Weather Variability, Climatic Change, and Grain Production

Weather variability is a much more important consideration in grain production than a cooling trend.

Louis M. Thompson

There has been more than usual attention in the press to weather and climatic change since mid-1974. The United States had so little variability in weather and grain production in the past two decades (until 1974) that an attitude of complacency had developed. There was frequent reference in the early 1970's to the fact that technology had advanced to such a level that weather was no longer a significant factor in grain production. In early 1974 the U.S. Department of Commerce warned of the probability of drought with the publication *The Influence of Weather and Climate on United States Grain Yields: Bumper Crops or Droughts* (*1*). In commenting on the publication, a committee of the U.S. Department of Agriculture (USDA) stated (*2*):

A comprehensive study published by this Department in 1965 evaluating the effect of weather and technology on corn yield in the Corn Belt for the years 1929 through 1962 concluded that through the use of better varieties and improved cultivation and fertilization practices, man has reduced variation in yields in both good and bad weather. It seems logical to assume that continued progress has been made since that date, particularly in the use of fertilizer, improved cultural practices and the increased benefits of mechanization.

The highly variable weather of 1974 was shocking to so many people that now there is more than usual concern over the future of our food supply.

An unusually wet spring over most of the U.S. corn belt was followed by drought in the Great Plains. Then came an early frost that further reduced production of grain at a critical time in history. Grain reserves were at a 20-year low in 1974 at a time when farmers were producing record numbers of hogs, cattle, and poultry. As a consequence of the short crop and high priced grain there have been serious financial losses in the livestock industry. The livestock producers could not afford the high priced grain, so they started liquidating their herds and flocks. The result was erosion of prices for livestock products on farms but a continuation of inflation in food prices. The resulting inflation is having serious effects on the economy as a whole.

Questions are being asked about what this all means to our future if weather should become more variable or if the cooling trend started about 1940 continues to the year A.D. 2000.

The Relation of Weather to Grain Production

Most of the world grain production is in the middle latitudes where summer temperatures average between 70° and 75° Fahrenheit (21° and 24°C). The grain belts are limited at lower latitudes by high summer temperatures and at higher latitudes by the length of the growing season. The highest yields of grain usually occur in summers of lower than normal temperature for a particular area. There are two important factors that are associated with this relationship. One is that higher rainfall is usually associated with the cooler than normal weather. The other is that cooler weather permits greater storage of photosynthate—that is, the products of photosynthesis are lost to a greater extent in warmer weather because of the higher rates of respiration.

The average temperatures for the summer months in the U.S. corn belt are as follows: June, 72°; July, 76°; and August, 74°F. The highest yields of both corn and soybeans have occurred in summers with lower than normal temperatures in July and August. Figure 1 shows the relationship of June, July, and August temperature to the yield of corn in the U.S. corn belt. The optimum daily average temperature is 72°F in each of the summer months. The optimum range is not less than 50°F at night nor greater than 86°F in the daytime. When the temperature rises above 90°F, the weather is unfavorable for corn. The same is true for soybeans. This crop has the same optimum temperature requirements as corn.

Figure 2 shows the year to year fluctuations in the average temperature for July and August in the corn belt since 1900. The summers from 1902 to 1911 were as cool as in the period 1960 to 1970. Every summer from 1930 to 1940 was warmer than the average for this century. The 1910's, 1930's, and 1950's had considerable warm weather while the alternate decades, the 1900's, 1920's, 1940's, and 1960's, were characterized by several cooler than average summers.

The highest yields of corn are associated with normal precipitation from September through June, and higher than normal rainfall in July and August. As much as twice the normal rainfall in July would be expected to produce the highest yields of corn.

The per acre yield of soybeans is related to July and August rainfall in an almost linear fashion (*3*). Because this crop can continue forming pods in August, soybeans can recover from a July stress period and produce a good crop with favorable weather after July. This means that soybeans are somewhat more drought tolerant than corn.

Wheat grown in the Great Plains responds with higher yields to greater than normal rainfall, whereas wheat grown in the corn belt, particularly in Illinois and Indiana, yields more when rainfall is normal or slightly below normal. Wheat grown anywhere in the United States is adversely affected by higher than normal temperature from flowering time until the crop is mature.

