Agronomy 541 : Lesson 1a

Weather Effects on Crop Yields

Introduction

Developed by E. Taylor and D. Todey

The principles and examples presented in Lessons 1 and 2 can be used to improve crop management and marketing skills. They are also intended to serve as a summary and introduction to a series of comprehensive lessons in the principles of applied agricultural meteorology. Many of the examples apply to maize (corn) in the central United States. The principles expressed are applicable to the production of many other crops and can be applied to an international scope.

What You Will Learn in This Lesson:

- Understand crop yield trends for the Midwest crops and other major crops throughout the United States.
- Relate climatic anomalies to their effect on crop yields.
- Learn how to calculate and use growing degree days and several applications.
Weather Effects on Crop Yields

Yield Trends

It is suggested that you watch Video 01A and complete the exercise in the video before continuing with the lesson.

Overview

The primary concern in this discussion is the influence of weather on crops and on crop production. Weather is the major uncontrollable factor that influences the development of crops. Initially, we will look at some of the historical trends in crop yield. We often hear about deviation from yield trend. This is a concern as deviation from midwestern yield trends during 1996-2007 was less than experienced during the previous 20 years and may be a phase of a repeated pattern. We attribute much of this to changing weather patterns and the interaction of the weather with the soils and the crops.

Yield Trends

The United States Department of Agriculture (USDA) publishes data with annual yields and trends. Typically, the USDA depicts yield trend as a straight line, averaging the yields of the past 30-years. The USDA trend estimate for corn, soybean, cotton, winter wheat, and rice was from 1970 through 1996 (Fig. 1.1).
Compare these yield trends with the Iowa state-wide average corn yields from 1972-2002. Notice the change in yield throughout the century. Study the figure and answer the discussion question that follows. Note: The U.S. Rice results are not typical of a trend; there seems to be a "stair-step" response over time. Try to rationalize the difference between corn trend and rice trend. Is winter wheat intermediate in trend response?
Fig. 1.2a Iowa state-wide average corn yield and trend. (data source: www.nass.usda.gov)

Fig. 1.2b Iowa state-wide total corn yield historical record. (data source: www.nass.usda.gov)

Discussion Topic 1.1
What kind of trend do you see in the yield data in Fig. 1.2a? Does it change over time? Does a straight line fit it? What do you think accounts for the change in yield? How does the Iowa data differ from the U.S. corn data? In figure 1.2b, does the straight line give a realistic view of the historical trend? Discuss your responses with other students.
A straight line yield trend may not be the most realistic depiction. Let's look at the actual yields for the state of Iowa as they have been observed the past century (Fig. 1.3). The yields were really quite flat, around 40 bushels to the acre, from the turn of the century until about 1940. There was variability year to year according to weather conditions. Some years the crop was reduced by almost 50%. During the Dust Bowl years, especially the more severe year of 1936, the yield was reduced by more than 50 percent.
To solve the following questions, the Excel version of Equation 1.1
\[ =38.27 + 85.78/(1+(\text{year}/1965.45)^{-217.01}) \] may be copied and pasted into a cell of an Excel worksheet. Replace the word "year" with the year in question.

**Study Question 1.1**

Compute the Iowa yield trend value for 1901.

[ ] BuA\(^{-1}\) **Check Answer**

**Study Question 1.2**

With an actual yield of 28.5 Bu/A, what was the deviation from the yield trend in 1901?

[ ] BuA\(^{-1}\) **Check Answer**

**Study Question 1.3**

What was the percent deviation from the trend in 1901?

[ ] % yield reduction **Check Answer**

**Study Question 1.4**

Calculate the trend yield for 1988.

[ ] BuA\(^{-1}\) **Check Answer**

Yield trends in the other Corn Belt states are qualitatively similar. The leveling of yield trends is more pronounced in the west half of the Corn Belt. Figure 1.4 shows actual yields by year and indicates deviations of 10% from the trend.

Click on a state to see the chart for each state, or click here to see the charts for all the Corn Belt states on one page.
Some significant variations in trend may be found within each state. In the southeast portion of Iowa, the trend line became almost horizontal after 1980 (Fig. 1.5), whereas in the west central and southwest portions of Iowa, the trend line was almost linear. This indicates continuing improvement in crop yield in western Iowa, but not in eastern Iowa.

Click on a district (1-9) to see the image, or click [here to see all the Iowa corn trend charts](#) on one page. Try to think of "why" the trends shown differ with locations in Iowa.
It is clear that the bad years hurt yields more than the good years helped. This can be compared to a person riding a bicycle into the wind. The wind slows the bicycle rider down. Turn around and go the other way; the wind at the cyclist's back is a great asset and a help to cycling along. But if a person were to time how long it takes to ride from home to work and back home again on a still day, the time would be better than on the windy day. In other words, the wind at your back does not make up for the adverse weather conditions when you're riding into the wind. Uphill versus downhill has the same influence. The bad years versus the good years are having the same effect on crops. The reason crop yields were leveling off during the 1980’s was an increasingly common occurrence of bad years. Perhaps it is better stated as increasingly erratic climatic conditions. Peak yields are acting a bit differently. Look back at Fig. 1.3 and consider the trend in peak yields beginning with 1937. We call the peak years trend the **realized potential yield**.

