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CLIMATE CHANGES AND IMPACTS ON MIDWEST CROP PRODUCTION

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Climate change has become a topic of worldwide concern. There are few locations where the general population has a greater vested interest in climate change than the Midwest. The economy of most Midwest communities is primarily dependent upon agriculture, and weather remains the primary uncontrollable factor inducing uncertainty in production. Perhaps the greatest potential effect of climate change is the influence on crops.

The extensive drought of 1988 prompted questions concerning long-term climate change. Could such a drought be anticipated as a natural effect of weather variation? Could such a drought have been expected as a result of some long-term effect of increased atmospheric carbon dioxide (greenhouse effect), or did some other force influence the development of the drought?

Midwest Drought

During the 1988 growing season, numerous locations were identified as experiencing conditions drier than 90% of all years. Moist regions which approximated the coverage of the dry regions were also identified (Fig. 1). There was, apparently, about as much precipitation falling upon the earth as normally—it was the distribution of rain that was different. Of the regions of the planet which are normally favorable for soybean production, a significant number experienced drought during the growing season. We must consider the possibility of global linkages of climate regions. It has been assumed that widely distributed growing areas serve to stabilize production. This assumption may not be valid in light of global climate events such as occurred in 1988 or in the case of global climate change. This question is important and deserves consideration.

Drought, in general, is defined as a deficiency of moisture. As far as agronomy is concerned, insufficient soil moisture is the primary expression of a drought condition. In the spring of 1988, the soil moisture in Iowa was generally favorable in 75% of the state (Fig. 2). Although portions of Iowa had experienced serious drought during the 1987 season, the fall rains resulted in much of the soil being at or near the field capacity of 10 to 11 inches of plant-available water in the top 5 feet. The 1988 rainfall was considerably below normal in most of the state, and serious drought conditions had developed by late June (Fig. 3).

Precipitation for 1988 may be compared with the precipitation of 1934, the most serious drought year in this century. The statewide precipitation total in 1988 was less than the total in either 1934 or the associated Dust Bowl year of 1936 (Fig. 4).

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The four major droughts of this century, as evaluated by effect on crop yield, are 1934 as the most serious, 1936 as the second worst drought year, 1901 as the third, and 1988 as the fourth most serious. Thus, there have been three years during this century with a more serious drought than occurred in 1988. Although there was less precipitation than in the drought of 1934 or 1936, the 1988 drought did not have as serious an effect on the crops. Two or three possible reasons may be suggested: First, crops of today may have improved tolerance to stresses associated with drought; second, cultural practice may be improved.

The primary factor, however, may well be temperature. Drought involves both temperature and precipitation, and the temperature in 1988 was considerably cooler in July and slightly cooler in August than it was in the drought year of 1936. The temperatures were also not as severe as in 1934 (Fig. 5). The combination of temperature and precipitation was not quite as severe as during the Dust Bowl years, when serious drought in 1934 and 1936 occurred over an extensive area. Some locations also experienced drought conditions in 1935 and some in 1937. But during these years, drought was not spread over a wide geographical area.

**Subsoil Moisture**

An annual spring survey of soil moisture is conducted in Iowa. Soil samples are taken from fields at more than 50 sites. The water content of the soil samples is evaluated and a statewide, generalized moisture map is published. Throughout the crop season, rain and evaporation measurements are used to compute the quantity of water retained in the subsoil (Fig. 6). The pattern of soil moisture depletion at Ames, Iowa, was typical for most of the state. The season at Ames began with 7 inches of plant-available water in the top 5 feet of soil. There were several small rain events in the spring. Normally, June is the month of greatest precipitation in Iowa (Fig. 7), and the June rain builds the soil moisture level to a value near the field capacity. Generally, by the end of June the drain tiles in at least half of the state are running, indicating that the soil is at its soil moisture holding capacity or slightly above it. The excess moisture often received in June provides a reserve supply in the soil and helps sustain crops through July and August. The months of July and August do not normally have sufficient rain to meet the needs of the crop, so crops must rely on soil moisture reserves. The light spring rains were an indication of developing weather conditions and the scant precipitation in June resulted in the reduction in yield experienced in 1988. By mid-June, subsoil moisture over most of Iowa was reduced to 4 inches of crop-available water in the top 5 feet of soil.