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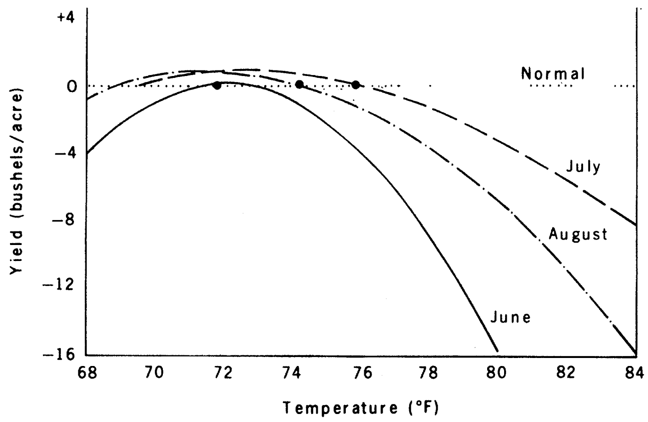


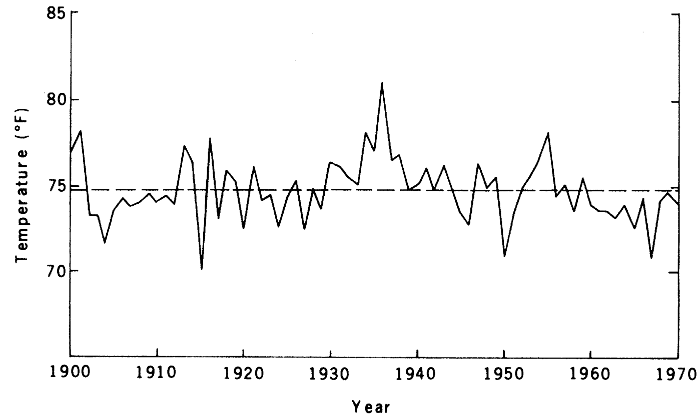


Fig. 1 (left). The relation of corn yields to summer temperatures in the U.S. corn belt. Fig. 2 (right). Fluctuations in average temperature during July and August in the U.S. corn belt.

Wheat (spring wheat) grown in Canada is also favorably affected by lower than normal temperature, but the problem in Canada is that lower temperatures are related to a shorter growing season. The fluctuations in yield of wheat from year to year in Canada are greater than in the United States and are highly related to weather.

Unlike winter wheat, spring wheat grown in the northern great plains of the United States and Canada has not shown a steep trend in yield increase. Spring wheat yield is so highly related to weather that heavy fertilization with nitrogen is less profitable than the same rates applied to winter wheat.

Recent Trends in Weather in the Middle Latitudes

The warm, dry summers of the mid-1930's were felt in both hemispheres in the middle latitudes. Grain yields were adversely affected in Russia, Australia, and Argentina just as they were in the United States. The decade of the 1940's was more favorable, except for the year 1947. There was severe drought in Russia in the 1950's, particularly in 1953. There was gradual improvement from 1953 to 1958 in Russia but the peak of the drought in the United States was in 1955. The summer of 1958 was cooler and wetter than normal in the middle latitudes of the Northern Hemisphere and resulted in new record yields in grain in both Russia and the United States. There were localized droughts in 1964 in the United States, but yields of corn and soybeans for the corn belt as a whole were about 95 percent of normal. The summer of 1964 was the least favorable in the decade of the 1960's from the standpoint of summer drought in the corn belt.

Figure 3 shows the yield of corn in the U.S. corn belt from 1930 to 1973. The yield variability was calculated from a multiple regression equation in which weather variables and technology were taken into account. The time trends from 1930 to 1960 and 1960 to 1973 indicate the technology trend as well as the trend in yield with normal weather. The yield trend with normal weather was determined by assuming no deviations from averages of the weather variables. Average (or normal) weather in the corn belt is good weather and associated with higher than average yields. In order for yields to be above the line for normal weather, the weather in July and August must be cooler and wetter than normal (*4*).

There were severe departures from normal weather yields of corn from 1930 to 1940, and significant departures in the mid-1950's. The years 1942, 1946, and 1948 were very favorable, but 1947 was a severe weather year. The first part of the summer of 1947 was too wet and the latter part was exceptionally warm and dry. The run of years from 1960 to 1973 was exceptionally favorable. The deviations from the trend line for normal weather were small, and half the years were normal or better. The low yield in 1970 was due to blight.

Figure 4A shows the effect of weather on corn yields for every year from 1891 to 1973, calculated from the regression equation with the assumption of a 1973 level of technology throughout the period (*1*). The most striking feature of this figure is the run of favorable years from 1956 to 1973. The yields were 95 percent of normal or better every year. There was much variability in weather from 1891 to 1956. From the standpoint of corn yields there was substantial improvement in weather from the mid-1930's to the early 1970's. So a significant part of the yield trend since the early 1930's can be directly attributed to improved weather. The most severe departures from normal on the negative side have been due to warm, dry weather. There was drought in about 10 percent of the years, enough to drop yields below 90 percent of normal.