**Study Question 1.5**

What is the trend in realized potential (maximum) yield for corn in Iowa based on Fig. 1.3?

- Similar to the trend (Fig. 1.3)
- Linear
- No trend in potential yield

[Check Answer]
IN DETAIL: Yields and Trends for All Corn Belt States

Yields and Trends for All Corn Belt States

State Wide Average Corn Yields
North Dakota

State Wide Average Corn Yields
South Dakota

State Wide Average Corn Yields
Nebraska

State Wide Average Corn Yields
Kansas

State Wide Average Corn Yields
Minnesota

State Wide Average Corn Yields
Wisconsin

State Wide Average Corn Yields
Iowa

State Wide Average Corn Yields
Missouri
IN DETAIL: Yields and Trends for All Corn Belt States

Corn Yields and Trends for All Iowa Districts

- Northwest Iowa
- North Central Iowa
- Northeast Iowa
- West Central Iowa
- Central Iowa
- East Central Iowa
- Southwest Iowa
- South Central Iowa
- Southeast Iowa

Legend:
- Raw Data
- Trend
While corn (maize) and soybean are the major crops in the Midwest, other crops are important in other areas. View some other crops and their trends over time (Fig. 1.6). Do the trends in these crops mimic those seen for corn and soybeans? Think about this on your own.

The crop each area grows is largely based on the climate experienced in that area. You can examine the climate of many areas of the country to compare the crop and climate in which it grows (Fig. 1.7).

We will discuss climate types more in Lesson 8.
Discussion Topic 1.2

At Lake Charles, Louisiana (C28), extra July rain would not aid a crop as normal rain meets the potential evapotranspiration (PET). Would extra June rain increase yield at Macon, Georgia (C29)? At Fort Wayne, Indiana (D19)?

Information from the [US Climate Divisions Plotting Page](http://example.com) will be helpful in answering the following study questions.

This is a very useful page to quickly determine climatic conditions across the United States. The following are the boxes that must be set:

<table>
<thead>
<tr>
<th>Variable</th>
<th>Choose the variable you wish.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type of plot</td>
<td>Usually, you choose anomaly to see how conditions differed from average. Play with the other types as you have time.</td>
</tr>
<tr>
<td>Anomaly or climatology</td>
<td>This allows you to choose the set of base years to compare.</td>
</tr>
</tbody>
</table>

Choose your month or range of months. If you want a single year, or a set of years, enter those in the boxes.

Click on Plot

There are other changes you can make if you wish. But these will get you started.

If you have other questions e-mail me.
Study Question 1.6

What weather event caused decreased cotton production in 1980?

Excessive  Deficient

[Radio buttons]  [Check Answer]
Weather Effects on Crop Yields

Atmospheric Effects on Crop Yields

The weather the crop experiences has obvious influence on the development and growth of the crop. How and when the weather happens makes a huge difference. Thompson (1986, 1988) developed charts, based on statistics, that express crop yield as influenced by monthly average temperature and total precipitation. The polynomial expression and coefficients for the temperature and precipitation relationships were given by Thompson (1986) and are summarized in Table 1.1. He noted that average temperatures across the Corn Belt have optimal contribution to yield during the month of June (Fig 1.8).

![Graph showing the response of corn to average monthly weather variables in the five central Corn Belt states.](image)

Fig. 1.8 The response of corn to average monthly weather variables in the five central Corn Belt states.

The general equation for the regression lines in Figure 1.8 is given as:
where $y$ is estimated corn yield (kg ha$^{-1}$), $x$ is the departure from average for temperature (°C) or rain (mm), and "a" is yield trend value (kg ha$^{-1}$).

Table 1.1 Coefficients to calculate the yield departures using Equation 1.2.

<table>
<thead>
<tr>
<th>Variable</th>
<th>b</th>
<th>c</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preseason precipitation</td>
<td>-0.404</td>
<td>-0.0022</td>
</tr>
<tr>
<td>June temperature</td>
<td>-2.5176</td>
<td>-27.5150</td>
</tr>
<tr>
<td>July rain</td>
<td>+9.5604</td>
<td>-0.0416</td>
</tr>
<tr>
<td>July temperature</td>
<td>-101.7318</td>
<td>-7.6832</td>
</tr>
<tr>
<td>August rain</td>
<td>+1.0902</td>
<td>-0.0026</td>
</tr>
<tr>
<td>August temperature</td>
<td>-90.8361</td>
<td>-16.2131</td>
</tr>
</tbody>
</table>

If the June temperature is 2 °C warmer than average, it results in a reduction in potential crop yield of around 100 kg ha$^{-1}$. If the temperature is 2 - 4 °C cooler than usual in June, it results in a decrease in June's contribution to the crop yield. Precipitation for April, May, and June, being normal or slightly below normal, seems to contribute to crop yield.

