In this paper I aim to go somewhat beyond the underlying scope of this seminar, which is the clarification of the separate roles of weather and technology in the upsurge of agricultural production in recent years. I want to focus on weather as the troublesome, unsolved "X" factor in agriculture. It has two aspects. One confronts us here in our efforts to unscramble the effects of nature from the effects of man's activities. It confronts us when we wonder how much of China's current food problem is due to weather, how much to Communist mismanagement. The same question hangs over the Russian grain production. Much the same problem is involved in judging Common Market grain output.

The other aspect of the "X" factor is the greater unknown, namely, the effect of weather on crops the next year and the next and the next. It is this aspect with which I wish to deal primarily. In fact, I wish to report on heretofore unrecognized annual characteristics in crop yield records. These somewhat novel findings are based on a considerable body of research that I have personally conducted over many years in an attempt to anticipate weather and crop yield changes a year or more in advance. And this has meant studying the interplay between trends, cycles and actual patterns of fluctuations.

Meteorologists have made great strides since former Secretary Henry A. Wallace asked the Weather Bureau forecasters to try their hand at forecasting 48 hours instead of 24 hours in advance. We now have extended forecasts for several weeks ahead. It may, therefore, be some time yet before year to year technical forecasts will be available in reliable form.

It is common belief among meteorologists, crop forecasters and nearly everyone else that weather and crop yield fluctuations are not predictable, since they appear to behave like random numbers. I hope to demonstrate to you why I think this is philosophically and statistically an erroneous view. I hope to show that these fluctuations appear to be governed by law and order — to show why this view, if more generally recognized, could be of great help toward a better understanding of the interplay between long time trends, cycles and annual fluctuations — why it would hasten the day when

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year to year or longer range forecasts in weather and crops will be officially possible.

As between the notion that weather and crop records represent random fluctuations and the view that they represent law and order I find myself readily accepting the latter, for it is in line with one of Einstein's last remarks. He said, "God does not play dice with the Universe." A corollary to this is that God, therefore, does not play dice with the weather since weather issues from an orderly universe. And a further corollary, in turn, is that God therefore does not play dice with crop yields since crop yields in the influence of man are the result of weather. If the universe is governed by law and order, if weather variations are the end product of an orderly system, if yield fluctuations are an index of the effects of weather, then both yields and weather must contain evidence of law and order and therefore must be predictable.

**Evidence That Patterns Repeat Themselves**

Though most of you may not be aware of it, part of the findings in this paper are not new. In a 1942 USDA bulletin entitled "Crop Yields and Weather" I called attention to numerous indications that weather and crop records are not just random numbers, that if properly investigated they reveal a large body of law and order and that both cyclical and year-to-year patterns of fluctuations tend to repeat. I illustrated with cotton and wheat yields and with rainfall in selected areas.

As a matter of record two other similar items are pertinent. On leaving the USDA in 1953 I supplied two forecasts to the new secretary and his associates. One was a forecast, dated January 1953, that the USDA December 1952 winter wheat appraisal, placed at a record low of 11 bushels, would turn out to be much higher, 14 to 16 bushels (the final figure was 15.5) and that the 1953 cotton yield, also based on the historical record no later than 1952, would be a record. This was based on a formula which first enabled me to give Secretary Henry A. Wallace a forecast in December 1936 of the coming record cotton yield in 1937 and which also continued to predict correctly, at least a year in advance, the record yields for 1942, 1944, 1948 as well as for 1953.

These findings, giving the results of these two studies in winter wheat and cotton yields, you will find in my testimony in the January 1954 hearings of the Congressional Joint Committee on the President's Economic Report. I used these wheat and cotton analyses and the proven forecasts for 1953 to justify my recommendations that long range statistical forecasting of weather and crops derived from the historical records be considered a field for basic research, since there was ample evidence that the accumulated records contained much "pay dirt."
Similar findings and views, more elaborately developed, are recorded in an address to the top officials of the USDA at the secretary's staff conference in June 1952. Here I dealt with evidence of rainfall cycles, repetitions in annual levels of runoff of the Missouri River at Sioux City and of peak levels of the Columbia River at The Dalles, Oregon. In the case of the flow of the Missouri River, my way of organizing the record revealed cycles and annual fluctuations that pointed to a flood in the spring of 1952 a year in advance. As some of you may recall this actually transpired. In the case of the Columbia River maximum flow, my findings would have given a year's advance warning of the great flood of 1948 when 16 lives were lost at Vanport near Portland.

That staff paper included three other examples of the way Nature repeats -- seasonal degree days at Philadelphia, potato yields in Maine and U. S. corn yields. In the case of corn yields my illustration showed that the corn crop failures of the 1930's were, to a large extent, repetitions of history. Had I known then what I have learned since I might have urged the U. S. Department of Agriculture to refrain from saying in 1935 that the chances were 100 to 1 against another crop failure in 1936 so soon after the crop failure of 1934.

