CLIMATIC VARIABILITY AND CROP PRODUCTION

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Abstract

Investigations of the dry end of the climatic spectrum in various areas have led to the development of a method for delineating drought periods and classifying each as to its relative severity. Drought has been treated as a local abnormality; therefore the derived drought severity index values are comparable both in space and time.

This method of climatological analysis has been programmed for machine data processing and a number of areas have been analyzed by months for the period 1931 to date. Thus far, a number of interesting maps and summaries have been produced.

High Risk Produced by Excessively Dry Climate. In the southwestern portion of the Great Plains the climate is so consistently dry that dry-land wheat crops can be expected to be unprofitable about eight years out of 10.

High Risk Produced by Large Variability in Moisture Supply. In the central Great Plains the climate is much less arid than in the southwestern part, but the periodic variability of the moisture supply is so large that the individual farmer cannot expect to be but occasionally "in step with the weather." He has little alternative other than to try to use the "good" years to make up for his losses during "bad" years. This is difficult to do under farm programs which regulate acres rather than quantity.

Occurrence of Serious Drought. Almost the entire Great Plains region suffered -- not necessarily concurrently -- from severe drought 10 percent of the time during the past 30 years, and in portions of Kansas and Nebraska 10 percent of the months produced extreme drought. Severe and extreme drought are, as one would expect, less frequent in most areas to the east of the Great Plains, owing to the relative briefness of the periods of abnormally dry weather.

Evidence of Periodic Recurrence of Extreme Drought in Western Kansas. An analysis of the meteorological record beginning in 1887 shows a surprising degree of regularity in the occurrence of severe and extreme drought in the western third of Kansas. Periods of really serious drought occurred in 1894 and adjacent years; 1913, 1934 and adjacent years, and in 1954 and adjacent years. These four fairly regularly spaced occurrences of severe and extreme drought may be coincidence. However, historical accounts mention exceptional drought occurrences in the early 1870's and in the early 1850's.

This apparent regularity leads one to speculate concerning the possibility that a drought of extreme severity will again occur in western Kansas sometime around the mid-1970's. Understanding of basic atmospheric actions and interactions is entirely inadequate to permit one to formulate any physical method for estimating the probability of such an occurrence. But, on the basis of past history the early or mid-1970's may be years one might well anticipate.

Drought Analysis for St. Louis, 1838 to Date. A similar analysis was run on the longest continuous meteorological record in the middle United States, viz., that at St. Louis, Missouri. The record is continuous from January 1838 to date. Peaks of maximum drought severity at St. Louis appeared in 1838, 1845, 1854, 1872, 1895, 1914, 1931 and 1955.

With the exception of the peak at 1845, this may appear to support the periodicity found in western Kansas, but it certainly can not be considered to be entirely independent evidence, nor does the rhythm appear so clear-cut as in the data for western Kansas.

The only justifiable conclusion at this point is that there is some statistical evidence for suspecting that serious drought tends to occur about every 20 years in the central United States and that the subject requires looking into in much greater detail with more powerful methods and techniques.

Introduction

Farmers have only five kinds of weather -- too hot, too cold, too dry, too wet or too windy. I am going to talk primarily about the too-dry kind which we call drought. However, I'd like to start by showing a couple of illustrations of agro-climatic risks which appear similar, but are basically quite dissimilar. I'll follow that with a brief discussion of a method of drought analysis which I have derived, and then show an example of the sort of maps which have been prepared from 30 years of monthly drought analyses for some 25 or 30 climatological divisions in the central United States. I'll close with some examples of an apparent periodicity in the occurrence of serious drought.

Agro-Climatic Risks

There are numerous factors in weather and climate which produce risk in an agricultural enterprise. I'll confine my remarks to certain aspects of the risk of a moisture shortage.
High Risks Produced by Excessively Dry Climate. Figure 1 is a good illustration of very high risk produced by an agricultural undertaking in a climate which is on the average and almost every year too dry to permit the operation to be profitable.

