Agronomy 541 : Lesson 13a

Soil Moisture and Crop Yield

Introduction

Developed by E. Taylor and D. Todey

It is suggested that you watch Video 13A and complete the exercise in the video before continuing with the lesson.

Podcast Version **Full Podcast List**

In this lesson, the student will:

1. Review a crop yield/water stress model (Shaw's Model).
2. Use an "Expert System/Knowledge-based" model to determine risk of reduced yield for years when initial soil moisture is at low, moderate, and high levels.
3. Estimate "pan evaporation" from temperature data to evaluate potential evaporation.

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Limiting Resource

The concept of a limiting factor in ecology or chemical reactions is useful if not universally applicable. Crop growth may be limited by temperature, light, carbon dioxide, nutrients, water, and numerous other resources. In the central U.S., water is the predominantly limiting resource. Crop yields have improved with modern genetics and management techniques. Functionally, it may be assumed that the upper limit of yield, or the potential, is determined by genetics and management. The realized yield is something less than the potential, depending upon weather conditions.

The premise that, if a crop consumes all the water that can be consumed, water will not be the limiting factor to growth, is the basis of water resource capture yield modeling. The basic assumption of a water resource capture analysis is that water use, less than the potential, is indicative of strain that will reduce crop yields (Figure 13.1).

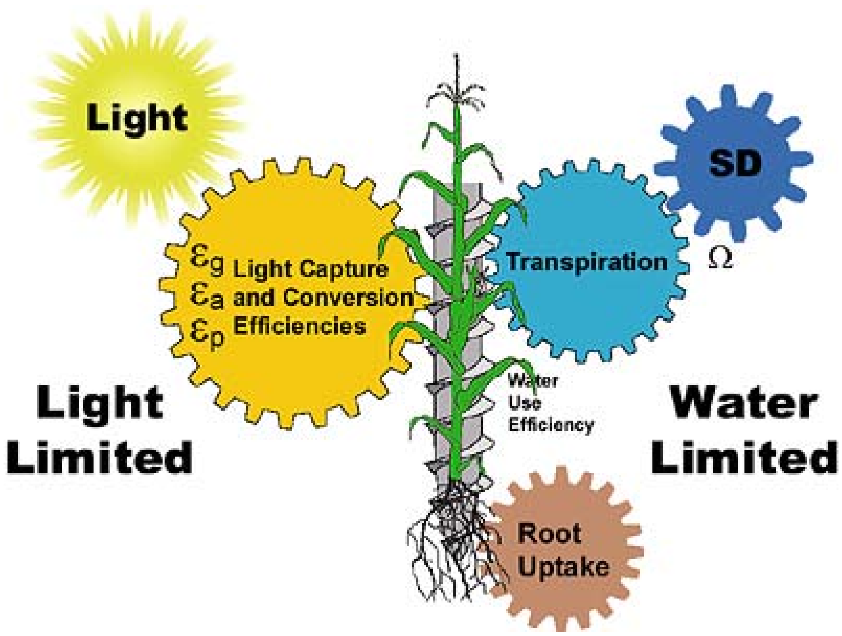

Fig. 13.1 Factors involved in resource capture.

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Potential Water Use (Potential Evapotranspiration)

The heart of all water resource capture crop models is the determination of "Potential Evapotranspiration." There are numerous methods for estimating the potential. The details of such methods are treated in a fundamental agricultural, rather than in an applied agricultural meteorology, course. One method that has proved effective and simple to apply involves relating the use of water by a crop to evaporation from a pan of water (Figure 13.2).

Fig. 13.2 Evaporation pan for estimating water use.

Water use is not directly connected to plant growth and development. Clearly water is essential to the life of the plant, but the great bulk of water "consumed" in crop production does not directly contribute to plant growth. Although it may require one million gallons of water per acre to produce a "full" crop in one locality (such as Idaho), in another location (Iowa), the identical yield may be obtained from an identical variety for one-half the water used in the growing cycle. If the crop has sufficient available water to meet the demand (or potential water consumption) in the locality, it may be expected to yield well if other factors (including fertilizer, light, etc.) are not limiting.

The resource associated with the greatest year-to-year variation of yield in the midwestern United States is water. In some locations light may be the limiting resource; in others the availability of nitrogen may limit growth. In this lesson the contribution of water stress in reducing crop yield is evaluated. The fundamental premise is: If crop water use is less than potential water use, the crop is experiencing yield reducing strain.

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Heat Stress Misnomer

Crops do not normally experience temperature "stress" at any temperature below 35°C (95°F). However, water stress is often associated with temperatures of only 30°C (86°F). Water stress is often coincident with increasing temperatures because other factors such as relative humidity, dew point, wind and solar radiation share some direct or indirect linkage to temperature. Increasing temperature by 4 - 5°C (10°F) will often be accompanied by a 25 to 50% reduction in relative humidity. This factor alone may result in a three-fold increase in water use under some circumstances. High demand for water rather than high temperature results in crop strain response.

Daily pan evaporation in Iowa may be approximated from observed daily temperature using the **ANTAL** relationship (Basnyat, 1987).

IN DETAIL : ANTAL Equation

The ANTAL equation:

$$E = 1.1 * ((e_s - e) \wedge 0.7) + ((1 + (T/273)) \wedge 4.8)$$
$$in/day = (mm/day)/25.4$$
$$e_s = 6.1078 * @EXP ((17.269*T)/(T+237.3))$$
$$e = 6.1078 * @EXP ((17.269*T_{min})/(T_{min} + 237.3))$$

Example: for T = 10°C, e_S = 12.272 mb

for T = 20°C, e_S = 23.380 mb

E is estimated pan evaporation (mm/day), e_S is saturated vapor pressure (mbar), e is the actual atmospheric vapor pressure (mbar), T is 24 hr average temperature (°C), T_{min} is the daily minimum temperature (°C). Use this to estimate evaporation unless you have dew point.