Updating of Studies

Let me now update three of these studies -- those dealing with yields of Maine potatoes, winter wheat and cotton -- before turning to evidence of cycles in both weather and yields. This updating will permit me to put these studies to a severe test as to whether we are dealing with random numbers or not. The fact that a certain kind of auto-correlation analysis continues to hold good for five or six years or even longer after the period of observation is not necessarily the ultimate test of law and order in time series, but let me apply this test nevertheless. For purposes of simplicity let me merely indicate what year-to-year changes or deviations from trend were indicated during the five or six years following each study -- Maine potatoes after 1950, winter wheat after 1952 and cotton after 1936. No actual data are given in the accompanying charts. Here you have three actual cases where an observed correlation held good for five years beyond the period of the analysis, and in two of them for six years.

In the case of Main potatoes the historical pattern of changes applicable to the years after 1950 was as follows:

1951 -
1952 -
1953 +
1954 - (sharply)
1955 + (sharply)
1956 +
Figure 1. Maine potato yields -- 1940-1956, actual and forecasting pattern. This is another case where a correlation for the period 1940-1950 held good for forecasting the variations for the following six years.
This extension of the 1940-1950 sequence actually took place.

In the case of winter wheat yields, the sequence called for after 1952 was:

- 1953
+ 1954
- 1955
+ 1956
+ 1957
- 1958

The first five indications in this extension of the 1942-1952 sequence took place. The 1958 projected decline missed the phenomenal winter wheat yields of 1958.

In the case of cotton the year-to-year sequence called for after 1952 was as follows:

+ 1953 (record)
- 1954
+ 1955
- 1956
- 1957
+ 1958 (record)

and these changes took place.

This projection of cotton yield variations is part of a longer experience. In the USDA bulletin on "Crop Yields and Weather" I showed that year-to-year changes in the yields for 1880-1890 repeated accurately the variations of previous years. This was also true for the period 1916-1927, and as already indicated, this led to forecasts of peak yields for 1937, 1942, 1944, 1948, 1953, and 1958. What is even more striking, the entire year-to-year sequence from 1937 to 1958, in terms of deviations from trend, turned out to be a striking example of historical repetition. There is a similar example of a continuous repetition over a span of 23 years, from 1924 to 1946.
Figure 2. U.S. winter wheat -- 1942-1952 and 1952-1957, and forecasting weather index. Shown here as an inverse correlation for the first 11 years, this analysis also provided a satisfactory basis for forecasting for five years beyond the date of the analysis in 1952.
Figure 3. U.S. Cotton yields, year to year changes in two periods. This chart illustrates the high degree of correlation between yields of one period with earlier patterns of fluctuations, obviously strong indications of non-randomness in the yields of the two periods of 11 and 12 years.
Figure 4. Patterns of fluctuations in U.S. cotton yields, 1924-1946 and 1937-1958 and in forecasting "weather index." Even though these deviations depend in part on the cyclical trends shown in Figure 3, the almost perfect correlation in these two sets of data borders on the phenomenal, especially since these correspondences over 23-year periods were first observed in 1936 -- 28 years ago.
Do these illustrations point to law and order in the effects of weather on crop yields? The last word has not yet been said by mathematicians and statisticians as to tests of randomness in time series. We know from experience, as a matter of fact that tests in common use fail to differentiate between series known to be random and constructed series that are not random. But suppose we use the simplest test. You and I toss coins and I match your head or tail every time in five or six throws before missing. We try another round, say eleven throws. I match your head or tail every time again. We try once more and I match you in this game twenty-two times in a row. Wouldn't you say on the basis of chance that I could match your six throws only once in 64 tries, your eleven throws only once in 2048 tries and your 22 throws only once in over 4 million tries?

I have so far called attention to evidence that patterns of annual fluctuations in weather effects, and therefore in weather factors, are not random. This is only a small part of what I am now engaged in putting together for publication in the near future.

Trends and Cycles

Let me now say a word about trends and cycles, as they emerge in these auto-correlations and in other types of studies. In the nearly 100-year record of Maine potato yields, as shown in one of the charts, a 10-year moving average reveals peak periods around 1870, 1890, 1910, 1930 and 1950. Is this a 20-year cycle? There is another hint -- and merely a hint -- for the record is not long enough, of a still longer cycle with peaks around 1870, 1910 and 1950 -- a 40 year cycle?

I am told that among statisticians it is common knowledge that a moving average of a time series automatically produces what looks like cyclical movements. So let me tell you about evidence of weather cycles in the Corn Belt without using moving averages.