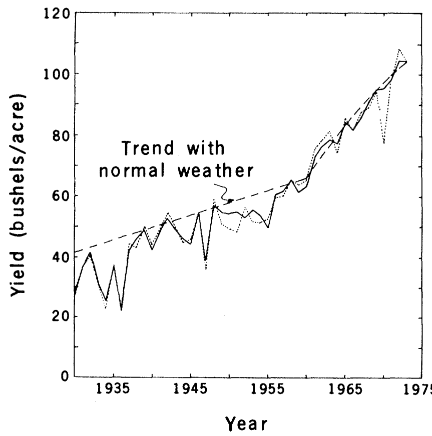
Figure 4B shows the effects of weather on soybeans, again calculated with the assumption of a 1973 level of technology. The run of favorable weather years from 1956 to 1973 shows up for soybeans just as for corn. It should be recognized that the normal yield is above the average yield for the period. Normal weather is good weather for soybeans in the U.S. corn belt. This figure further illustrates the concept that soybeans are less vulnerable to drought than corn.

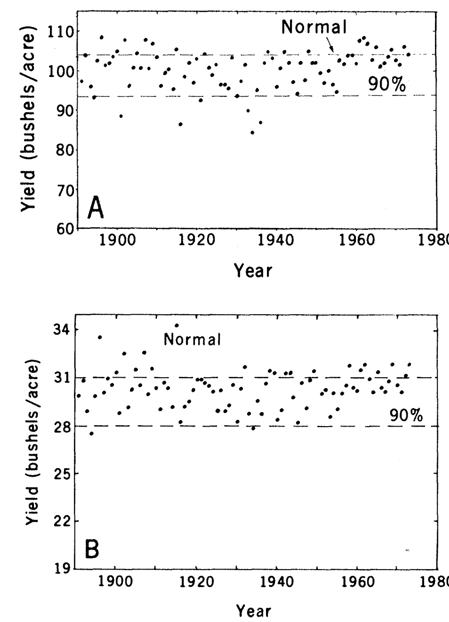
In a similar study with wheat, there was not the run of favorable years in the Great Plains that occurred in the corn belt. The variability in weather was almost as great in recent years as in the entire period from 1891 to 1973. The probability of yields below 90 percent of normal was about 11 percent. The periods of least desirable weather were in the 1890's, 1910's, 1930's, and 1950's from 1891 to 1973.

Projections of World Grain Production

Any projections on U.S. grain production must take into consideration the fact that corn accounts for about two thirds of the total tonnage of cereal grains produced in the United

Fig. 3 (left below). The trend in corn yields in the U.S. corn belt. Dotted lines connect annual yields estimated by the USDA. The solid line shows the yield variability calculated from a multiple regression equation in which weather variables and technology were taken into account. Fig. 4 (right below). Average corn yields (A) and soybean yields (B) for five states in the U.S. corn belt calculated with the assumption of a 1973 level of technology for all years (*1*).



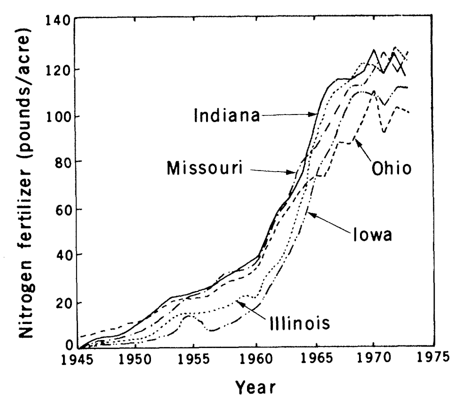


States. Corn yields per acre have doubled since 1950 and the corn belt had unusually favorable weather from 1956 through 1973. The most significant increase in yield of corn occurred after 1960 when nitrogenous fertilizers became cheap and plentiful. Figure 5 shows the trend in use of nitrogenous fertilizers on corn in the five central corn belt states. The use of such fertilizers appears to be leveling off at about 120 pounds per acre (135 kilograms per hectare). Such an amount seems logical because in every bushel of corn there is about a pound of nitrogen, and it is conceivable that 120 bushels per acre (7.5 tons per hectare) will be the average yield for the corn belt in a year of good weather by 1985.

Figure 6 shows the yield of corn on seven experimental farms in Iowa in recent years compared to the average yield in the state. When the yields are corrected for the effects of weather the trend appears to be level with an average of about 120 bushels per acre, but with a yield as high as 145 bushels per acre in the most favorable year, in 1972. The average yield for Iowa has trended upward very steeply since 1960 and is approaching the level of the experimental farms where all known technology is being applied as recommended to farmers. That the trend in yields on the experimental farms remained level in the decade of the 1960's can be explained by the absence of any breakthroughs in technology. The simple fact is that farmers are consuming technology faster than it is being produced by research.

Figure 7 was developed by using a regression equation derived from corn yield and weather data in Illinois. The time trend since 1960 was derived by use of a linear and squared term. By assuming no departures from normal weather the equation shows a leveling of yields at 120 bushels per acre in Illinois by 1985.