*Note: These yields are for the early 1980's. The time trend of yield was not considered in this case. In 2010 the spae of the response may be similar but not the quantity.

Study Question 1.8

If July is colder than normal by 2°C, how much will the yield be affected?

In July, the effect of temperature becomes very different from that of June. In July a normal temperature (an average July) results in average contribution to crop yields. Should July be warmer than usual, the potential July contribution to crop yield drops off significantly. A cooler than usual July (2 or 3°C cooler than usual) contributes substantially (or enhances substantially) the yield of the crop.
Moisture in July is also very significant. Average July precipitation gives an average contribution to yield. Extra moisture during the month will substantially increase the July contribution to yield, (Fig. 1.6). Some of the estimates that are used for assuming what a crop will be, assume just that--"the more rain, the more grain." We know from 1993 that this is not so. There can be a point at which there is absolutely too much moisture around. But only twice in the past 100 years (1915 and 1993) have we observed a case where too much moisture reduced the state yield (Fig. 1.9).

![Ames Growing Season 1900 to 1996](image)

Fig. 1.9 Growing season precipitation for Ames, IA 1900 - 1996.

Although not as impressively wet as 1993, 1915 was wet and very cool, creating excessively wet conditions. Cool weather reduced the amount of water needed for evapotranspiration.

Try This!

Return to the Climate Division Plotting page and plot the growing season precipitation anomaly for 1993 and 1915.

Although too much moisture (Fig. 1.10) may reduce the yields on the low-lying areas, it is more than compensated for by increased yield on upland portions of the state. Assume that up to a certain point, increased July moisture helps the state yield and below normal July moisture depresses the potential yield.
Considering soybeans, the July pictures would be more appropriate for August (Fig 1.8). In other words, the soybean in August is responding much as corn is responding in July if looking at the temperature and the moisture responses for our crop.

Of the factors considered here, we emphasize temperature and moisture. There are many other factors that influence the development of the crop. The primary one, of course, is light. The assumption in the U.S. Corn Belt is that sunlight is sufficient for the growth of the crop. It is not always so. Maybe one year out of four will have a month when light is not sufficient for optimal crop growth. In England, or even in some other parts of the United States, light is often the limiting factor and very much needs to be considered. However, at this time, we are not going to consider the factor of light or of wind or of relative humidity or any of a number of other factors that tend to be minor if we are just considering the development and growth of the crop in the Corn Belt. These "other" factors should be analyzed in the same manner as those considered directly in this course.
FYI: Converting kg/ha to Bu/A

Converting kg ha\(^{-1}\) to Bu A\(^{-1}\):
kg ha\(^{-1}\) x 0.0159 = Bu A\(^{-1}\)
or
62.71 x Bu A\(^{-1}\) = kg ha\(^{-1}\)

Note that kg ha\(^{-1}\) and kg/ha are interchangeable terms for kilograms per hectare.
Weather Effects on Crop Yields

Soil Effects on Crop Yields

It is suggested that you watch Video 01B and complete the exercise sheet before continuing. While viewing the video, work through Video Exercise Sheet #1B.

When the temperature is high and soil moisture is low, a crop can experience stress. In a strict sense, heat stress is a very rare thing. Water stress is common, being induced by increased crop needs for water (or high atmospheric demands for water because of high temperatures). Temperature can change the demand for water; crops in Iowa and across the Corn Belt usually respond to water stress rather than high temperature stresses. Consider the stress of limited moisture and the effect of moisture stress on the crop. Limited moisture is not a stress if demand for water is low. Before emergence a plant needs moisture but not in great quantity.

Begin with the seed, or with shelled corn and its equilibrium moisture at a temperature of 70°F (21.1°C) and a relative humidity of 50% (Table 1.2). These are not atypical values for the Midwest in the springtime. The corn in natural air at this temperature (70°F) would come to equilibrium at about 11 or 11.5% stored moisture.

<table>
<thead>
<tr>
<th>Temp. (°F)</th>
<th>Relative Humidity, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>11.9 13.1 14.5 16.0 17.9 20.5</td>
</tr>
<tr>
<td>50</td>
<td>11.2 12.5 13.8 15.4 17.3 20.2</td>
</tr>
<tr>
<td>60</td>
<td>10.6 11.9 13.3 14.8 16.8 19.7</td>
</tr>
<tr>
<td>70</td>
<td>10.0 11.4 12.7 14.3 16.3 19.3</td>
</tr>
</tbody>
</table>

At a humidity of 70% and 70°F air temperature, the corn’s moisture would be somewhere around 14%. It does not take a whole lot of increase in humidity to begin to increase the moisture in the corn by a considerable amount. However, even at 90% humidity, the corn is only at about 19% equilibrium moisture.

The percent of moisture in corn just when it becomes mature and before it has begun dry down is a key value. Experience would tell people it is on the order of 25-35%. Obviously, then, that would be near the amount of moisture required in the seed for it to germinate and to grow.

