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Unique 2004 Growing Season Weather Conditions Resulting in Record High Crop Yields in Illinois and the Midwest

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Abstract

Weather during the 2004 growing season in the Midwest, along with improved plant genetics and farming practices, produced exceptionally high yields of all major crops with resulting record yields 10 to 25 percent above prior records, an exceptional increase. Record corn and soybean yields in Illinois and five other states had profound effects on crop prices, given the large foreign demand and the decreasing dollar value, resulting in a huge income increase for Midwestern farmers, $13– $14 billion. Crop experts, regional farmers, and crop-weather models failed to detect and predict the enormous magnitude of the final yields. This inability to assess the magnitude of the 2004 crop yields likely resulted from a lack of information about the presence and effect of the frequent days with clear skies in 2004. The number of clear days, 50 percent to 105 percent above average across the entire Midwest, also were accompanied by much below average temperatures and normal rainfall. Examination of Illinois climate conditions over the past 117 years reveals that when many clear days occurred, most summers were quite hot and dry. Only one prior summer (1927) had comparable conditions to those in 2004. Summer 2004 weather conditions also were unusual in other respects, including having characteristics that were beneficial for all crops. For example, prior record high yields occurred in 2003 for corn, in 1994 for soybeans, in 2001 for sorghum, and in 1990 for alfalfa. Seldom does the entire Midwest experience near uniform summer weather conditions, reflecting another climatologically-unique aspect of summer 2004 weather. Canadian high-pressure centers, resulting from the intrusion of 20 strong cold fronts, frequently dominated the atmospheric circulation across the central United States during the summer, limiting the movement of warm, moist air into the region and creating the season's high frequency of clear days.

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Introduction

The harvest of corn and soybean crops across Illinois in fall 2004 revealed what crop experts had been predicting—extremely high yields. The statewide average corn yield was 180 bushels per acre (bu/acre), 16 bu/acre above the record set in 2003. For the first time in many years, corn yields were high across all parts of the state and were record highs in all nine crop districts in Illinois. The average soybean yield for Illinois, 50.5 bu/acre, was 5 bu/acre above the previous record set in 1994. Other lesser crops including grain sorghum and alfalfa hay also set yield records. Such exceptional yields for all major crops are highly unusual and are considered indicative of a growing season with near perfect crop-weather conditions. For example, when high U.S. corn yields also occurred in 2003, soybean yields were below average, revealing differences in growing season weather conditions affecting each crop. The record yields also partially reflect the continuing increases in crop yields relating to improvements in crop genetics and farm practices.

Record high corn yields in 2004 also occurred in Iowa, Indiana, Ohio, Nebraska, and Missouri, leading to a new national yield record (160 bu/acre, 18 bu/acre above the record set in 2003). Assessment of the crop-weather conditions leading to the 2004 record corn and soybean yields was the goal of this study, and the investigation was based primarily on Illinois weather conditions that also were representative of conditions in adjacent Corn Belt states in 2004.

Weather conditions that affect crops and their yields have undergone intensive study for more than 80 years. These studies have included field tests (Hollinger and Changnon, 1993), and statistical analysis of how various Midwestern weather conditions affect yields (Wallace, 1920; Changnon and Neill, 1968; Thompson, 1969; Garcia et al., 1990). The major focus of those studies was on the effects of temperature and rainfall conditions, and most findings agreed that soil moisture (rainfall) and temperature levels in mid to late summer were most critical for determining the yields of the corn crop. Because the extremely hot and dry summers of the 1930s drove corn yields to record lows, earlier planting was devised by technological advances as a means for getting the temperature and moisture-sensitive periods of corn development to occur earlier, in late June-early July, before crop stress from weather conditions that often develop in the Midwest from mid-July through August.

Another critical plant development-yield factor is sunlight. Sunny conditions promote photosynthesis in corn and soybean plants, thus greatly aiding plant development. Clear skies in June cause rapid vegetative growth, and such conditions in July greatly help tasseling and pollination. Clear skies are a useful indicator of solar radiation, a key input in crop growth and development models; with temperature and rainfall. Unfortunately, few long records of solar radiation in the Midwest exist (Grant et al., 2004). Thus, numerical models typically are used to estimate radiation, and the model found best at estimating solar radiation in the Midwest (Grant et al., 2004) relies on measures of clear sky conditions (Mahmood and Hubbard, 2002). Corn breeders have developed varieties that are increasingly less sensitive to weather stresses. These genetic improvements, along with numerous agricultural technology developments, have led to a major upward trend in corn yields since about 1940, and better corn-weather conditions also have been common in Illinois since 1970 (Changnon and Winstanley, 2000). Technological improvements during the latter part of the 20th Century have been reported to create a one percent per year increase in national corn yields (Troyer, 2004). These factors collectively explain why most corn yields records have been set one or more times during the past 15 years.