The USDA has made projections of world grain production to 1985 as shown in Table 1 (*5*). It is indicated that the annual percentage increase in production of grain in the world will be at least 2.2, which is greater than



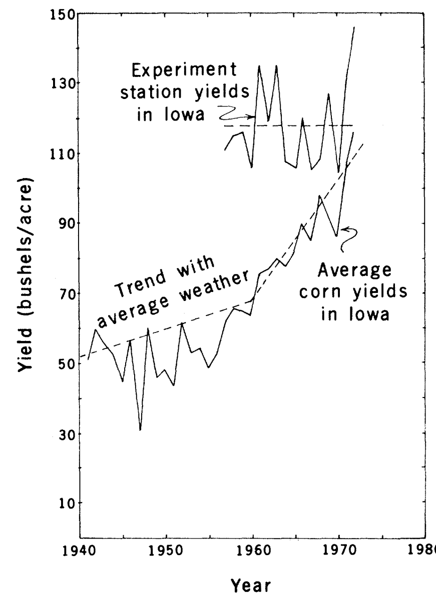


Fig. 5 (left). The trend in the use of nitrogenous fertilizers on corn in the U.S. corn belt. Fig. 6 (right). Corn yields on seven experimental farms in Iowa compared to average yields in Iowa.

Table 1. World production of cereal grains projected to 1985 compared to production during 1969 to 1971. The USDA projections are based on four alternative assumptions* (*5*).

Production in 1985 (metric tons × 10^6)					Annual increase to 1985 (%)			
1969 to 1971	1	2	3	4	1	2	3	4
			World					
1081.8	1550.4	1620.6	1503.6	1645.7	2.4	2.7	2.2	2.8
			Developing countries					
443.1	632.4	648.7	626.2	721.0	2.4	2.6	2.3	3.3
			Developed countries					
638.7	918.0	971.9	877.4	924.7	2.4	2.8	2.1	2.5
			Deficit in developing countries					
−23.5	−58.8	−77.5	−52.4	−22.5				

* The four alternate assumptions are as follows. Assumption 1: Economic growth has been temporarily slowed, but resumes strong expansion in the late 1970's and early 1980's. However, under this alternative, continued high internal prices limit expansion of world trade. Assumption 2: There is a high, worldwide demand for imports. Under this alternative, income grows at a faster rate, in both developing and developed countries, than with assumption 1. In addition, there is progress toward removing barriers to trade in the developed world, and the centrally planned economies increase their efforts to improve diets. Assumption 3: Demand is low, economic stagnation continues into the late 1970's, and recovery does not occur until the 1980's. Assumption 4: The developing countries' import needs are reduced because they increase their investments in food production by embarking on a policy of increasing the bundle of inputs used to produce food.

the expected increase in world population growth by 1985. Such optimism is not widely shared because the projections are based on coefficients developed from a period when weather was generally favorable, when there was a significant improvement in varieties of wheat and rice, and when there was a significant uptrend in the use of nitrogenous fertilizers on all cereal grains throughout the world.

As we look to the future of grain production we must recognize that weather is becoming a limiting factor, as well as technology. The unfavorable weather of 1972 and 1974 in the middle latitudes and the failure of the monsoons in India and the sub-Sahara over the past several years have caused greater recognition of weather and climate in relation to food supply in the world. I shall now consider climatic change as a factor in world food supply.

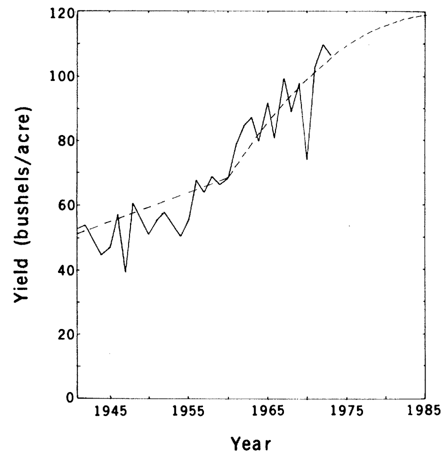


Fig. 7. A projection of corn yields in Illinois up to 1985. A decade of normal weather is assured.

Recent Trends in Climatic Change

There was an upward trend in mean annual temperature in the middle latitudes from the latter part of the 17th century until about 1940. The trend increase was about 3°F; however, the fluctuation in temperature from decade to decade was in a range of about 4°F. The coolest part of the last 1000 years occurred late in the 17th century. This cool period was preceded by one almost as cool around A.D. 1400. These cool periods have been referred to as the Little Ice Ages. There have been many references to the fact that unfavorable weather had serious effects on agriculture in Europe during the Little Ice Ages. Such a change in climate would undoubtedly have a serious impact on agriculture of North America, particularly in Canada.