With 4 inches of plant-available moisture in the soil, on a sunny day the corn leaves are rolled by 10 or 11 o’clock. The plants usually recover soon after sundown, when the heat of the day is broken. Mid-day wilting or leaf rolling may slightly reduce the development and growth of the crop. When 2 or 3 inches of water remain in the soil, the leaves will often remain rolled throughout the 24-hour period, and there may be some reduction in crop surface area; soybeans and corn tend to abort more of their lower leaves and corn leaves may remain rolled day and night. Some of the leaves may begin to "fire" and be lost. By the time moisture is reduced to 1-2 inches of plant-available water in the soil, the plant has ceased to grow. The plants do not necessarily die but begin to transfer the foodstuffs from the stems and roots to the grain, if grain has begun to form.
By mid-August of 1988, crops in most of Iowa had ceased to function as developing plants although nutrients were still being translocated to the grain. Significant rains came in August, although some areas did not receive rain until the end of September. By late August, corn and soybean plans were no longer using moisture from the soil. Although there still may have been some leaves that were green, there was little water consumption.

The amount of moisture in the subsoil on March 1, 1989, was approximately the total rainfall that occurred after the crop stopped growing. For much of Iowa, the actual amount of moisture present in Iowa soils was equal to the amount of rain that fell after the last week in August. Some locations had a little more resulting from residual soil moisture reserves, but most did not. When intense rain events occur, the full amount of moisture will not be absorbed by the soil because of rapid runoff.

**Cause of the 1988 Drought**

Meteorologists have determined that there are a few persistent features of the global climate that can serve as reliable indicators of weather patterns. El Niño and anti-El Niño events have consistent global influences as does the pressure pattern of the North Pacific. During 1988, the weather map indicated some deviations from normal which appeared to have a direct influence on the Midwest drought pattern that dominated most of the growing season. A simplified and basic weather map of normal summer conditions is characterized by a persistent low pressure area just east of Hudson’s Bay, a high pressure region over Bermuda and a high pressure region over the Hawaiian Islands (Fig. 8). A clockwise flow of air around the Bermuda High brings the moisture from the Gulf of Mexico, up the Mississippi River Valley into the Midwest.

During the late spring and early summer of 1988, ocean temperatures between Hawaii and Acapulco were well above normal and storms to the southwest of California were perhaps more pressure system in the Gulf of Alaska. This low is termed the persistent Pacific negative anomaly, because once in place, it will often stay for 60 to 90 days. The low pressure was responsible for the warm January of 1988 and was a harbinger of the dry year to come. The pressure system caused air to flow directly over the mountains and into the Midwest during the winter and spring and resulted in an effect that was essentially a large scale chinook. The chinook often occurs in Wyoming, Montana and adjacent parts of Canada. As the air passes from the West Coast and over the mountains, it loses its moisture and descends warm and dry into the Plains (Fig. 10). Because of the lack of moisture in the air, it heats more than it would if it were moist air. It may come onto the Plains warmer than it began on the Pacific Coast. The chinook effect reached well into the Midwest and persisted for several months during 1988.

Additionally, there was a localized high pressure over land, which normally is not the case in summer. The Bermuda High failed to develop, at least in its normal location. The high pressure over the Midwest resulted in a shunting of the moisture from the Gulf into northern Mexico, Arizona and the adjacent areas. The warm ocean temperatures between Hawaii and the coast of Mexico resulted in low pressure development and additional moisture impinging upon the Southwest.
Coast of the U.S. These two moisture paths colliding in the Southwest resulted in parts of Arizona receiving Iowa's normal rainfall. A record moist year resulted in Arizona, New Mexico, Utah, and Colorado. The drought began in Kansas and, under the influence of the continental high pressure, affected the weather of the entire Midwest.