Data and Analysis

Long-term climatic records at Urbana, Illinois, located in the center of the Midwest and where record high crop yields have occurred, were examined first, as a guide to further analysis. Inspection of the Urbana records dating back to 1888 revealed an extremely high frequency of days with clear skies (daytime sky coverage by clouds of 0.3 or less). Other Illinois stations with long-term sky cover records dating back to early 1900s (Springfield, Chicago, and Moline) also had many clear days. Urbana and all other weather stations across Illinois, also had much below average temperatures for June, July, and August 2004, the most critical months. The summer 2004 mean temperature for Illinois was the fifth lowest on record for the 1888–2004 period. Unlike 2004, three of the other four coolest summers on record (1915, 1967, and 1992) had an above average frequency of cloudy days and few clear days. The other cool summer (1927) had an above average frequency of clear days like 2004, but 1927 also had an above average frequency of cloudy days.

Further assessment of the historical weather conditions focused on conditions at Urbana for which the region's longest record of sky cover was available . Sky cover measurements at a few other locales, including Moline, Springfield, and Chicago, were for a shorter duration than the Urbana measurements.

The summer 2004 frequency of clear days at Urbana was 54 days, nearly double the long-term average of 30 such days. Those clear days came instead of cloudy days in 2004. Frequencies of cloudy days at Urbana and other Midwestern stations were much below average, but the frequencies of partly cloudy days were similar to long-term averages. Solar radiation, as measured at Water Survey sites in northern, central, and southern Illinois during the summer 2004, was 9.6 percent above the 1991–2003 average. Daily temperatures at or above 90ºF occurred on very few days at Urbana and other Midwestern stations in 2004. Timely rains also occurred across the Midwest on 25–33 days at most weather stations.

Table 1 presents the Urbana 2004 temperature, rainfall, and sky cover values and departures from average. Summer 2004 rainfall at Urbana and most Midwestern locations was at or slightly

Table 1. Sky Cover, Temperature, and Rainfall Values for Summer 2004 at Urbana, Illinois

Months	*Total Clear days*	*Mean Temperature, ºF*	*Total days 90ºF or higher*	*Rainfall* Total, inches	*Rainfall* Number (days)
June	20 (+10)	69.6 (-2.2)	2 (-4)	3.8 (-0.3)	12 (+2)
July	18 (+8)	72.6 (-2.4)	3 (-4)	5.7 (+1.2)	12 (+3)
August	16 (+6)	68.2 (-4.8)	0 (-5)	3.6 (-0.4)	10 (+1)
Summer	54 (+24)	70.2 (-3.1)	5 (-13)	13.1 (+0.5)	32 (+6)

Note: Departures from 1888–2003 averages are shown in parentheses.

above the long-term average. All summer conditions that lead to high corn and soybean yields occurred in 2004: 1) many sunny days with extensive solar radiation, 2) cool, nonstressful temperatures, and 3) near average or above rainfall. The first three weeks of April were dry and sunny, which facilitated early planting of corn in most of the Midwest. That encouraged deep rooting and getting the crop-sensitive periods like tasseling to occur prior to the temperature-moisture stress of late summer, a condition that did not occur in 2004, however. Early planting also allowed crop development to be more closely aligned with the climatological peak in solar radiation in 2004. The 2004 trend of clear days continued in September, with 10 to 15 days above average across the Midwest, and also above average temperatures, resulting in clear, warm conditions that hastened corn maturity and then corn drying in the Midwest's northern areas, a good start for the 2004 harvest season.

The climatological assessment of the 2004 conditions involved examining historical records to identify past years with clear, cool, and near average precipitation conditions similar to those in summer 2004. The two most anomalous and crop-relevant conditions in 2004 became the basis for the climatological assessment of past summer conditions using initially the 1888-2004 Urbana records. The goal was to identify past summers with above average frequencies of clear days, and below average temperatures in all three months. An assessment of estimated crop yields issued during the 2004 growing season also helped identify the most critical weather conditions leading to the record yields.

Growing Season Predictions of 2004 Crop Yields

Assessments of crop quality and crop yields issued during the 2004 crop season provided useful information about the weather factors affecting yields. Detecting crop quality and predicting yields during a growing season both rely heavily on visual plant inspection and resulting estimates typically use outputs from crop-weather models that incorporate temperature, precipitation, and yields from past years.

From late May through July 2004, thousands of farmers across the nation reported on the quality of their corn crops, and those reports were used to develop state and national values. For example, the June 2004 values of the corn crop classed as "good to excellent" for Illinois, Iowa, and the United States were 79, 65, and 68 percent, respectively. By late July, those values had increased to 86 percent for Illinois (+7), 77 percent for Iowa (+12), and to 76 percent for the nation (+8). Temporal improvement of corn crop quality occurred across the Midwest.