There was a cooling trend between 1825 and 1840 that was very sharp and represented a change of mean annual temperature of about 3°F for the eastern seaboard of the United States.

Figure 8A shows the mean annual temperatures from 1738 to 1967 for the eastern seaboard in an area centered on Philadelphia. From the 1830's to the 1930's there was a long-term warming trend that was marked by many reversals of years cooler than the previous one. There was as much variation in the mean annual temperature from decade to decade as there was change in average over a century. The warming trend over a century was about 3°F and the variation from decade to decade was as large.

The precipitation pattern for the eastern seaboard (Fig. 8B) shows a period of considerably more precipitation around 1850 than there is now. There has been so much variability in precipitation in this area that it is difficult to show a trend, but in looking at a span of 100 years there has been a marked downtrend in precipitation of about 15 percent.

There is also indication that the carrying capacity of the rangeland of the Great Plains of the United States declined significantly during the latter part of the 19th century (*6*).

In a general way one can say that climate changed during the century from the 1830's to the 1930's. The change was a warming trend with declining precipitation. Yet the fluctuations from year to year were greater than the change that occurred during the century.

The warming trend was reversed in the late 1930's and this reversal continues to the present time although it was interrupted by a warming period of about 5 years in the mid-1950's. There has been particular concern about the unusual climatic conditions of the past 6 years. The droughts associated with failure of monsoons in India and the sub-Sahara region have received much attention. Probably as significant is the excessive snowfall that occurred over the 5-year period from 1968 to 1973, and reported by Kukla and Kukla in 1974 (*7*). It is believed that further expansion of the area covered by snow and ice in the Northern Hemisphere would increase weather variability and result in a trend toward the climate experienced in the first half of the 19th century. However, a recent personal communication from George Kukla indicates that the expansion of the snow and ice in the Northern Hemisphere may have been reversed in 1974.

The question is whether or not we have passed the warm peak of the present interglacial period. While this is a real possibility it is interesting to consider the probability of our being near the peak. The Ad Hoc Panel on the Present Interglacial (*8*) stated the probability as follows:

> The probability of occurrence of a transition associated with the fundamental 100,000 year glacial–interglacial vacillation is about .002 in the next 100 years and .02 in the next 1000 years.

There is no way of knowing when the peak of an interglacial period occurs, and there is no way of predicting long-term changes in climate. When one looks at the record of pulsations in climate of the past there is the inescapable conclusion that once the peak of the interglacial period has been reached, the long-term cooling trend will be interrupted many times by warming intervals. When measured in change in global temperature over a thousand years the average annual change will be very, very small compared to the 1°F change that has occurred since 1940. It is important, however, that climatic changes be monitored and that agricultural scientists be alert to changes that we might have to make as we project a cooling trend or a warming trend.

The Impact of Human Activity on Climatic Change

There has been much speculation about the relationship of pollution resulting from human activity to the recent change in climate, that is, the cooling trend may have been caused by human activity. There are at least three ways in which pollution might become a factor in climatic change: (i) As a result of our burning fossil fuels, carbon dioxide is accumulating in the atmosphere where it has a warming effect; (ii) smoke particles and dust screen out the sun's energy; and (iii) lead or other particles that pro-

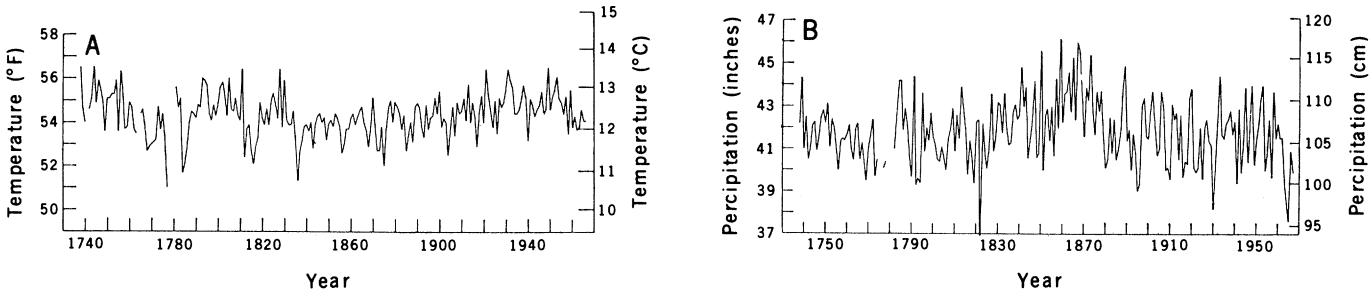


Fig. 8. Mean tmperatures (A) and total annual precipitation (B) for the eastern seaboard of the United States for the period 1738 to 1967. The data are from representative, reconstructed synthetic series centered on Philadelphia. [From Landsberg (*11*)]

vide nuclei for precipitation increase total precipitation or cause redistribution of natural precipitation patterns.