One can define moisture demand as potential evapotranspiration -- I computed monthly values by the Thornthwaite method (1). Also, moisture supply can be estimated as monthly precipitation plus the computed decrease in soil moisture storage during the month. The difference between supply and demand is, then, a measure of the absolute moisture surplus or deficit during the month. The abscissa of Figure 1 is this estimate for the months of April and May, which make up one of the critical periods for winter wheat production in the northeastern climatological division of New Mexico. The ordinate shows wheat yield in Curry County, which lies in this division. Data are for the years 1931-1955. Note that in only three of these 25 years could one call the yields truly profitable. Obviously, the rather routine moisture deficiency in spring accounts for nearly all the cases of total or partial crop failure. Apparently one spring was too wet for wheat; I suspect lodging and rust. Overall, the odds are about 7 to 1 for winter wheat being unprofitable in this area.

High Risk Produced by Large Variability in Moisture Supply. Figure 2 is an illustration of a different sort of climatic risk. The abscissa is the same as in Figure 1 except in this case the entire 12 months, August through the following July, are represented for the northwest climatological division of Kansas. Wheat yield is for Thomas County for the period 1932-1955. There was apparently a trend in the yield, but this particular sequence of years is an exceptionally unsatisfactory sample on which to base calculations of long-term trend. The 1930's were mostly drought years and the 1940's and very early 1950's were mostly years of rather favorable weather, but with considerable variation from year to year. Therefore, the sample greatly exaggerates the long-term trend in yields.

For the purpose of this illustration, true trend is not particularly important and the ordinate of Figure 2 shows departures from an approximated trend of around +0.5 bu. per year.

The outstanding feature of Figure 2 is the great variability in the moisture picture. Nearly half the years in this particular sample were drought years and about one-fourth were years of surplus moisture. To the east and south of northwestern Kansas the variability, particularly in summer, is even greater than found here.

This exceptional variability in the moisture supply poses some extraordinary problems for the farmers in this central Great Plains region. This sort of risk exists in all agricultural undertakings, but it reaches some sort of supremacy in the central Great Plains where the summer variability in
SPRING WEATHER IN N.E. NEW MEXICO
(APRIL + MAY)

Figure 1. Spring Weather in NE New Mexico.
MOISTURE VARIABILITY IN N.W. KANSAS (AUG.-JULY)

Figure 2. Moisture Variability in NW Kansas.
moisture supply is nearly twice what we find in Illinois and Indiana. In northwestern Kansas the driest summers produce weather similar to that one would expect to find around Del Rio, Texas. In such years, poor pasture is about the best one could expect from the land; profitable crop production is very unlikely. On the other hand, the wettest years produce regular corn-belt type weather suitable for the production of corn and alfalfa. Since these variations are, as yet, essentially unpredictable, it is rather obvious that it is impossible for agriculture in this area to operate in-step with the weather of each year. The fallow-wheat program which has, through trial and error, been adopted in this area is about the best one can do. One must recognize the great variability of the weather and expect to use the good years to make up for his losses in lean years. But, this is easier said than done.

There is a tendency for serious drought, once established, to persist for many months, or even for years. But, most of the dry spells last only a few weeks -- just long enough to cut crop production a little or a lot. There is no good way of telling which year will be a good crop year, so a farmer must manage in such a way that he is always in a position to take advantage of favorable weather, should it occur. The restrictions imposed by the acreage control program make it nearly impossible for any individual wheat farmer to hedge against future crop losses or to make up for past losses. If the restrictions were on marketed bushels per year, it seems to me that a wheat farmer could build up and personally store his own surplus for marketing in years when -- because of drought, winterkilling, duststorms, rust, hail or some of the other items which plague him -- his production was less than his marketing quota.

Most of these risks exist in other areas also, but nowhere else in the United States are they so pronounced as in this central Great Plains region, where the primary area of winter wheat production and the region of maximum summer moisture variability closely coincide. Farm programs for this region should take more account of the climate. Apparently, the humid area philosophy which Webb (2) has so lucidly pointed out is still operating to the detriment of the Great Plains.