The U.S. Department of Agriculture (USDA) issued its first estimates of state and national crop yields (corn and soybeans) in August (table 2), based largely on farmer and crop expert reports. In each succeeding month, September-November, the USDA issued new yield estimates. As shown in figure 1, corn yields in Illinois, Indiana, Iowa and the nation increased slightly above the August and September estimates. They then increased dramatically above September values to those for October, followed by further growth into November when actual yield values, not estimates, were provided.

Table 2. 2004 Crop Yields (bu/acre) from August-Predicted Values vs. Final Yields, and Percent Change from August Value to Final Yield

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	Predicted Yields		*Final Yields*		*Percent Change, August to Final*	
Location	*Corn*	*Beans*	*Corn*	*Beans*	*Corn*	*Beans*
Illinois	168	44	180	50	7	14
Indiana	156	40	169	53	8	32
Iowa	162	40	183	49	13	23
United States	149	38	160	43	8	13

The temporal distribution of USDA-predicted soybean yields (figure 1) exhibited a slight decrease from August to the predictions issued in September, resulting from crop experts who believed there would be negative impacts from the cool, wet late August weather. Then, from September to November, soybean yield values increased dramatically, reflecting actual measures of yields from the on-going soybean harvest. As shown in table 2, August corn yield predictions for Illinois, Indiana, and Iowa were underestimates in the 7–13 percent range, and soybean predictions were underestimates in the 13–32 percent range, compared to the final yield values in November.

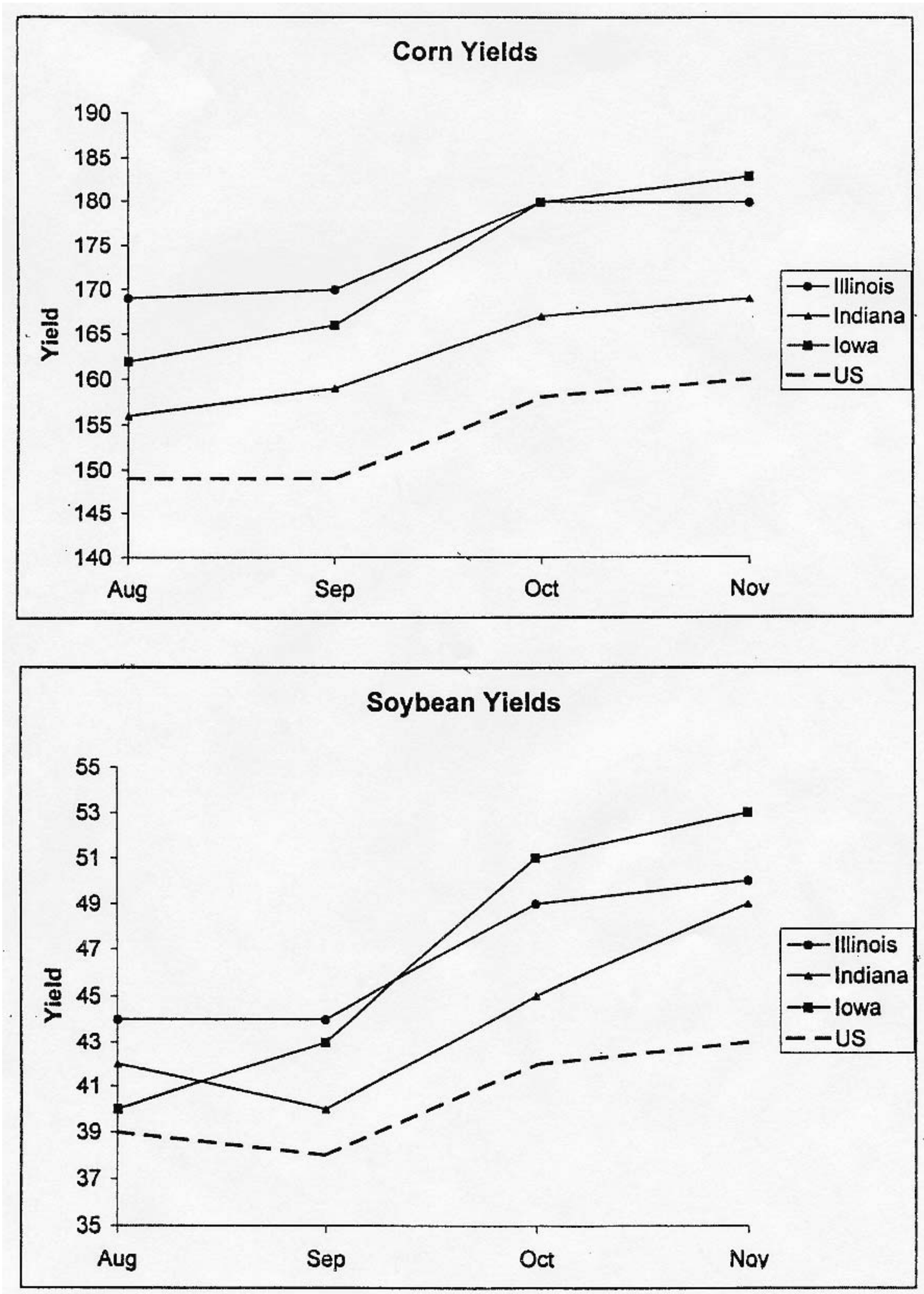

Figure 1. Monthly corn and soybean yield values issued by the U.S. Department of Agriculture for Illinois, Indiana, Iowa, and the nation during 2004.