Even though the relative humidity may be around 90% and the temperature from 50-70°F, there will not be enough moisture in that seed for it to germinate, emerge, and sustain growth. Therefore, we must assume that the humidity in the soil, if the crop is to germinate, is something above 90%. And indeed it is. Soils have to be very, very dry for the humidity in the soil to drop below 90%. When the plants have withdrawn all of the water from the soil available by the action of its roots, the soil is crumbly and dry. The relative humidity in the soil would still be at 98-99%. This is enough, then, for the seed to swell, perhaps germinate, and prepare to emerge.

The "wilting point moisture content" of the soil is considered to be at -1.5 MPa for agricultural crops (older literature considered the wilting point a -15 bars). The relative humidity (RH) in soil at the wilting point can be approximated by the equation (Salisbury and Ross, 1992, pp. 103, 104):
Equation 1.3

\[-1.5 = 1.06 \times T \times \log_{10}(100/RH)\]

T is temperature in °K. Relative humidity in the soil is surprisingly high even when plant-available soil moisture is fully exhausted. If moisture is discernable by touch or by appearance, the soil contains at least half of its plant-available moisture capacity.

One of the problems often seen in a dry spring is just enough moisture in the soil to initiate germination and emergence, but not enough to continue growth. Considerable damage from drought right at or just after planting time is occasionally reported.

Assuming that there is sufficient moisture in the soil for plants to germinate, emerge and begin their early growth, the only concern is temperature. The temperature effect on emergence of corn and soybeans is dramatic. The primary soil temperature or the temperature at which corn and soybeans will emerge most rapidly is near 80 °F (26.7 °C). If the temperature is 50 °F (10 °C) or less, emergence will be very slow or not occur at all (Fig. 1.11). The temperature 50 °F is a base temperature, the temperature below which no development of corn or of soybean will occur. This is the base temperature for the corn and soybean varieties that are grown in the Midwest, in the Corn Belt area. There are some varieties of corn that will grow at temperatures considerably below 50 °F, and some that the base temperature is something above 50 °F. Other crops have varying base temperatures.

Fig. 1.11 Effect of soil temperature on emergence of corn and soybeans. Emergence is slow at temperatures near 50°F (10°C). Emergence is rapid near 90°F (32.2°C).
If the soil temperature is averaging 50 to 55 °F (10-12.8 °C) at the time of planting, corn may take 3 weeks to emerge. Temperatures averaging 60 °F (15.6 °C), may have emergence in 10 days to 12 days. If the temperature is averaging 70 °F (21.1 °C), 5 days, and, of course, at optimal temperatures for the soil, which almost never happen at planting time in Iowa (we would hope we are planted well before that, but it may apply in other parts of the United States, particularly the South), the crop may emerge in 3-4 days with soil temperatures somewhere near 80 °F (26.7 °C).

Soybean has about the same optimum temperature, but for the most part we like to see temperatures of the soil near 60 °F at planting time for soybeans. Soybean will emerge with vigorous growth if temperatures are somewhat above the base temperature.

Study Question 1.9

What would be more correct base temperature than 50°F for soybean?

°F  
Check Answer

Study Question 1.10

How long would it take soybean to be 50% emerged if temperatures averaged 70°F?

days  
Check Answer

Study Question 1.11

How much longer would it take soybean to reach 50% emergence, compared to corn, at a temperature of 65°F?

days  
Check Answer

Consider the normal temperature of the soil near the planting date. The best planting date in Iowa is considered to be the first part of May. During the first week in May, the central Iowa average soil temperature, measured at the 4-inch depth, is 60 °F (15.6 °C). This is suitable for soybean and very good for corn (Fig. 1.12). Occasionally, the soil temperatures may be 55° F (12.8 °C) and rarely in the low 40s. The warmest at this date in central Iowa is in the upper 70s. Normally, on the first of May, the soil temperature in central Iowa is somewhere between 55 °F and 68 °F (12.8 and 20 °C). Soils will warm to their peak in mid-July, near 80° F. Soils in Iowa are seldom, if ever, too warm for the crop. During the hottest period of the summer, the crop usually covers the ground such that the soils do not heat above that which is ideal.

Fig. 1.12 Annual 4” mean and extreme soil temperature for Ames, IA
What were the 4” soil temperatures in Ames, Iowa on May 1 for 1997-2008? Go to www.mesonet.agron.iastate.edu. Choose: ISU AgClimate, Request Daily Data, Ames, Average 4” soil temperature, May 1. to find out.

Temperature is a very important factor in determining when the plant will emerge and when it will go through its growth stages. There is a big difference between development of the plant and growth of the plant. The chart of the effect of temperature and monthly moisture on the “growth” of the crop is not necessarily directly associated with the “development” of the crop. In the next section we will evaluate the effect of temperature on crop development. The growing degree day is used to integrate the influences of temperature and time on plant growth development.