In the chart dealing with Nebraska corn yields and annual rainfall, you will see that I set aside extreme variations. The rest fall in positions that can be zoned in by two parallel lines. This device marks out the changing level of the central tendency, or trend. This treatment reveals the low levels in the 1890's and 1930's and another low level in the 1950's, but in this case relative to a rising trend. The recent high yields centering around 1960 are like those of the cyclically high yields of the 1920's and 1880's. Dr. Louis Thompson's extensive correlations of corn yields with factors covering the period since the 1930's has defined both the trend factor, or technological factor, and the impact of weather for several of the corn states. The fact that these cyclical variations are essentially due to weather variations is indicated by the annual record which shows the same cyclical changes as the level of their central tendency. What man and his technology has done to Nebraska corn yields can be visually derived from the fact that the rainfall level around 1960 and that of the late 1920's is about the same. The yield level about doubled in that interval -- from about 25 bushels to about 50.
Figure 5. **Trends and cycles in Maine potato yields.** This chart presents fairly clear evidence of a long-time cycle, of around 20 years. The data are 10 year moving averages.
Figure 6. *Cycles in Nebraska Corn Yields and Annual Rainfall, 1870-1961.* This chart illustrates the presence of cyclical changes in yields which correspond to similar changes in rainfall, with the yield-trend from 1930 to 1960 obviously due to non-weather factors.
Figure 7. Corn yields, six states, 1890-1961. The central cyclical tendencies in corn yields reflect the central tendencies in a weather index (rainfall + temperature as deviations from 80°), and the yield trend from 1930 to 1960 is also clearly shown to be due to non-weather factors.
If this does not convince you that law and order in addition to man govern the food production in the Corn Belt, let me introduce another illustration. Take the yield per acre of corn for six most important corn producing states, from 1890 to date. Here too if you set aside the extreme years to track down the changing location of the central tendency, you observe clear cyclical changes and of course the technological lift as well.

These yield cycles for most of the Corn Belt are similar to those in Nebraska -- but there are also differences with which we are not concerned here. What is important is that as in Nebraska, weather underlies these cycles as well. The several cyclical weather influences I here represent in perhaps a novel way, for I have combined one rainfall series, June-July-August rainfall with another June-July-August temperature, thus making one broad variable out of six. The unusual operation is that I first deducted the temperature figures from 80 degrees and then added the difference to the rainfall figures, thus recognizing that lower temperatures are generally beneficial and temperatures near 80 degrees are detrimental.

Here too the sag in yields in the 1950's in relation to trend is associated with the low phase of the weather cycle.

I want to return to the unique cotton analysis to show what trends and cycles seem to be involved when they are derived by the application of the graphic method of multiple curvilinear correlation without benefit of the electronic computer. (See my articles on "Graphic Multiple Curvilinear Correlation" in the December 1929 and December 1930 Journal of the American Statistical Association -- and also Richard Foot's article on "The Bean Method," in the December 1953 issue of this journal.)

The problem here is conceived as simply a correlation of annual yields with two independent factors -- time and patterns of seasonal variations. By identifying those points in the series that are comparable with the historical "weather indexes" that are being repeated, it is possible to hold the influence of those points constant and thus obtain directly the net changes in the time factor.

The cotton charts show what historical batteries or weather indexes I have identified as being repeated and what trends emerge in both the actual and the forecasting series. For both the 1924-1946 period and for the 1937-1958 period, cycles of about six years in duration seem to emerge. The rising trend around which these cycles are located is of course evidence of influence of man and his technologies. The downward cyclical phases could also be due to man, but for the most part I suspect they indicate weather effects just as do the annual patterns of variations.
Figure 8. U.S. cotton yields 1924-1946 and a forecasting weather index. It is often said that it is one thing to correlate and another to predict on the basis of that correlation. Here is an illustration where a correlation for the period 1924-1946 made in 1936, held good for the 10 following years.
Figure 9. Trends and Cycles in U.S. Cotton yields, 1924-1946 and 1937-1958. This chart illustrates the net cyclical movements derived from our auto-correlation. For both periods the cycles are about six years in duration.
Figure 10. U.S. Cotton yields, 1924-1958. This chart illustrates the standard result of fitting a trend where the data are considered as random points around a trend line.
The main purpose of this paper has been to try to convince you that weather and crop yield data are not random but governed by a high degree of law and order. To summarize let me refer you to the figures which follow. Five of them deal with trends and cycles, four with evidence of law and order, and four with applications of the fact of law and order in actual forecasting. If these illustrations still leave you skeptical, I hope to have more success with you when I put these and many more similar studies from an even much wider range into book form, in which methods and problems will be dealt with in more detail.
Figure 11. July rainfall in three Iowa crop reporting districts (1, 5, 9) and forecasting indexes, 1947-1960. This is my most recent find. It illustrates that even current monthly weather for a local area or station is the result of a great deal of "law and order" that tends to repeat with a great deal of fidelity the fluctuations of preceding periods.
Figure 12. South Dakota wheat yields, year to year changes in two periods. This chart is also strongly indicative of the non-randomness in yields for the two 11-year periods.