The final yields also were compared with yields derived from sophisticated crop-weather models that utilize daily temperature and precipitation values from throughout the growing season. The CERES-MAIZE and SOYGRO models also underestimated yields of both crops. These underestimated values for corn yields were 16 bu/acre for Illinois, 19 bu/acre for Indiana, 14 bu/acre for Iowa, and 8 bu/acre for the nation. The model's underestimates of the soybean yields were 6 bu/acre for Illinois, 12 bu/acre for Indiana, 3 bu/acre for Iowa, and 3 bu/acre nationally. Thus, the crop-yield models also did not detect the magnitude of the record high yields, but the magnitudes of their underestimates are similar to those issued in August by the USDA (table 2).

Various measures and estimates of corn quality and yields issued from late May through September showed a continuous improvement over time. Still, actual harvested values in November revealed a sizable jump over August-predicted corn yields. These increases took yields to new state and national record levels. Various estimates of soybean yields from early August into September showed no increase or a decrease. Then, as the harvest began in late September and October, soybean yields increased dramatically and continued to increase into November, also setting new state and national yield records.

The measures of crop experts (estimated yields) and estimates based on models using temperature and precipitation values both missed the magnitude of the high corn and soybean yields in 2004. This suggests that key weather influences were not detected, as in 2003 in central Illinois (Changnon and Hollinger, 2005). A key unrecognized factor in both 2003 and 2004 was the influence on plant photosynthesis of additional sunshine due to a much above average frequency of clear daytime skies in June and July.

Important Weather Conditions in 2004

Sky Cover

Historical 1888–2004 data for sky cover at Urbana revealed 34 years with above average numbers of clear days in all three summer months, including 2004 (table 3). Nine such summers had 54 or more clear days, thus matching or exceeding the 2004 total. However, their other summer weather conditions were drastically different during all these summers: 1) much above average summer temperatures, and 2) below average rainfall. Seven of these summers occurred during the

1931–1941 severe drought period, and the others occurred in 1944 and 1953.

Temperature conditions then were examined for the 33 clear sky summers prior to 2004. Inspection of monthly temperature values of these 33 years revealed three types of summer conditions (table 3): 1) one with much above average temperatures (19 summers), 2) one with near average monthly temperatures (11 summers), and 3) one with below average temperatures as in 2004 (3 summers). Summer temperatures were more than 2.1°F above average in at least two of the three summer months in all 19 hot-dry summers, with above or near average temperatures in the third month. Those summers occurred in 1903, 1919, 1922, 1925, 1930, 1931, 1933, 1934, 1935, 1936,

Table 3. Average Summer Weather Conditions in Summers with Above Average Frequencies of Clear Days in All Three Summer Months at Urbana, Illinois, 1888–2003

Conditions	*June*	*July*	*August*	*Summer*
Hot-dry summers (19)				
Temperature departures, °F	+3.0	+2.6	+2.2	+2.9
Average number of clear days	15	18	16	49
Rainfall departures, in.	-0.8	-2.4	-1.2	-4.4
Near-average summers (11)				
Temperature departures, °F	-0.9	0.0	+1.2	+0.1
Average number of clear days	15	18	17	50
Rainfall departures, in.	+0.6	-1.1	-0.9	-1.4
Cool summers (3)				
Temperature departures, °F	-1.3	-2.0	-3.3	-2.2
Average number of clear days	15	14	12	41
Rainfall departures, in.	+0.3	-0.8	-0.4	-0.9

1940, 1941, 1944, 1952, 1953, 1980, 1983, 1984, and 1988. Many occurred during past droughts, including the extremely hot-and-dry 1930s, the 1952–1955 drought, and the 1988–1989 drought. The monthly and summer average temperature departures based on these 19 summers appear in table

3. Monthly rainfall values in all 19 summers were low and averaged 4.4 inches below average for the entire summer (33 percent of the average). Only one summer had above average rainfall (1983), and rainfall was 4 inches or more below average in 14 of the 19 summers. Rainfall in July, the most critical monthly rainfall for corn, was below average in all 19 summers. August rainfalls critical for soybeans and often for corn, were below average in 17 of those summers. These 19 summers are classic examples of the hot, dry summers characteristic of the continental climate of Illinois and the Midwest (Changnon et al., 2004).