Short-term Weather Events and Crop Yields. In passing, I would like to point out the lonesome case in the upper left portion of Figure 2. This was the year 1955. It was a drought year, but wheat yields in this area were surprisingly good. Early prospects were dim. At heading time the wheat was extremely short and rather thin. One or two good rains at just the right time produced long, well-filled heads. This case illustrates the difficulty of estimating local crop yields from meteorological data. Crop yields are greatly influenced by brief periods of very favorable or exceptionally unfavorable weather, especially, if they occur during the more critical phases of the development of the crop. Gross measures such as the annual values shown in Figure 2, or even monthly values, completely obscure some of the short-term but extremely significant weather events.
Drought

Risks Produced by Prolonged Drought. In both Figure 1 and Figure 2 the years of particularly large moisture deficit were sequences of years of drought. In my opinion, one of the greatest of all agricultural risks is the risk of prolonged disastrous drought. As a matter of fact, between 1948 and 1962 drought accounted for 39 percent of the indemnities paid to farmers by the Federal Crop Insurance Corporation. By comparison, the next largest cause of loss, flooding, accounted for only 14 percent of the payments. Other causes were insects, 11 percent; hail, 10 percent; freezing, 10 percent; wind, 6 percent; disease, 5 percent and other causes 5 percent (3). This places drought far ahead of any other single cause of crop loss. Of course, most farmers expect an unusually dry year now and then and the prudent ones are prepared to survive one dry year. The real danger is that the abnormally dry weather will stretch out for three or four or more years. Each successive year of drought takes its toll of capital and resources and each year sees more and more farmers -- and those with whom they do business -- with nothing left except debts.

The Drought Problem

A Definition of Drought. We have been saying a lot about drought in this seminar, but none of us has bothered to define it. When one does try to define drought, it soon becomes obvious that one's definition depends on viewpoint. I am sure I could get at least a dozen different definitions right in this room. Considering the agricultural interests represented, I believe the concensus would center around "too dry for crops." However, the economists might think in terms of "an adverse factor in the economy," while the hydrologists would think more in terms of "low streamflow and depleted reservoirs."

All such viewpoints are reasonable. But, on reflection, it becomes apparent that these are all concerned with the effects of a period of unusually dry weather. Therefore, I submit that the basic problem is meteorological and that an evaluation of meteorological drought may permit each special group to use such a measure to determine the effect relationships in which they have an interest.

To make a long story short, I have defined drought as a prolonged and abnormal moisture deficiency. By this definition drought severity is a function of moisture demand as well as moisture supply. Also, it depends on the climate itself because drought is a relative condition. For example, the imbalance between moisture supply and demand which is usual in western Kansas would be regarded as drought if it occurred in, say, Illinois. The other factor which must be considered is time. Floods can develop overnight, but it takes a good while to develop a serious drought situation. Therefore, drought severity depends not only on current weather but on antecedent weather as well.
Objectives. So far, I have only defined the drought problem. I'd like to digress for a moment and discuss how and why I got into this drought research and what I am trying to do.

I hung up my meteorologist's hat in 1951 in time to spend the drought of the 1950's operating a wheat and cattle farm in southwestern Nebraska. I had endured the drought of the 1930's out there as a young fellow and when I again returned to meteorology in 1956, I began to look into the drought problem. I had and have no illusions about predicting occurrences of drought. I am interested in defining, measuring, evaluating and classifying meteorological drought, and in determining climatological expectancies of drought severity.

A number of years ago I met quite regularly with the Drought Disaster Designation Committee of the U.S. Department of Agriculture. In large part, the committee was forced to make subjective decisions based almost entirely on the judgment of its field men. The chairman was acutely aware of the need for an objective criterion and urged me to do what I could to develop such a measure of drought severity.

After the exploration of numerous approaches which turned out to be blind alleys or closed circles, I have succeeded in devising an analytical technique which appears to provide drought severity index values which are locally significant as well as comparable in space and time. That work is to be published soon (4) and I'll not repeat it here. I will point out, however, that results are in terms of monthly index values to which I have rather arbitrarily assigned the following descriptive names.

