weather variation (3) a tendency for fluctuations to occur in such a manner as to cause alternation of groups of favorable and unfavorable years (4) a similarity of weather patterns in neighboring states of the midwest but dissimilarity of weather patterns when comparing the midwest to the Atlantic coastal area and (5) weather in the midwest which has been very favorable to crops since 1956, giving rise, therefore, to a steep trend in crop production from 1950 to 1960.
Bibliography