Eleven of the 33 clear sky summers prior to 2004 had a mixture of temperatures with one summer month having an above average value and the other two months with near to below average temperatures (table 3). These summers occurred in 1890, 1906, 1923, 1929, 1937, 1938, 1939, 1942, 1946, 1947, and 1982. Six of the 11 years had summer temperatures above the long-term average values, and the 11-year average was +0.1^{o}F above the long-term average. Eight of the 11 summers were dry and rainfall totals were more than 2 inches below average in five summers. August was dry in seven years and dry July and August occurrences resulted in a 11-year average summer departure of -1.4 inch. These 11 summers averaged 50 clear days, a higher value than did the other two types, but their other weather conditions were unlike those in 2004.

Three of the 33 clear sky summers had below average temperatures in all three summer months just as in 2004. Those summers occurred in 1917, 1920, and 1927, with an average temperature departure of 2.2^{o}F below average (table 3), one degree warmer than in 2004. Clear days in those three summers averaged 41 days, as compared to the 54 such days in 2004. Rainfall in 1917 and 1920 was below average, 0.9 inch below the long-term value and quite different from the 2004 rainfall, which was 0.5 inch above average (table 1). The major difference in monthly rainfall values occurred in July, a 3-year average departure of -0.8 inch, as compared to +1.2 inch in July 2004. Because the only clear sky summer of this type with rainfall conditions somewhat like those in 2004 was 1927, conditions during these two summers were compared.

As shown in table 4, the 1927 summer temperature was 3.6^{o}F below average, close to that in 2004 (-3.1^{o}F). June and August rainfall totals in 1927 exceeded those in 2004. The monthly rainfall amounts from April through October 1927 were each much above average, delaying planting and making 1927 the wettest year on record for 1888–2004. Such extreme wetness before and after the summer was not the case in 2004.

Table 4. Comparison of Summer Conditions, 1927 and 2004, at Urbana, Illinois

	Number Clear Days				*Average Temperature departures, °F*				*Average Rainfall departures, in.*			
	J	*J*	*A*	*Sum*	*J*	*J*	*A*	*Summer*	*J*	*J*	*A*	*Summer*
1927	16	15	14	45	-4.3	-1.6	-4.0	-3.6	+1.6	+1.3	+0.5	+3.4
2004	20	18	16	54	-2.2	-2.4	-4.8	-3.1	-0.3	+1.2	-0.4	+0.5

The Illinois corn yield in 1927 was 36 bu/acre, 2 bu/acre less than the 1921-1930 average yield. Hence, sky cover and temperature conditions contributing to the major record yields of 2004 did not produce similar high yields 77 years earlier. However, the extremely wet conditions throughout the 1927 growing season likely reduced yields. It is also important to realize that 1927 did not have as many clear skies as did 2004 (table 4). Furthermore, weather conditions capable of producing high yields in the 21st Century relate to current crop genetics and agricultural technologies that are vastly different and improved over those available in 1927. Farming in 1927 was quite different than in 2004, and no hybrid seed corn nor commercial fertilizers were available.

Assessment of the 2004 weather conditions across the Midwest revealed that much above average numbers of clear days occurred everywhere in all three summer months (table 5). The summer total departures of clear days ranged from 43 percent above at Indianapolis to 110 percent above average at Columbia, Missouri, and Lincoln, Nebraska. All the Midwestern stations listed in table 5 also had much below average temperatures in all three summer months. Summer 2004 was the coldest summer on record at several stations, including Springfield, Illinois, and Sioux City, Iowa (*Weatherwise*, 2004). The frequency of days with daily temperatures at or above 90°F totaled only three days at Peoria, Illinois (a 102-year record low number), four days at Kansas City (fewest since 1915), and no such days at stations in Indiana and Ohio (*Weatherwise,* 2004). Crop stress did not occur because high daily temperatures were minimal or absent in 2004.

Table 5. Summer 2004 Weather Conditions at Stations from West to East Across the Midwest (Shown are Departures from Long-term Averages for the Frequency of Clear Days, Monthly Mean Temperatures and Total Summer Rainfall)

	Lincoln, Nebraska	*Des Moines, Iowa*	*Columbia, Missouri*	*Springfield, Illinois*	*Indianapolis, Indiana*	*Columbus, Ohio*
Clear Days						
June	+10	+8	+12	+10	+6	+7
July	+10	+4	+11	+8	+7	+6
August	+10	+2	+7	+3	+6	+10
Temperature, of						
June	-3.8	-2.7	-2.3	-3.2	-0.7	-1.1
July	-4.3	-3.8	-3.2	-3.4	-2.3	-1.4
August	-3.8	-5.1	-5.5	-5.3	-3.8	-3.0
Summer rainfall, in.						
	+2.1	+1.6	+2.5	+0.7	+4.5	+3.0

Summer rainfall amounts at most stations were above average. Summer 2004 was very sunny, cool, and with generally adequate rainfall for all crops across the entire Midwest (table 5). One of the highly unusual climatological aspects of the summer 2004 weather was this uniformity of conditions across the entire 11-state Midwest region. Seldom does this large area experience widespread similar summer weather. Even Illinois with its 400-mile north-south extent, seldom has uniformly good or bad summer weather conditions across the entire state, such as occurred in 2004 (Changnon et al., 2004).