It is believed that carbon dioxide has a "greenhouse effect" on the earth's temperature in that it allows transmission of the sun's energy as short rays but absorbs the longer rays reradiated from the earth's surface. The result is a warming effect. The amount of carbon dioxide released has been increasing by about 0.2 percent per year, primarily because of the burning of fossil fuels. It is estimated that a 10 percent increase in carbon dioxide would increase temperature between 0.5° and 0.6°F.

Particulate matter such as dust and smoke can screen out the sun's energy by reflection of light rays. While there are vast amounts of particulate matter released to the atmosphere much of it soon settles or is washed out in rainfall. Particulate matter has received much attention in recent years and a real effort has been made to reduce pollution by smoke in urban areas. As a result of national policy, to reduce pollution by smoke this factor in climatic change should tend to level off in the next several decades.

Lead particles from exhausts of automobiles can lead to increased precipitation which in turn can have a cooling effect. We are seeing a turning point in this form of pollution in the requirement that new automobiles use a nonleaded gasoline. However, it will take another decade to correct this form of pollution. There are other forms of pollution, such as man-made aerosols, that can cause increased precipitation and as more is learned about these an effort will be made to reduce them.

It is now believed that the cooling effect of particulate matter has been offset by the warming effect of increased carbon dioxide. However, it is expected that by the year 2000 the effect of carbon dioxide will overbalance the effect of particulate matter by a wide margin.

The Ad Hoc Panel on the Present Interglacial (*8*) stated:

> In balance, it is more likely than not that the impact of human activities on the climate of future centuries will be in the direction of warming. Such being the case, it appears that man's intervention in the natural climatic trends of the future—whatever their direction—might, if anything, tend to prolong the present interglacial, rather than to cause its premature breakdown.

In addition to pollution effects man has affected climate significantly on a local basis. In areas of irrigation in the western states it is estimated that 10 percent of the precipitation that occurs locally is that which was evaporated from irrigated fields.

There is a significant increase in precipitation in and around cities because of pollution. The cities are also warmer than surrounding country because of the greater release of energy from the burning of fossil fuels.

Man changes climate locally by removing a forest or grassland cover to cultivate the soil. Vegetation tends to increase the humidity of the atmosphere and can contribute to cloudiness and more precipitation.

Removal of vegetation to expose different colored soils can cause local differences in climate. There is some indication of differences in rainfall in communities being associated with soil color. The darker colored soils are favored by greater precipitation.

The construction of lakes, ponds, and reservoirs in subhumid regions has a favorable effect on climate, although mostly this effect is very small. The larger the lake the greater the sphere of influence.

As one considers all of the factors of human influence on climate it has to be concluded that there is little likelihood that the change in temperature trend around 1940 was caused by human activity.

Possible Effects of a Continuation of the Cooling Trend

If the cooling trend of the past 35 years should continue to the year 2000 the effect might be only slightly detrimental to the production of grain in the middle latitudes, but any further reduction at this time could have serious consequences since there are such small reserves of grain supplies in the world.

As has already been pointed out, the highest yields of corn and soybeans are made in years of lower than normal temperatures in July and August. A continuation of the cooling trend would benefit these crops at lower latitudes but would be detrimental at higher latitudes because of the decrease in the length of the growing season. The outcome would be a gradual shift in the boundaries of the corn and soybean belts to lower latitudes.

The greatest concern we might have for corn and soybeans is the increased variability in yields we might expect with the cooling trend. To date, in this cooling trend, there has been greater stability of summer weather in the corn and soybean belts until 1974 (*1*).

If weather should become as variable from now until the year 2000 as it was in the corn and soybean belts from 1890 to 1955 the average yield would be reduced by about 3 percent.

The curvilinear relationship of wheat yields to temperature has not been worked out as clearly for wheat as for corn. I have published results of regression analysis of wheat yields in six states which provide some notion

Table 2. Effects of climatic change on the average wheat yields in six states. The average mean yields are, for North Dakota, 25.0; South Dakota, 21.1; Kansas, 25.9; Oklahoma, 25.2; Illinois, 36.3; and Indiana, 36.3 bushels per acre. The data are from Ramirez *et. al.* (*10*).

