Drought Risk in Agriculture

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1. Introduction

Weather is the primary uncontrollable factor influencing the production and marketing of crops. Variations in temperature, precipitation, and sunlight cause yields to be uncertain. Temperature variability is the leading cause of yield reduction in the Midwest. Precipitation is a close second. Sunlight is seldom a limiting factor. Technology has almost eliminated excessive precipitation as an over-all negative factor although local areas prone to flooding or poorly drained are impacted. Drought is the weather factor of greatest concern among farmers. Drought seldom has a single cause. Most drought conditions are a composite of excessive temperature, light, and wind, together with a deficit of precipitation. Any combination of the factors can be responsible for drought. Some have defined drought as precipitation deficit, but a simple definition is seldom satisfactory.

Drought is a risk to U. S. agriculture. Risk is manageable and the producer that utilizes historical and forecast weather condition data can compensate for crop loss that may occur. Management according to historical risk is beneficial. Some adjustment to long-term weather risk is feasible using long-lead forecasts and crop weather indicators. The "leading" crop weather indicators are: Subsoil moisture, the stage of the ENSO (El Niño Southern Oscillation), and the phase of the 19-year weather cycle (Benner Cycle).

2. Agricultural drought

Central North America experienced 17 general drought years during the past century. Non-irrigated yields were less than optimal because of sub-optimal water conditions during 80% all years. Most farmers do not consider that a year was a drought unless the crop yield was below average, or more specifically below the 30-year crop yield trend line (Fig. 1). Drought years since 1970 are usually considered to be 1974, 1983, 1988, and perhaps 1995. Low yields in 1993 were not caused by drought.

The concept of drought is well established but is not well defined. To the forrester drought may mean high likelihood of forest fire, to the urban manager a shortage of culinary water. Ecologists may not consider dry conditions as a drought unless the species composition begins to change. Most farmers agree that yields at 90% of trend or less are substantially reduced and this may constitute drought. Carlson, Todey, and Taylor (1996) computed crop production risks influenced by weather. Yield beyond

110% of trend or below 90% of trend were considered to deviate substantially and to be indicative of abnormal weather. Abnormally dry conditions that do not result in substantial yield reductions are considered incipient drought.

There is a 17% historical probability that any randomly chosen year will be a Midwest drought. The "risk" of drought is about 1-in-6 (17%). Producers and others impacted by variability in agricultural production should anticipate that drought would likely occur with this frequency over an extended period of time. In reality drought conditions, as indicated by tree ring records of the past 800 years, do not occur at random.

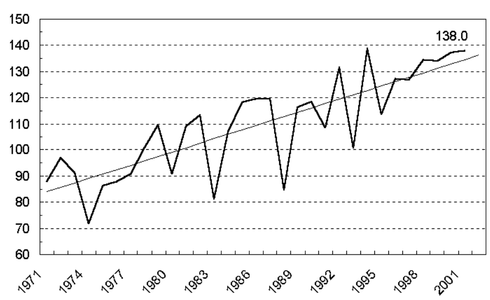


Figure 1. U. S. corn yield (bu/acre) with trend line (from USDA-NASS).

3. Benner (19-year) climate cycle

Decadal climate cycles of about 10 and 20 years occur in the Midwest. Observations during the past 150 years and implied conditions from tree rings (proxy records) substantiate these cycles. The 20-year cycle appears to be more consistent than the 10-year cycle. These may be related to the 18.6-year Lunar Cycle or to the 22-year Sunspot cycle. Benner (1891) defined the "weather cycle" as a repeating multi-year cycle rather than as a "20-year" or other clearly defined cycle.

The Benner cycle recognizes a high drought risk six-year period (2 droughts are anticipated) followed by an 11 or more year period of low risk (one drought anticipated). The Benner cycle was defined by grain and pig iron prices rather than in terms of climate. The cycle corresponds well to the tree ring record and with observations since 1885.

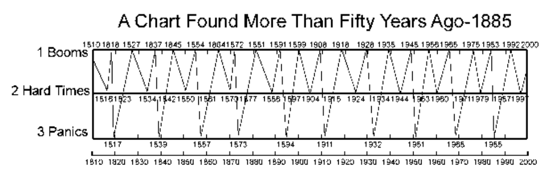
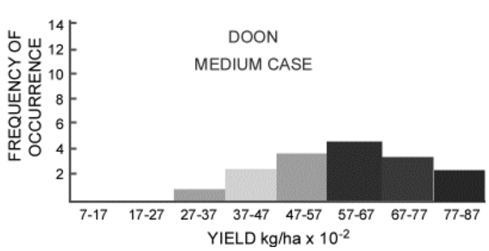