During early stages of development, soil temperature has dramatic effects. Some controlled soil temperature studies in the field were conducted in Illinois (Bellero, Bullock and Hollinger, 1996). Greenhouse work has shown dramatic differences in plant development between heated air and under-the-bench radiant heating. Cold soil and warm air may result in abnormal coloration of young corn.
FYI: Kelvin

Boiling point of water is 100° C = 373° K
Kelvin or absolute temperature scale is obtained by adding 273 to the Celsius temperature.
Agronomy 541 : Lesson 1b

Climate Effects on Crops

Introduction

Developed by E. Taylor and D. Todey

In this section we consider the effect of weather patterns on crop production in the U.S. Corn Belt.

Section 1a discussed trends in yields and individual effects some years had on these trends. What causes these years can often be related or forecasted based on several climatic patterns.

While long-range outlooks are not completely indicative of expected conditions, certain things can be determined, based on several larger scale effects, such as El Nino (Fig.1.13).

Fig. 1.13 Correlation between the SOI, and temperatures in August. Positive correlations mean that high SOI numbers are indicative of warmer temperatures. The SOI will be defined later in the lesson.

What you will learn in this lesson:

- Discuss several large-scale effects on climate in the midwest.
- Relate how yields are affected by some of these factors.

Reading Assignments:
• pg. 207-208—Aguado & Burt, 3rd pg: 232-234, Semi-permanent cells
• pg. 446-447—Aguado & Burt, 3rd pg: 486-487, Historic Warmth
• pg. 229-231—Aguado & Burt, 3rd pg: 255-258 and 263, El Nino
• pg. 350—Aguado & Burt, 3rd pg: 386-387, Forecasting
Agronomy 541 : Lesson 1b

Climate Effects on Crops

Climate Variability

Around 1960 the average annual precipitation for the state of Iowa was 31-31.5 inches. Something on the order of 33.5 inches is now typical of the precipitation for the state of Iowa (Fig. 1.14).

This 10% increase in annual precipitation over a 30-year period represents a very dramatic change in climate. By any standard, it is a major climate shift. That change in the amount of precipitation can be directly seen as responsible for some very marked effects on regional yields in the state of Iowa.

Records showed the yield trend in western Iowa increasing in a linear manner (Fig. 1.5); whereas, it has leveled off in the eastern part of the state (Fig. 1.5). It may be no surprise then that this increase of 10% in precipitation has had a great effect in the western part of the state; perhaps the greatest effect is in that area. Locations most limited in productivity by precipitation are likely to benefit the most from increased precipitation. The trend in Iowa is similar to that seen in many areas of the country (Fig. 1.15), where precipitation has increased significantly during the last century.
Almost all of the Corn Belt has seen a precipitation increase. Especially on the western end of the Corn Belt, this will help productivity in an area where water is usually limited.

A widespread drought has not occurred since 1988 (Fig. 1.16). This may be influenced by the change in precipitation amounts. However, there is no reason to assume that the changed average precipitation is a permanent climate change.
1990's. The incidence of flooding also increased. The change of climate had the greatest impact on rivers and crops in South Dakota.
Bermuda High

The most important climate pattern is shown in Fig. 1.17. It shows a high pressure over Bermuda, appropriately named the Bermuda high pressure. It is not a permanent feature. The Bermuda high pressure appears during the summer. It may appear as early as February, but usually becomes established in April and May lasting through the summer. The Bermuda high pressure follows the sun. As the sun moves back toward the Southern Hemisphere (the apparent position of the sun), the high pressure moves south of the Bermuda-centered position and the east. The "Azores High" may be thought of as the winter condition of the Bermuda High.

Fig. 1.17 Influence of the Bermuda High on Midwest weather patterns. This causes warm, moist air to be brought from the Gulf of Mexico.

The clockwise air flow around the High moves warm, moist air from the Gulf of Mexico into the Midwest.

When the southerly air flow begins with the onset of the Bermuda High, spring and summer weather develops in the Midwest. These southerly winds become the prevailing winds for summers in the Midwest. Warm, humid nights in the spring when the temperature does not fall below 40°F become common. An influx of insects occurs in the spring with the change of wind direction. Black cutworms move from the Texas-Mexico area into the Midwest, and many related things happen. But mainly it brings the moisture. If it were not for the Bermuda high pressure, the Corn Belt of the United States would have a different name. It would be called The Great Desert of North America. The Bermuda high pressure is the great singular aspect of the meteorological environment that makes the Midwest what it is, at least as far as summer weather conditions are concerned.

Midwest rain results from a combination of things. The warm, moist air moving up from the Gulf of Mexico combines with disturbances crossing the Rockies, perhaps traveling along a jet stream flow that comes from
near the state of Washington and Oregon, across the Rockies. The disturbances lose most of their moisture when they cross the mountain ranges. When they reach the Midwest, they are just a trough aloft or an atmospheric low pressure. When that disturbance encounters warm, moist air in the Midwest, it triggers spring storms and can also contribute to the development of scattered summer thunderstorms.