Climatic change	Change in wheat yields (bushel/acre)					
	N. Dak.	S. Dak.	Kans.	Okla.	Ill.	Ind.
			No change in temperature			
Change in precipitation (%)						
−30	−3.70	−1.85	−2.84	−2.81	+3.08	+3.24
−20	−2.49	−1.58	−1.80	−1.56	+2.25	+2.18
−10	−1.07	−0.67	−0.85	−0.62	+1.22	+1.10
+10	+1.21	+0.42	−0.76	+0.31	−1.41	−1.13
+20	+2.39	+0.60	+1.41	+0.30	−3.02	−2.28
+30	+3.62	+1.42	+1.99	−0.02	−4.84	−3.45
			No change in precipitation			
Change in temperature (°C)						
−2°	+1.18	+0.47	+1.44	−2.00	+2.36	+1.69
−1°	+0.68	+0.87	+0.74	−0.28	+1.16	+0.88
−0.5°	−0.36	+0.47	+0.37	+0.04	+0.62	+0.44
+0.5°	−0.41	−0.55	−0.38	−0.40	−0.64	−0.46
+1°	−0.86	−1.17	−0.77	−1.16	−1.24	−0.94
+2°	−1.90	−1.64	−1.57	−3.76	−2.69	−1.93
			A decrease of 2°C in temperature			
Change in precipitation (%)						
−30	−2.52	−2.29	−1.40	−4.80	+5.44	+4.93
−20	−3.32	−1.14	−0.35	−3.56	+4.61	+3.88
−10	−0.06	−0.03	+0.59	−2.62	+3.58	+2.80
+10	+2.38	+0.89	+2.30	−1.69	+0.94	+0.57
+20	+4.41	+1.07	+2.86	−1.70	−0.66	−0.58
+30	+4.80	+0.98	+3.43	−2.01	−2.48	−1.76
			A decrease of 1°C in temperature			
Change in precipitation (%)						
−30	−2.62	−1.88	−2.10	−3.09	+4.24	+4.12
−20	−1.81	−0.71	−1.06	−1.83	+3.41	+3.06
−10	−0.56	+0.29	−0.11	−0.90	+2.38	+1.98
+10	+1.89	+2.33	+1.49	+0.04	−0.25	−0.25
+20	+3.07	+1.47	+2.16	+0.03	−1.86	−1.40
+30	+4.30	+1.39	+2.73	−0.29	−3.68	−2.58
			A decrease of 0.5°C in temperature			
Change in precipitation (%)						
−30	−3.33	−2.29	−2.47	−2.77	+3.70	+3.69
−20	−2.13	−1.11	−1.42	−1.51	+2.87	+2.63
−10	−0.87	−0.20	−0.48	−0.58	+1.84	+1.55
+10	+1.58	+0.80	+1.19	+0.35	−0.79	−0.68
+20	+2.76	+1.07	+1.79	+0.34	−2.39	−1.83
+30	+3.99	+0.98	+2.36	+0.38	−4.22	−3.01
			An increase of 0.5°C in temperature			
Change in precipitation (%)						
−30	−4.11	−3.31	−3.22	−3.21	+2.44	+2.78
−20	−2.90	−2.13	−2.18	−1.96	+1.61	+1.72
−10	−1.48	−1.22	−1.25	−1.02	+0.58	+0.64
+10	+0.63	−0.13	+0.36	−0.09	−2.05	−1.59
+20	+1.98	+0.05	+1.04	−0.10	−3.66	−2.74
+30	+3.21	+0.03	+1.61	−0.42	−5.48	−3.91
			An increase of 1°C in temperature			
Change in precipitation (%)						
−30	−4.56	−3.92	−3.61	−3.98	+1.84	+2.31
−20	−3.35	−2.75	−2.75	−2.72	+1.01	+1.25
−10	−1.93	−4.66	−1.62	−1.79	−0.02	+0.17
+10	+0.19	−0.66	−0.01	−0.85	−2.65	−2.06
+20	+1.53	−0.19	+0.65	−0.85	−4.25	−3.21
+30	+2.77	−0.65	+1.22	+1.18	−6.08	−4.39
			An increase of 2°C in temperature			
Change in precipitation (%)						
−30	−6.71	−4.39	−4.41	−6.57	+0.39	+1.32
−20	−4.39	−3.22	−3.37	−5.31	−0.44	+0.26
−10	−3.14	−2.39	−2.42	−4.38	−1.47	−0.82
+10	−0.69	−1.13	−0.82	−3.45	−4.10	−3.05
+20	−0.49	−0.67	−0.16	−3.45	−5.71	−4.20
+30	+1.72	−1.12	+0.42	−3.77	−7.53	−5.38

of the possible effects of climatic change (*9*). My model was used by Ramirez *et al.* (*10*) in evaluating change in temperature and precipitation. The results of their studies have been reproduced and shown as Table 2.

The coefficients were developed from data over the period 1920 to 1965 when yields were doubled. The coefficients show average effects of departures from normal weather with low yields and with high yields, both having effect on the coefficients. Had they been developed over a period of high yields only the results would appear to be more heavily influenced by weather variables as they departed from normal. Despite the fact that the coefficients underestimate the effects of weather they do indicate the direction of the effect.