Temperatures

A second climatological analysis based on 2004 conditions assessed past summers at Urbana when all three months had below average temperatures, an infrequent event. Assessment of the 1888-2004 historical data for monthly temperatures revealed there were 19 years with below average temperatures in all three summer months. Occurrences of the 18 cool summers before 2004, sorted by decades, were 1889–1900 (3), 1901–1910 (4), 1911–1920 (4), 1921–1930 (1), 1931–1940 (0), 1941–1950 (1), 1951–1960 (1), 1961–1970 (1), 1971–1980 (0), 1981–1990 (1), and 1991–2000 (2).

Other weather conditions associated with the 18 cool summers prior to 2004 were evaluated. Assessment of the sky cover conditions revealed that the number of days with cloudy skies was above average in 17 of the 18 summers, and much above average (>9 days) in 11 of those summers. Only one summer had a below average frequency of cloudy days (1912), but it had a much above average frequency of partly cloudy days, 63 days of the 92 summer days. In contrast, frequency of clear days was near average or much below average in 14 summers. The four years with an above average frequency of clear days in summer were 1889, 1917, 1920, and 1927. These sky conditions results reveal, as expected, that cool summers in Illinois typically have more frequent cloudy days, a finding that differs from the cool, clear conditions of 2004, and also those in 1917, 1920, and 1927.

Rainfall amounts in the 18 cool summers before 2004 were quite varied. Seven of the cool summers had much above average rainfall, exceeding 13.5 inches, whereas seven other cool summers had below average summer rainfall, all between 9.9 and 11.1 inches. The remaining four cool summers experienced near average rainfall, within one inch of the 12.6-inch average. Thus, no distinct rainfall characteristic was associated with the 18 cool summers before 2004. The 2004 rainfall value fit within the near average category found with four prior cool summers.

Surface Weather Conditions

What caused the unusual weather conditions in summer 2004? Analysis of the surface atmospheric conditions showed frequent penetrations of cool, clear Canadian air masses into the Midwest. Analysis of the mean daily temperatures for Urbana revealed several major periods when temperatures fell dramatically, by 5–16^{o}F within a 2- to 4-day period (figure 2). Also plotted on figure 2 are daily daytime sky conditions. Comparison of these conditions and the daily temperatures reveals that most sizable temperature decreases were followed by several clear days. For example, five clear days followed the June 1-2 temperature drop, and 11 clear days followed the June 17–19 temperature drop.