Occasionally a droughty weather pattern develops, (Fig. 1.18). The weather pattern in 1988 associated with the drought did not have a typical Bermuda High. There was a high pressure over Colorado and perhaps out further in the Atlantic. Low pressure disturbances were not crossing the Rockies because of low pressure that was a persistent feature in the Gulf of Alaska. The disturbances were being deflected up into the Yukon. During the drought of 1988, the Yukon had a record wet year. With no Bermuda high pressure to force moisture into the plains, it was a record dry year. It was drier, actually, than the Dust Bowl years. It was not as hot, however, so it was not as stressful as those years.

Fig. 1.18 Weather conditions during the drought of 1988. Moisture from the Gulf of Mexico was shifted westward.
Climate Effects on Crops

Global Temperature Cycle

Video 1b discusses global warming starting at about “minute 8” in the video. The most important factor affecting crop weather seems to be global temperature change or is associated with episodes of global warming and global cooling. Figure 1.19 shows the global temperatures as best we know them. The period from 1880 to 1940 exhibited a global warming trend. From 1940 through about 1972, the warming trend stopped and a period of global cooling began. After 1972 the global warming trend resumed. This will be discussed in more detail later in the course.

The global temperature change is the most important weather influence on variability for the simple reason that the El Niño effect during the time of global cooling was not detectable in the Midwest. We did not detect the effects of the El Niño or the effects of the post-El Niño, sometimes called La Niña or anti-El Niño, between 1940 and 1972. The effects of the El Niño-La Niña seemed confined to Peru and Australia, but during the time of global warming, the effect can be measured in the Midwest. In other words, we have greater variability of weather during times of global warming than during times of global cooling.
Climate Effects on Crops

20 Year Cycle (18.6 Year)

Another influence on Midwest climate is the 20-year cycle. This cycle can be seen in drought assessments of the 19th Century. Tree rings give an indication of periods of significant water stress and periods of ample water in the Midwest. Tree ring analysis show moist periods for the western two-thirds of the United States (Fig. 1.20.). On this chart where there is no mark, the trees are growing well. Favorable episodes seem to develop periodically. The higher the line on this chart, the greater the number of sites that are showing stress influencing tree growth.

![Droughts Western 2/3 of USA](image)

**Fig. 1.20 Number of stations reporting drought-stressed trees (1800-1900).**

Favorable growth periods come along at rather regular intervals rather than at random. Looking at that pattern, we recognize that there is a periodic (or semi-periodic) aspect to the occurrence of stressful and ideal weather in the western two-thirds of the USA.

Three droughts in an 18- or 19-year period is the pattern typical for the Midwest. If we look at the years when crop yield has been reduced by greater than 10% (that is, falls to 10% below the trend line or lower), we would consider that to be a drought year (assuming that most of the low yields are due to drought and not to something else).

There have been a couple of times in Iowa, 1915 and 1993, when low yield was due to too much water. We have some slightly low years, lower than would have been expected (1970 and 1974), when the yield was reduced by crop disease and frost conditions, respectively. There can be other factors. But basically three yield-reducing droughts occur in an 18- or 19-year period where the distribution of them is six years with two droughts, and twelve or thirteen years with only one.

That cycle is known as the 18.6-year cycle. It has become quite well known in the Midwest and quite well known around the world. This 18.6-year cycle exists in the center of the large land masses, at least of the temperate continents. It is true in Africa, in South America, on the North American continent, and on the Asian continent. It even appears in the middle of the Australian continent.
An interesting manifestation of this cycle can be found in Russia. The flood periods on the River Neva at St. Petersburg are marked on the walls of the Peter and Paul Fortress (Fig. 1.21, and Fig. 1.22).

This cycle does not appear as well during the 20th century. A more apparent effect is the ENSO cycle.
The El Niño/Enso Cycle

The El Niño event is the second most important factor influencing our crop weather in the Midwest. If the El Niño is going on, the drought will not begin. Historically, we have not detected a widespread drought in the Corn Belt when an El Niño event was in progress.

When the El Niño is going on, the airflow from the Gulf of Mexico may be somewhat stronger. And in fact, the Canadian flow may also be stronger, so there could be a cooler than usual summer, because of the flow of northerly air, but also the air collides with moisture from the Gulf. Increased precipitation results near the Gulf of Mexico and sometimes pushes as far north as Iowa. Southern Iowa and Missouri might expect increased August moisture during an El Niño year. And from Des Moines north, a little bit cooler than usual summer, or at least not warmer than usual. This would be the normal weather pattern expected during the summer and strengthened during an El Niño year.

The El Niño event itself has to do with warmer than usual water in the Central and Eastern Pacific Ocean (Figure 1.23). That warm water results in more evaporation of water and more rain than usual over Tahiti. Tahiti would normally receive 2 or 3 inches of water during the year and occasionally 5. During El Niño conditions it might receive 20-50 inches of precipitation. So when the El Niño is going on, there will be more rain in the center of the Pacific, less rain in Australia, and hot and perhaps dry conditions in southeast Asia (from India to Korea and Japan would be typical).