In the states of North Dakota and South Dakota, spring wheat would benefit from cooler temperatures with no change in precipitation. A combination of lower temperature and higher than normal precipitation would also be beneficial. There was no consideration of length of growing season in this study. However, these states represent the southern boundary of the spring wheat region of North America which reaches as far north as 55° latitude.

If the length of the growing season were not a factor one would expect cooler summer weather to be beneficial to spring wheat in Canada. However, there is a correlation between temperature and length of growing season which means a gradual shift southward of the northern boundary of the wheat region of Canada with a cooling trend. The two major wheat producing regions of the world that would be most adversely affected by a continuation of the cooling trend would be Canada and Russia. Canada produces spring wheat, and about half the wheat crop in Russia is spring wheat.

Kansas and Oklahoma produce hard red winter wheat. The highest yields in Kansas have been made with cooler than normal weather and greater than normal precipitation. The reverse is true also. The lowest yields have been made with warmer and drier than normal weather. It is not clear why normal temperature is optimum for Oklahoma. The regression analysis indicates a decrease in yield with temperature departing from normal in either direction.

Both Illinois and Indiana produce soft red winter wheat. More rainfall occurs during the growing season than is needed for wheat in these states.

Therefore, the regression equation indicates a benefit from less than normal rainfall and cooler than normal temperature.

This analysis indicates that a cooling trend to the year 2000 would not be detrimental to winter wheat.

Summary

A cooling trend in the world's climate would have serious effects in the monsoon belts depending on whether or not the recent changes in snow and ice cover in the polar regions were responsible for the droughts in Africa and the failure of the monsoons over South Asia. The cooling and shrinking of the atmosphere at the higher latitudes is believed to have brought the subtropical anticyclones nearer to the tropical rainbelt and have caused a shifting of the monsoon belt.

The regions that would be most severely affected by a continuation of the cooling trend to the year 2000 would be the higher latitudes (above 50 degrees) where spring wheat is grown and the warm band below 30 degrees latitude where rice is the principal grain crop.

Weather variability is a much more important consideration in grain production than a cooling trend. Our highest yields are made when weather is near normal or slightly cooler than normal. It is when weather variables deviate greatly from normal that yields are lowest. Even if the weather does trend toward the coolness of a century ago yields will not be reduced significantly unless the weather becomes more variable.

References and Notes

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India: A Perspective on the Food Situation

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In any discussion of the world food situation, India necessarily looms large. One out of every six persons in the world is an Indian, and the population, which is approximately 600 million at present, may well reach 1100 million by the turn of the century. Recent developments have led to renewed fears concerning the ability of the nation to feed her growing millions. Popular accounts present a truly alarming picture of millions of people faced with imminent starvation, at a time when world food reserves are seriously depleted. The current mood of pessimism, following so closely on a period of optimism when it was widely held that the Green Revolution was bringing about dramatic changes and that India was on the way to becoming a net exporter of food grains, clearly calls for a reevaluation of the situation and what it implies for the future of India and, indirectly, for the rest of the world.

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In this article we examine the current food situation in India and the recent performance of Indian agriculture, and attempt to ascertain the reasons for the abrupt change in outlook and to arrive at tentative conclusions on the ability of India to feed her growing population in the future.

We conclude that the situation, although serious, is far from calamitous. The Green Revolution has not proved to be the deus ex machina that it was once supposed by many to be. Nevertheless, India has a considerable potential for increasing her agricultural output, and there seems little basis for excessive pessimism concerning the willingness or ability of Indian farmers, given appropriate incentives, to adopt new measures. There are reasonably good prospects that India will be able to feed her growing population in the foreseeable future.

Current Food Situation

The Indian diet is dominated by food grains (cereals and pulses), rice being the preferred grain in most of the country, with wheat taking its place in the northwest. Approximately 74 percent of the average total caloric intake is from food grains, with sugar, vegetable oils, starchy roots, fruits, and vegetables making up most of the remainder (*1*).

Domestic production, imports, and per capita availability of food grains from 1951 to 1974 are given in Table 1 and Fig. 1. From an initial low level of 134 kilograms per year, per capita availability increased to 165 to 170 kg/year, except for the bad years (1958, 1966, and 1967), when it dropped to about 145 kg/year. The mean per capita availability between 1961 and 1974 was 163.9 kg/year, corresponding to roughly 1550 calories per person per day from food grains. The proportion of cereals has increased (from 85 to 91 percent of total food grains by weight), reflecting the poor production record of pulses.

The official estimate of food grain production for the crop year 1973–1974, which essentially represents the supplies available for consumption in 1974, was 103.6 million tons (*2*). Estimates of food grain imports for 1974 range from 5.6 million tons (*3*) to 6.1 million tons (*4*). Estimates of stocks in hand at the end of 1973 varied between 2.7 million and 4 million tons. If we assume that 1 million tons were kept on hand and allow for