The existence of the drought became apparent in April and commodity prices were thought to be influenced by the developing weather conditions. If we assume that the soybean market was driven by weather, the drought conditions had become apparent to almost everyone by June, as was demonstrated by increased soybean prices. In late June there was a change in the weather pattern indicating that July, August and September were likely to be near normal in the Midwest. Because normal summer weather does not provide sufficient precipitation to meet water usage, the crops could not achieve their genetic yield potential with the limited soil moisture reserve going into the summer season. The return to normal weather did permit an assessment of the extent of potential crop loss. The analysis of drought stress, distributed as a news release by the Extension Service at Iowa State University, anticipated a 28% reduction in both corn and soybeans and that was an accurate prediction. As the crop season progressed, precipitation did become normal and the actual crop loss could be calculated with normal weather for the remainder of the growing season. By late June, the market ceased responding to anticipation of worsening drought.

Departure from Normal

In Iowa, 1988 ended as one of the drier years in history (Figs. 11a and 11b). The annual deficit was about 15 inches less precipitation in nearly two-thirds of the state than is usually received. The extreme was 20 inches less than normal precipitation in Taylor and Ringold Counties. There was considerable variability even within a county-size area. Some locations received normal moisture in areas where their neighbors had less than usual.

The precipitation required to correct the drought conditions in the state is not necessarily the amount to compensate for the annual deficiency. If a "drought" is considered to be the height of water standing within a well and the sustained flow of springs and rivers, it is not likely to end during 1989. It will not be likely to end for several years. The groundwater must recover to its normal levels before stream flow can be sustained at normal stream levels and the depth of water in wells is corrected.

However, if "drought" is the effect on subsoil moisture which influences our crops, called the agricultural drought, it cannot take more than 10 inches to correct because the capacity of the soil is only 10-11 inches. The -15 and -20 inch moisture deficits are not realistic if the crop production aspect of drought is being considered. The actual amount of precipitation required to correct an agricultural drought is the amount required to return subsoil moisture levels to normal. The Iowa soil moisture map for the beginning of 1988 indicated that most areas had 5 to 7 inches of moisture and would require 4 to 6 inches of precipitation to recharge the soils (Fig. 12). A few areas had normal to above normal subsoil moisture. There was considerable variation in subsoil moisture within a local area and even
between farms. Also, the fields planted to forage crops continued to expend soil water well into the late fall and the fall rains that served to somewhat recharge corn and soybean fields were not sufficient to recharge pasture and hay lands.

Normal precipitation in April, May and June would be sufficient to bring soil moisture levels to normal for fields which were planted to corn or soybean crops during 1988. The forage lands where plants remain green and consumed moisture late in the season would require somewhat above normal rain to fully recharge. In Iowa, forage lands began 1988 as very dry, because fall moisture was not retained.

**Long-range Weather Outlook**

The National Weather Service provides extended outlooks which assess the probability of normal weather conditions for up to 90 days. The 30- and 90-day outlook predictions make use of the global features that have proven reliable as indicators of 30- and 90-day weather patterns. A statistical method employed by some climatologists considers the sequence of events and the occasions when a similar sequence was expressed historically. The cold and dry February of 1988 (4.2 degrees colder than normal and only 50% of normal precipitation) was followed by a hot and dry spring and early summer. Is the probability increased that the cold (9.1 degrees below normal), dry (55% of normal precipitation) February of 1989 will be followed by another dry and hot spring?

The weather conditions that were directly responsible for the drought of 1988 did not exist in February of 1989 and thus a favorable outlook for springtime moisture to be near normal and perhaps slightly to the wet side was implied. The odds at that time were not greatly in favor of a moist spring, but at least they did not lean towards continued drought in 1989.

What about the summer? If an extensive drought develops during the summer of 1989, it will not be caused by the same forces in nature that were directly responsible for the drought of 1988. The conditions present in 1988 did not exist in early 1989. So if drought conditions develop in the summer, it will be for some other reason. A disastrous year is not anticipated. However, because soil moisture reserves are less than normal, the region is more susceptible to drought than it would be if the soil profile were saturated with water. Because the normal rain in July and August is not sufficient to meet crop needs, a deficiency of soil moisture in the spring greatly increases the possibility of agricultural drought during the summer.