If we would look at the entire world during an El Niño, there is typically a drought going on in southeast Africa, floods on the equator in Africa, harsh conditions from India to Korea, and warm winters from Alaska to Nebraska (they may influence Iowa). When the El Niño is going on, the summer will be a little cooler than usual from Des Moines north. And it may be wetter than usual from Des Moines south (Figure 1.22).
In South America, there is normally plenty of moisture where they grow the corn and soybeans. In Peru where El Niño gets its name, the El Niño is a wet year.

The sea surface temperature anomalies alternate sides of the Pacific during a La Niña, or opposite of El Niño, the western Pacific becomes warmer than normal. Australia becomes wet; Peru becomes dry. Conditions are reversed from those in Figure 1.24. These two extremes alternate on a 2-7 year cycle.
Climate Effects on Crops

Enso Effects on Corn Yields

It is possible to utilize an index associated with El Niño conditions that has some forecast value for crop production in the U.S. Corn Belt. The El Niño can be detected by a difference in pressure between the center of the Pacific and the north edge of the continent of Australia. This difference in pressure is called the Southern Oscillation. If the pressure is high over Australia, it is low over Tahiti. If it is high over Tahiti, it is low over Australia. When it is low over Australia, they get moisture. This difference in the index of pressure is called the Southern Oscillation Index, or the SOI.

The SOI does have an impact on the Midwest (Table 1.2). When the SOI is significantly negative (less than -0.8), there may be crop yield enhancement. A negative SOI can result in a yield that is 10% above the trend line. In 22 years with a negative SOI, 7 had enhanced crop yields, 12 years were near normal, and only 3 years had really bad yields (that is 10% below trend line). And those three yields included one year when there was a flood. In 15 years where the SOI was >0.8 (opposite of El Niño conditions), Iowa had a high yield only once, very low yields 6 times. Major droughts are associated with a high value of the SOI.

Table 1.3 Cross tabulation of corn yield and SOI values. Total years for Corn Belt states with El Niño, La Niña, and in between conditions (Carlson, Todey, and Taylor 1996).

<table>
<thead>
<tr>
<th>State</th>
<th>SOI code b</th>
<th>&gt; 10%</th>
<th>in between</th>
<th>10%</th>
<th>Total</th>
</tr>
</thead>
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<tr>
<td>Iowa</td>
<td>&lt; -0.8</td>
<td>7</td>
<td>12</td>
<td>3</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8</td>
<td>1</td>
<td>8</td>
<td>6</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>in between</td>
<td>14</td>
<td>30</td>
<td>7</td>
<td>51</td>
</tr>
<tr>
<td></td>
<td>Total</td>
<td>22</td>
<td>50</td>
<td>16</td>
<td>88</td>
</tr>
<tr>
<td>Illinois</td>
<td>&lt; -0.8</td>
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<td>14</td>
<td>1</td>
<td>22</td>
</tr>
<tr>
<td></td>
<td>&gt; 0.8</td>
<td>3</td>
<td>7</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>in between</td>
<td>14</td>
<td>28</td>
<td>9</td>
<td>51</td>
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<td></td>
<td>Total</td>
<td>24</td>
<td>49</td>
<td>15</td>
<td>88</td>
</tr>
<tr>
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<td>&lt; -0.8</td>
<td>9</td>
<td>11</td>
<td>2</td>
<td>22</td>
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<td></td>
<td>&gt; 0.8</td>
<td>3</td>
<td>9</td>
<td>3</td>
<td>15</td>
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<td>in between</td>
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<td>23</td>
<td>50</td>
<td>15</td>
<td>88</td>
</tr>
<tr>
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<td>10</td>
<td>9</td>
<td>3</td>
<td>22</td>
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<tr>
<td></td>
<td>&gt; 0.8</td>
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<td>2</td>
<td>7</td>
<td>15</td>
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<tr>
<td></td>
<td>in between</td>
<td>16</td>
<td>19</td>
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<td></td>
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<td>Total</td>
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<td>18</td>
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</table>

\[ a \] 10% above or below yield expectation (y) defined by Eq. 1.

\[ b \] Standardized monthly air pressure difference occurring during any of
Throughout the Corn Belt, the SOI effects seem to be strongest in Iowa, Illinois, and Missouri. The temperature effects are greatest from Iowa into Minnesota and the Dakotas. Moisture seems to be involved in southern Iowa toward the east. A forecast may be based on what the SOI is doing. In 1997 the SOI began to drop in early April. Allowing about 45 days for the effect to get to the Midwest, we expected things to start to get wet by the time we got into May and into June. The National Weather Service said, "Well, it will likely be an El Niño year, so expect it to be above normal moisture in August, in the southern half at least of the Corn Belt, and a little bit cooler than usual in the north." These conditions make for a low stress year. A low stress year will result in above trend-line yields. The El Niño is influenced by many factors: SOI and sea surface temperature are important, but trade winds, sea levels, depth of warm water, QBO (quasi bi-annual oscillation), and others are likewise significant.