-0- = normal (for place being analyzed
-.50 to -.99 = incipient drought
-1.00 to -1.99 = mild drought
-2.00 to -2.99 = moderate drought
-3.00 to -3.99 = severe drought
≤ -4.00 = extreme drought

As a rule of thumb, one can regard incipient drought as corresponding to the sort of dry spell in which the need for rain becomes definitely apparent. Extreme drought, on the other hand, is a very, very serious situation which results from many months, or even years, of abnormally dry weather. Very rarely, if ever, would one find a drought reaching the extreme category in less than four months. During extreme drought crop yields are ordinarily near zero or so low as to be unprofitable; industries and municipalities may face the need for rationing water, and the local or regional economy begins to become disrupted. So, extreme drought is not merely an inconvenience; it is essentially a disaster -- not of the sudden and spectacular variety but of the gradual and extended variety.
Incidentally, the index numbers also delineate and classify periods of abnormally wet weather, but this is sort of a by-product to which I have given little study.

Before going on to the results which have been obtained thus far, I'd like to again point out that the data handling procedure provides a measure of the character of the weather spells themselves. It does not measure the many and diversified effects of the weather. That is a separate problem -- in fact, there are a dozen or so separate problems there.

Results. This numerical method of drought analysis has been programmed for machine data processing on the Honeywell-800 computer at the Weather Records Center in Asheville, North Carolina. The method can be applied either to point data, i.e., rainfall and temperature data from an individual observing station, or to areal average data.

The Weather Bureau regularly publishes areal averages of monthly mean temperature and monthly precipitation for each of the climatological divisions into which each state is divided. To date, most of the drought analyses which have been run are areal analyses based on these climatological divisions. Many more areas and some point data are being or will be analyzed in the near future, including all divisions in the northeastern United States and all divisions in the Ohio River Basin. The northeast areas are being done by the Regional Technical Committee for the application of climatology to agriculture in the Northeast (known as the NE-35 Committee). The Ohio River Basin work is sponsored by the Resource Development Economics Division of the Economic Research Service of the U.S. Department of Agriculture. Before long most areas in the United States east of the Rockies will be included as well as some points in the west, but at present the only region for which a semblance of complete coverage is available is the central and southern Plains region shown in Figure 3. This figure is based on analyses for only 27 climatological divisions; so it must be regarded as somewhat preliminary.

Frequency of Serious Drought. Figure 3 illustrates one of the kinds of climatological analyses that can be derived. The machine results provide a drought index number for each area for each month for the 30-year period, 1931-1960. Figure 3 shows the drought severity that was exceeded during 36 of the months in the 360-month period analyzed. This figure indicates that almost the entire Great Plains region suffered -- not necessarily concurrently -- from severe drought 10 percent of the time during this 30-year period, and that in portions of Kansas and Nebraska 10 percent of the months produced extreme drought. In this predominantly agricultural region, extreme drought is almost synonymous with disaster, because the economic consequences of such a pronounced water shortage reach to nearly all levels of the local economy. On the basis of a few scattered analyses, severe and extreme drought are, as one would expect, much less frequent in most areas to the east of the Great Plains, owing to the relatively brief duration of the periods of abnormally dry weather.
Figure 3. Drought Severity that was exceeded 10% of the time.
Evidence of Periodic Recurrence of Extreme Drought in Western Kansas.
Among the few long meteorological records which I have investigated are those since 1887 for the western third of Kansas. Although no effort was made to discover "cycles of drought," the relative regularity of the occurrences of severe and extreme drought in western Kansas is rather striking. The periods of serious drought since 1887 are shown in Figure 4. The points represent the maximum severity for each year that severe or extreme drought was reached. The arrows along the abscissa mark the year of maximum severity in each of these four periods of drought. These four fairly regularly space occurrences of maximum severity may be coincidence. However, historical accounts (5) mention exceptional drought in Kansas in the early 1870's and in the early 1850's.