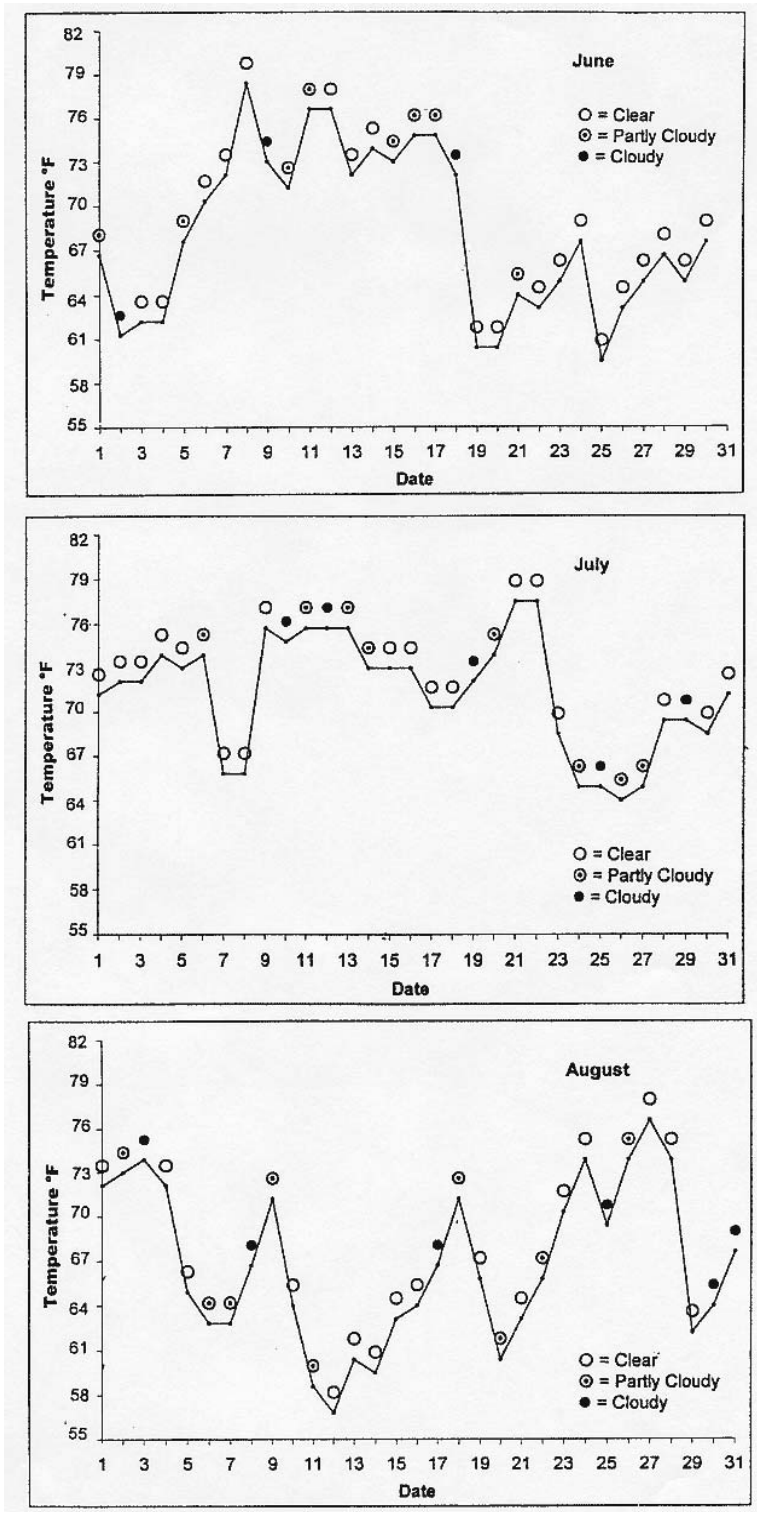

Figure 2. Mean daily temperatures for June, July. and August 2004, and daily daytime sky conditions, Urbana. Illinois.

Periods when cold air masses moved across the Midwest and caused major temperature drops are shown for two widely separated locations, one in Nebraska and one in Illinois (table 6). These notable decreases in the mean daily temperatures (10 events at each location) occurred at both sites over 2- to 4-day periods. Comparison of the dates when the sizable temperature decreases occurred reveals that all those events at both stations were in temporal agreement, and were followed by three or more days with clear skies, as shown in table 6.

Table 6. Periods When Major Decreases in Temperature Occurred and Ensuing Frequencies of Clear Days at Two Midwestern Locations, Summer 2004

Lincoln, Nebraska			*Urbana, Illinois*		
Period	*Decrease, of*	*Number of clear days*	*Period*	*Decrease, of*	*Number of clear days*
6/8-12	12	4	6/8-10	9	4
6/15-18	16	4	6/17-19	14	6
6/23-25	14	4	6/24-25	9	9
7/4-7	13	6	7/6-7	10	3
7/13-14	8	8	7/13-14	5	6
7/21-24	20	6	7/22-24	14	4
8/3-6	15	5	8/3-5	10	2
8/8-12	15	4	8/9-12	16	6
8/18-20	14	6	8/18-20	12	4
8/26-28	12	4	8/27-29	13	3

Analysis of the daily surface weather maps for 2004 revealed that 20 cold fronts originating in Canada penetrated into the Midwest during June–August. As shown in table 7, this frequency of cold fronts was slightly above average. Two cold fronts dissipated and 6 became stationary fronts across the Midwest, but the other 12 cold fronts were responsible for the 10 temperature decreases (table 6). Two closely adjacent cold fronts swept across the Midwest (June 8–12 and June 15–19), but the other eight temperature decreases were due to the passage of single cold fronts. As one weather expert noted, "Another unusual blast of cool air reached the Midwest on August 20–21 causing unprecedented early frosts" (*Weatherwise*, 2004). In all instances, the cold fronts moved across the entire Midwest, leaving in most instances strong high pressure and low dewpoint temperatures across the region.

Table 7. Point Frequencies of Surface Fronts and Number of Days with High-Pressure Centers in the Western and Eastern Parts of the Midwest for the Summer 2004, and Their Average Values (Morgan et al., 1975)

Portion of Midwest	*Cold fronts*	*Warm fronts*	*Stationary fronts*	*High-pressure centers, days*
Western Half				
2004 values	20	3	6	23
Averages	19	7	24	6
Eastern Half				
2004 values	20	4	10	22
Averages	18	8	18	7

Frequencies of warm fronts and stationary fronts in the Midwest in summer 2004 (table 7) were more than 50 percent below average. This is significant because these fronts typically produce long periods of cloudiness. The number of days with high pressure centers present in the Midwest during June–August 2004 was up to four times more than average. Statistics in tables 6 and 7 reveal that the numerous cold fronts were often followed by quite cold and dry air masses and by major high- pressure systems that persisted and dominated the atmospheric circulation over the Midwest. The cold air masses and ensuing strong high-pressure centers across the entire Midwest resulted in the high frequency of clear days.