SOI relationships vary slightly for different states. In fact in Ohio, we find that a positive SOI doesn't have as dramatic an effect as it does in Iowa. In Indiana, a positive SOI has no effect at all statistically, where 3 good years and 3 bad years have occurred during positive SOI. The negative SOI generally has a very positive effect across the Corn Belt. El Niño conditions generally produce positive yield effects in the Corn Belt. These will be discussed in more detail in Lesson 11.
Climate Effects on Crops

Enso Effects on Corn Yields

Persistence

Applying these previous items with some evaluation of soil moisture and potential stress, we can begin to put the picture together. A southerly air flow might be warm and moist. So a warm summer would likely be a summer that is "warm and moist". It would be rare to have it be hot and moist, just warm and moist. Where does the heat come from? When we have a very hot summer, it is the air flowing in from the West off of the mountains. Water does not come from that direction. So hot and dry would likely go together. And in fact, cool and moist would be a more likely combination than hot and moist. We have quite a few combinations that are possible. Some of them go together well. Hot, dry--cool, moist; each would go together well. The other two combinations would not persist very long. Cool and dry we would not expect to be a persistent condition in the Midwest during the summer, nor would we expect hot and wet to be a persistent condition in the summer. We will discuss these more in the radiation section.

Fig. 1.25 Iowa persistence data. a.) Percent of occurrence explained by conditions in the table at the bottom of the figure. b) Percent time that such occurrences persisted to the following month.

The condition of above average temperature, and above average precipitation (indicated by a blue square) does not occur often during July in Iowa (~16% of the time). Below average temperatures occur much more often (~35%). How often these persist to the next month is another issue. Looking at part b., the blue box for July indicates that about 18% of the time July warm and wet conditions persist to August if they occur in July. For July cool and wet conditions, we see that they will persist to August about 42% of the time.

The statistics have been worked out on those things so that we can evaluate (sometimes well in advance) just what we can expect from our summer season (Fig. 1.26). For example, in Missouri there is a 35-37% chance in
June of a weather condition 2 (cool temperatures and above normal precipitation). As we get into July, there is a 30% chance that we would have condition 3 (hot temperatures and dry). So the most likely condition to occur in Missouri, if you do not have any forecast: “The summer will likely be cool and wet,” if you just have to make a guess. It could be hot and dry, but not as likely, and it is very unlikely to have the condition of hot and wet or of cold and dry. They add up to a 100% chance. Similar chances exist all across the Corn Belt for our different states and give the probability of having combinations of weather if you do not have any forecast means (Fig. 2.23).

![Map of state averages if above/below average temperature and above/below median precipitation expectations for each month and their chances of persisting to the next month. Plots are based on the contingency table shown in each figure. Click on map to display a state. (Todey 1995)](image)

**Study Question 1.13**

For Ohio, in what season do cool and wet conditions occur more frequently, winter or summer?

- [ ] Winter
- [ ] Summer

**Check Answer**

For Ohio, what percentage of the time do cool and wet conditions persist from June to July?

[ ] %

**Check Answer**

For Kansas, if conditions were warm and wet in September, would you expect them to persist?
Using the SOI charts and persistence probabilities allows an adjustment of the odds as to which one of these conditions is most likely. From this discussion and use of the figures presented, an individual can calculate what the yields might be under the varying weather conditions that exist in the Midwest. This discussion of agriculture and weather and weather's effects on the variability of agriculture explains much of the crop yield variability in the Corn Belt and provides the information necessary to calculate the probability of reduced or enhanced crop yields for any year.

Assignment 1.1

Click here for Assignment 1.1

Lab Assignment 1.1

Click here to get the Lab 1 assignment as a Powerpoint file.
Send your lab assignment to Dr. Taylor, via email, as an Excel document.

Lesson 1 Reflection

Why reflect?
Submit your answers to the following questions in the Student Notebook System.

1. In your own words, write a short summary (< 150 words) for this lesson.
2. What is the most valuable concept that you learned from the lesson? Why is this concept valuable to you?
3. What concepts in the lesson are still unclear/the least clear to you?
4. What learning strategies did you use in this lesson?
Climate Effects on Crops

References


Todey, D. P., 1995: Categorical Persistence as a tool to improve extended range forecasting. PhD Dissertation, Iowa State University

Agronomy 541: Lesson 1a

Weather Effects on Crop Yields

Introduction

Developed by E. Taylor and D. Todey

The principles and examples presented in Lessons 1 and 2 can be used to improve crop management and marketing skills. They are also intended to serve as a summary and introduction to a series of comprehensive lessons in the principles of applied agricultural meteorology. Many of the examples apply to maize (corn) in the central United States. The principles expressed are applicable to the production of many other crops and can be applied to an international scope.

What You Will Learn in This Lesson:

- Understand crop yield trends for the Midwest crops and other major crops throughout the United States.
- Relate climatic anomalies to their effect on crop yields.
- Learn how to calculate and use growing degree days and several applications.