**Drought Cycle**

If weather conditions were truly chance, close to one-half of all weather recording locations would have below average rain and half above average rain in any given year. However, when a count is made of the number of weather stations west of the Mississippi River that reported below normal rain during each of a series of years, it becomes apparent that periods with greatly increased dryness develop every 15 to 20 years (Fig. 13). The data indicate that droughts do come somewhat in cycles, and these cycles may be predictable.
Dr. Louis Thompson at Iowa State University has gathered data concerning moist and dry years and compared them with market values for grain. A chart of the grain price variation (Fig. 14) is strikingly similar to the drought record. Dr. Thompson noted that there is an identifiable 18.6-year period to the drought conditions that sometimes adversely affect the production of grain in the United States (Fig. 15). Some good years occur during the times of shortage and some droughts do develop during the times when production is mainly high; however, two-thirds of all serious agricultural droughts appear to fall within the 6-year period of shortage and only one-third of the droughts develop during the subsequent 12.6 years.

There is a possibility that the 18.6-year cycle is predictable, but a possibility also exists that it is simply coincidence. There are sufficient historical data to show that a mechanism responsible for the cycle could possibly be identified. Some mechanisms have been proposed that could explain the periodic development of droughts on the order of the 1988 event. However, it should not be assumed that the drought experienced in 1988 and the droughts that may come in the next few years are a direct effect of climate change. They may be a natural function of cycling of periods of drought and periods of plenty in the Midwest.

**Climate Change**

Regular measurement of atmospheric carbon dioxide began about 1957. Thirty years of data show a carbon dioxide build-up in the Earth’s atmosphere (Fig. 16). This build-up is expected to continue in the pattern we have seen since measurements began. There is no doubt concerning the change in the carbon dioxide of our atmosphere. However, the direct effect on temperature and precipitation is not known. A postulated effect of carbon dioxide on the earth’s temperature is commonly referred to as the "greenhouse effect". The greenhouse effect of carbon dioxide and of several other gases in our atmosphere appears to be significant.

In evaluating the greenhouse effect, both that occurring naturally and that being influenced by our modification of the environment must be considered. The natural greenhouse effect is a result of carbon dioxide and other gases and is considered to be responsible for the earth's temperature being approximately 60 degrees, on the average, worldwide. If it were not for the natural greenhouse effect, it is thought that the world’s temperature would average about 40 degrees and this planet would not be suitable for life as we know it.

The man-made greenhouse effect is an influence due to things that we have modified, such as the carbon dioxide increase. If the carbon dioxide is doubled, would it add another 20 degrees to the world’s temperature? Would it add another 5 degrees to the world’s temperature? If 5 degrees are added to the world’s temperature, would it have a similar influence to that which we experienced this past year when the world was reported to be about 1 degree warmer than usual? Was our drought a forecast of things to come? Will the sudden, man-made change of climate upset the balance of atmospheric processes and cause the weather to fluctuate wildly over an extended period of time?
Adjusting to a modified climate that is stable and predictable would not be as difficult as would adjusting to an unstable situation of intermittent hot dry weather and interludes of some other extreme. Problems associated with plant breeding efforts to adapt crops to a changed climate would not be insurmountable if the change is over a reasonably long period of years. These are questions that could be answered with well-supported research and will eventually be answered by observation over the next 20-40 years. It would be good to answer them from science initially and not have to wait and see.

Since 1880 the average temperature of the world increased, at least until 1950 (Fig. 17). At about that time, there seemed to be a turnaround and the temperature of the world appeared to be decreasing. By the mid-1970s, temperature began to climb again. There are theoretical indications that warming may be accompanied by more arid Midwest conditions, but there are some who feel that if the climate does warm, the Midwest could become more moist. Some analyses of global warming that may be associated with the greenhouse effect say that eventually most of North America will become arid. Others say that the Mountain West will be more arid and the East will become very moist. We really don't know which, if either, is correct. The NASA greenhouse computations indicate that Midwest precipitation and temperature will increase. The Weather Service computes that the Midwest may become warmer and drier (Fig. 18).

There is no strong reason to believe that the weather this past year was due to greenhouse warming because there have been three years of droughts more serious during this century when we didn't have the man-made greenhouse effect, and cycles do seem to occur naturally. According to historical weather cycle data, 1988 was the first year of the 6 years when droughts may be more likely (Fig. 15).