Summary and Conclusions

Crop yield predictions issued during the crop growth period and up through August 2004 failed to anticipate the high magnitude of the corn and soybean yields that actually occurred across the Midwest. Sophisticated crop-weather models relying on daily temperature and rainfall data also did not calculate yields as high as those that occurred. Predictions and model-generated yields were 7–15 percent under the final corn yields for the 11 Corn Belt states, and 15–33 percent below the final soybean yields of the Midwestern states. These outcomes help reveal that weather conditions critical to generating extremely high yields of all Midwestern crops either were not detected or understood. The interactions of these conditions with the ever changing crop genetics also appear to be not well understood.

There is strong evidence that the much above average frequency of summer days with clear skies was a critical and beneficial factor for all Midwestern crops. Climatological analysis revealed that when a large number of clear days occurred in most previous summers, conditions were hot and dry with much above average temperatures and below average rainfall. Temperatures in 18 of the 33 summers with numerous clear skies between 1888 and 2003 averaged between 1.2^{o}F and 4.5^{o}F above the long-term average.

Summers with frequent clear skies, well below average temperatures, and above average rainfall only occurred in two years during the past 117 years, 1927 and 2004. However, the 2004 summer had many more clear skies than did 1927, and the rainfall amounts in June and August of the two years had different magnitudes. Summer 2004 temperatures were lower than the average of the three similar summers with clear skies and below average temperatures. Thus, the 2004 conditions appear to be anomalous.

Summers with below average temperatures in all three summer months, as in 2004, occurred in 18 previous summers between 1888 and 2003. Sky conditions with these cool summers were mostly cloudy, an outcome quite different than found for 2004.

The climatological evaluation of the summer 2004 weather conditions revealed they were unlike any experienced during the past 117 years. The sunny, cool conditions of 2004 were due to 20 cold fronts from Canada that crossed the Midwest, followed by strong high-pressure systems persisting for several days. Each such intrusion brought temperature decreases of 5^{o}F to 15^{o}F, and then a series of several clear days. High-pressure centers dominated the atmospheric circulation and kept warm and stationary fronts with their attendant penetrations of warm, moist air masses. from penetrating into the Midwest. The atmospheric circulation during the 2004 summer was unusual. However, the conditions and their crop impacts are not considered indicative of those expected with a change in climate due to global warming (Changnon and Hollinger, 2003).

The 2004 growing season conditions were also climatologically unique with respect to two other weather conditions. One was the widespread similarity of the summer conditions across the 11-state Midwest, a highly unusual event, and a factor in setting new national yield records for corn and soybeans. The other unique outcome was that the combination of weather conditions from April through September 2004 led to record high yields in all Midwestern crops: corn, soybeans, sorghum, and alfalfa hay. Never before had all these crops reached record high yields in the same year.

The uniquely good growing season across the entire Corn Belt had positive effects for all crops. Record high corn and soybean yields averaged 7–33 percent above previous state yield records in seven states (Nebraska, Iowa, Missouri, Illinois, Indiana, Ohio, and Kentucky) with near record yields in Kansas, South Dakota, Wisconsin, and Minnesota. The U.S. average corn and soybean yields were also new national records.

The net effect of this near perfect crop weather was a national corn harvest of 11.74 billion bushels and a soybean harvest of 3.15 billion bushels, more than 10 percent above past record totals and 30 percent above the nation's average grain production for 1994–2003. The increased production, taken at standard prices, equated to $14 billion dollars above the average farm incomes during 1994–2003. The U.S. Department of Agriculture reported that the huge harvest coupled with strong crop prices resulted in a U.S. farm income totaling $73.7 billion in 2004, an amount 25 percent above any prior year (Miller, 2004a). The Secretary of Agriculture stated, "This record income total related to near perfect growing conditions and increased foreign demand, partially a result of the weakened dollar" (Miller, 2004a). The average 2004 income for Illinois grain farmers was $92,000, nearly double that of 2003, and $40,000 above the 1999–2003 average income (Lattz, 2004). This huge income boost to Midwestern farmers has been realized in several ways. Manufacturers of farm equipment have experienced large sales, and sales of tractors and combines raised John Deere's Third Quarter earnings by 32 percent (Miller, 2004b). Farmland prices throughout the Midwest also increased, reaching $5000 per acre (Bridson, 2004).

This study reveals that better in-season monitoring of sky conditions is needed because these data can be used to estimate solar radiation for input to weather-yield models (Grant et al., 2004).

A recently developed model uses sky cover conditions to successfully estimate solar radiation in the Midwest (Mahmood and Hubbard, 2002).

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