Figure 2. Benner Cycle of grain and pig iron price. The cycle consists of observations before 1885 and an extrapolation to the year 2000. Anticipated high drought risk periods include 1934, 1954, 1974, and 1988. (Adapted from Dun's Review Oct., 1937. p 42)

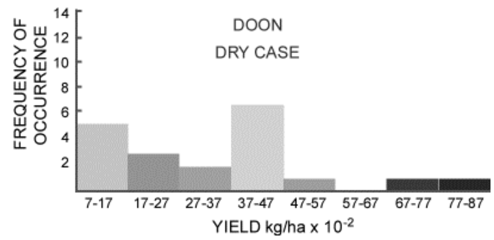
Risk of drought is considered to be 33% for years associated with the major ascending lines and 8% for any given intervening year. Using the Benner graph to make any finer scale analysis may be possible but does not appear to be of value for management decisions. It is possible that an intermediate or transition risk, could be defined for the 7 years preceding the high-risk 6-year period. It is difficult to identify an exact period for cycles that have high "noise" levels, as is the case with the Benner cycle. No physical cause of the Benner cycle has been demonstrated. Accordingly, it is not to be regarded to have the consistency of cycles driven by rotation or revolution of the Earth (daily and annual cycles) or those that are otherwise well defined. Tree ring studies do verify that the cycle has been rather consistent over the past 800 years.

4. Subsoil moisture

Crops are not sensitive to rain. Crops are sensitive to soil moisture availability. Only rarely is rain synonymous with subsoil moisture availability. In regions where growing season precipitation is not sufficient for optimal crop growth and development, the initial plant available subsoil moisture is critical to crop yields. In western Iowa the growing season precipitation is sufficient for trend line yields only 20% of all years. Initially dry soils result in substantial yield reduction 60% to 70% of the time. The same soil moisture conditions in eastern Iowa result in reduced yields only 50% of the years. In western Iowa a full yield is possible with half of normal subsoil moisture at planting time, but usually the yield is somewhat below the potential (Fig. 3a) when moisture is 25% of normal crop will yield less than half of the potential in 45% of all years (Fig. 3b).



(a)



(b)

Figure 3a,b. Near average crop yields are observed for near average subsoil moisture (a). Crop yield is often substantially reduced (in west Iowa) when subsoil moisture is less than normal (b). (Adapted from Shaw 1983)

Soil water deficits may range from 0 to 10 inches. Deficient precipitation need not always result in deficit soil moisture as plant available subsoil moisture is only removed from the soil by active vegetation. Precipitation will reduce a deficit, but below normal precipitation does not necessarily result in deficit moisture conditions. The Crop Moisture Index (short-term Palmer Index) is a reasonable approximation of subsoil moisture conditions most years. Risk planning makes use of pre-season soil moisture conditions. Long-lead forecasting of soil moisture has not been effective in risk management.

The historical crop yield risk associated with preseason subsoil moisture content may be combined with the Benner cycle risk. Logically the chance of substantial crop yield reduction is not as great if the subsoil contains optimal crop available moisture as when the moisture is depleted. It should not be assumed that the risk associated with subsoil moisture is independent of the Benner cycle. However, computation of risk assuming the variables to be independent is a reasonable first approximation until linkage is better established.

Subsoil moisture measurement programs have been established in much of the Midwest. The Iowa subsoil moisture survey was initiated in 1954 and is likely the oldest statewide record. With the development of "coupled" forecast meteorological models increased emphasis is likely to be placed on observations of plant available subsoil moisture in the near future.

5. El Niño Southern Oscillation (ENSO)

Since the late 1970s the ENSO has been recognized as an influence on Midwest weather conditions. Above trend crop yields are most likely during the ENSO warm phase and are near trend or below during the cold phase (Carlson, Todey, and Taylor, 1996). Crop response to temperature moderation under warm phase conditions appears to be a greater factor than the influence of the ENSO on precipitation. Historically there have been no widespread droughts during El Niño events and no El Niño summers are included in the hottest 25% of all summers. Random occurrence would imply that one of every four El Niño events would fall in the warmest quarter of all years. (With 0.25 chance of warm conditions for each event, the chance of 23 events without "hitting" a warm year is 1-(0.75x0.75x0.75x…..n=23) = 0.001338 or about one in a thousand). Some of the years have been in the lowest quartile of precipitation, but low precipitation alone is not sufficient to cause drought.

The ENSO condition gives a statistically strong signal for Midwest crop conditions. When the ENSO signal is combined with the phase of the Benner cycle and the risk associated with subsoil moisture status, the overall forecast value of the factors exhibits sufficient skill to be of value in crop production planning and risk management.

6. References

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