Another factor that directly affects our droughts in the Midwest is the El Nino event that came to public attention in about 1982. Major El Nino events develop every 2 to 6 years (Fig. 19). Midwest droughts are not likely to develop during an El Nino event. The El Nino of 1982 was by far the strongest in recent history, and was followed by a Midwest drought in 1983. The El Nino of 1987 was followed by the drought of 1988. All of our major droughts since 1936 have been on a year following an El Nino event. It is possible that there is a physical relationship between the conditions that follow an El Nino and the development of droughts in the Midwest.

Not all El Ninos were followed by a drought; however, El Ninos occurring during the 6 years when shortages are most likely have been followed by droughts of a serious nature. The combination of cycle and El Nino information provide a 1-year prediction or at least a prediction of likelihood of conditions that bring drought to the Midwest. If there is an El Nino occurring, when it ends there may be a higher probability of drought, and the possibility is greater if it is a time of expected shortage as judged from the 18.6-year weather cycle that has been postulated to exist in the Midwest.
Fig. 1. Exceptionally dry regions during the 1988 growing season (May, June, July)
Fig. 2. Plant available moisture in the top 5 feet of soil (January 1, 1988). Clear and stippled areas have more than 8 inches of reserve moisture. Cross-hatched and shaded zones have less than 8 inches of plant-available water reserve.
Source: E. Taylor.
Subsoil Moisture

Fig. 3. Subsoil moisture in Iowa on June 29, 1988. Source: E. Taylor.
Fig. 4. Monthly accumulated precipitation for Iowa. Comparison of 1988 with Dust Bowl years of 1934 and 1936.
Source: ISU Climatology
Fig. 5. Average monthly temperature for Des Moines, Iowa. Comparison of 1988 with Dust Bowl years of 1934 and 1936. Source: ISU Climatology.
Soil moisture and rainfall in 1988

Ames

Fig. 6. Soil moisture reserve at Ames, Iowa, diminished from near 8 inches in May to less than 2 inches by mid-August. Source: E. Taylor
Fig. 7. Normal monthly precipitation for Iowa (1941-1970).
Source: Paul Waite, state climatologist.
Fig. 8. Normal early summer weather pattern. High pressure in Atlantic (off Florida) induces flow of moist air from the Gulf of Mexico to the upper Midwest.
Source: E. Taylor.
Fig. 9. Early summer 1988 weather pattern. Low pressure anomaly off the West Canadian coast and high pressure over the Midwest contributed to a displaced moisture pattern and severe Midwest drought.
Source: E. Taylor.
orographic lifting causing clouds and precipitation which releases latent heat of condensation

Fig. 10. Airflow over a mountain range; a mechanism of a chinook.
Fig. 11a. MOST RECENT YEAR WITH LESS PRECIPITATION THAN IN 1988

Fig. 11b. DEPARTURE FROM NORMAL ANNUAL PRECIPITATION DURING 1988 (IN)

Subsoil Moisture  May 24, 1989

Fig. 12. Plant available subsoil moisture for corn and soybean fields

- Average subsoil moisture less than 7 inches
- Average subsoil moisture 7 inches or greater

Grass and alfalfa fields may have substantially less moisture. Land planted to soybean in 1988 may have 1 or 2 inches less moisture than corn land. Subsoil moisture normally exceeds 7 inches in 90% of Iowa on June 1.
Fig. 13. Climate stations reporting below normal annual precipitation.
THE CYCLICAL PATTERN OF THE AGRICULTURAL ECONOMY
18-19 YEARS

Fig. 14. A graph found in a distillery in 1885 predicting the economic cycles to 1985.
Source: Dun's Review, 1937.
### Agricultural Production 18.6 Year Cycle

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**Fig. 15.** Historical periods of weather-related variations in grain production in the Midwest. Periods of shortage include more than half of all wide area droughts. Source: Louis M. Thompson, *Cycles*, Dec. 1988, 286-287.
Fig. 16. Changes in the atmospheric concentration of carbon dioxide.
Average Global Temperatures

GREENHOUSE WARMING

GISS NASA       Warm and Moist       +4.5 °C
GFDL NOAA       Warm and Dry        +6.5 °C

1°C ≡ 100 miles

Fig. 18. Anticipated effect of doubling the atmospheric carbon dioxide using two global climate models. The result indicates model forecast for the Midwest.
Major El Nino events

Fig. 19. Curves for an index of El Nino. Solid lines are sea surface temperature anomaly. Dashed line is pressure anomaly.