This apparent regularity produces a strong temptation for one to conclude that a similar period of serious drought will occur in this area in the mid-1970's, but caution dictates that one realize that this is merely a possibility rather than a foregone conclusion. Understanding of basic atmospheric actions and interactions is entirely inadequate to permit one to formulate any physical method for estimating the probability of such an occurrence. But, on the basis of past history alone, the early or mid-1970's may be years one might well anticipate.

Drought Analysis for St. Louis, Missouri, 1838 to Date. In an attempt to produce more evidence bearing on this question of periodic occurrence of severe and extreme drought, an analysis was run on the longest continuous meteorological record in the middle United States, viz., that at St. Louis, Missouri. The record is continuous from January 1838 to date. However, it does not appear to be a homogeneous record. The first 32 years seem to be much wetter than the remaining years. On the assumption that the climatic averages for the period 1838-1869 at St. Louis were similar to the climatic averages for the period 1931-1960, the early record was adjusted and the drought analysis was carried out. Peaks of maximum drought severity at St. Louis (marked by the arrows in Figure 5) appear in 1838, 1845, 1854, 1872, 1895, 1914, 1931 and 1955.

With the exception of the peak at 1845, this may appear to support the periodicity found in western Kansas, but it certainly can not be considered to be entirely independent evidence, nor does the rhythm appear so clear-cut as in the data for western Kansas. However, it is interesting to see that the meteorological evidence at St. Louis tends to substantiate the historical accounts of major droughts during the latter half of the 19th century.

As an illustration of the "cycles" that one may find in a time series if he puts his mind to it, it may be worthwhile to point out that since the 1840's no serious drought is shown in Figure 5 during the last third of every other decade. These periods are marked by the short horizontal bars in Figure 5.
YEARS OF SEVERE AND EXTREME DROUGHT IN WESTERN KANSAS

Figure 4. Years of Severe and Extreme Drought in Western Kansas.
YEARS OF SEVERE AND EXTREME DROUGHT AT ST. LOUIS

Figure 5. Years of Severe and Extreme Drought at St. Louis.
Personally, I'll be surprised if this sort of thing holds true in future years. However, it is a bit difficult and probably unwise to completely ignore the possibility that there is a real physical mechanism of some sort behind this regularity.

One possibility that one can explore is the relation between these occurrences and the sunspot cycle. The annual means of the relative sunspot numbers as given by Chernosky and Hagan (6) are also plotted on Figure 5. On inspection, one can see that some of the periods of no serious drought -- as well as one of the times of maximum drought severity -- roughly coincide with the times of sunspot maxima, while other periods of no serious drought -- and again, some of the times of maximum drought severity -- closely coincide with the times of sunspot minima. Too, the transition periods, both before and after sunspot minima, were periods of no serious drought. There seems to be little or no evidence here that these aspects of drought are related to the cycle of mean annual sunspot numbers. I don't know what the basic physical mechanism is. In fact, at this point I am not prepared to say whether this apparent periodicity in the occurrence of drought is real or not. The "cycle" I have pointed out may be purely accidental. One can hope -- and, I think, expect -- that in one way or another the future holds the key to meteorological riddles such as this.

Conclusions

The problems and risks associated with weather and crop production vary considerably from region to region. I have mentioned only a few aspects of the moisture problem; there are numerous additional problems. We must recognize them, do our best to solve or at least understand them and efficiently incorporate the knowledge into individual as well as regional farm policies and procedures.

As far as drought "cycles" are concerned, the only justifiable conclusion at this point is that there is some statistical evidence for suspecting that serious drought tends to occur about every 20 years in the central United States and that the subject requires looking into in much greater detail with more powerful methods and techniques -- preferably with longer homogeneous meteorological data series which, unfortunately, are nonexistent. The real need, of course, is for a quantum jump in fundamental understanding of the atmosphere. So long as we are unable to really explain the major meteorological events, then so long must we grope through our data in search of clues -- and wind up with uncertainty.
Bibliography