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Subsoil Moisture

Crop yield as influenced by the weather is in large measure a function of the strain response of a crop to the stress of differential water availability and atmospheric evaporation demand. Evaluation begins with the subsoil moisture. The relationship of crop yield to soil water was introduced in Lesson 2a. We make **maps of the Plant Available Soil Moisture** (Figure 13.9).

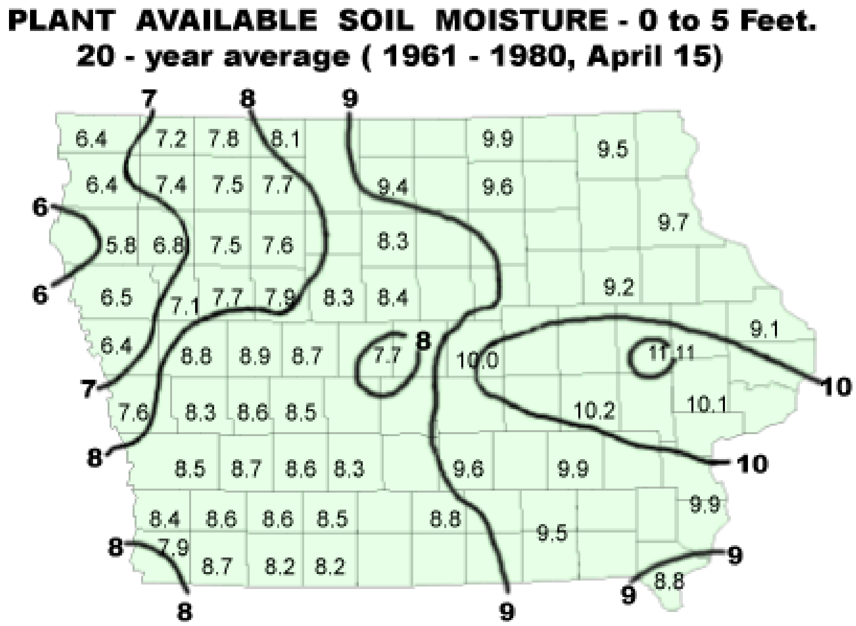

Fig 13.9 April plant-available soil moisture.

Subsoil moisture usually increases through June (the wettest month in Iowa), then decreases through September. Normally by October 1 or November 1, there is more moisture than on September 1 as rains begin to recharge the soil and evaporative demand decreases. September soil conditions are usually about as dry as soil gets during the season.

The long-term average amount of moisture in Iowa on September 1 is shown in Figure 13.10. Usually in the center of Iowa there is approximately 4 in. (102 mm) of plant-available water in the top 5 ft. (1.52 m) of soil. We consider that both corn and soybeans root to the 5 ft. depth. Therefore, we evaluate subsoil moisture in the top 5 ft.

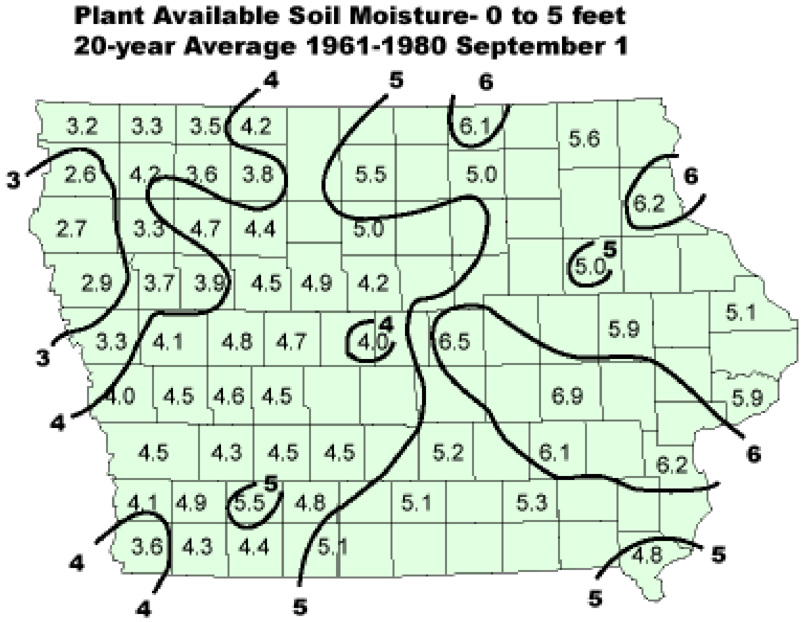

Fig. 13.10 Average plant available soil moisture on September 1

The moisture-holding capacity of our soils is around 10-12 in. (250-305 mm). On September 1 in the center of the state there will typically be 4-5 in. of subsoil moisture available to the crop. This is typical of much of the state, except in the northwest where the amount will usually be closer to 3 in. (76 mm).

By the end of the growing season, subsoil moisture is often essentially expended in the northwest portion of the state.

A serious drought developed in most of the U.S. Corn Belt in 1988. The subsoil reservoir of water has a significant influence on the severity of drought. As we went into the winter of 1987, we had about 7 in. (178 mm) of subsoil moisture over much of Iowa (Figure 13.11). Part of the state had as little as 5 in. (127 mm). The Pocahontas area, Webster County, and the southeastern portion of the state were dry, with Lee County having only 3 1/3 in. (85 mm) of soil moisture. The rest of the state had 6-7 in. (152-178 mm) of moisture, and 10 in. (254 mm) of moisture in Audubon, Cass, and east Pottawattamie. With this amount of moisture in the state, a good crop year was anticipated in 1988, because subsoil moisture was good to start with.

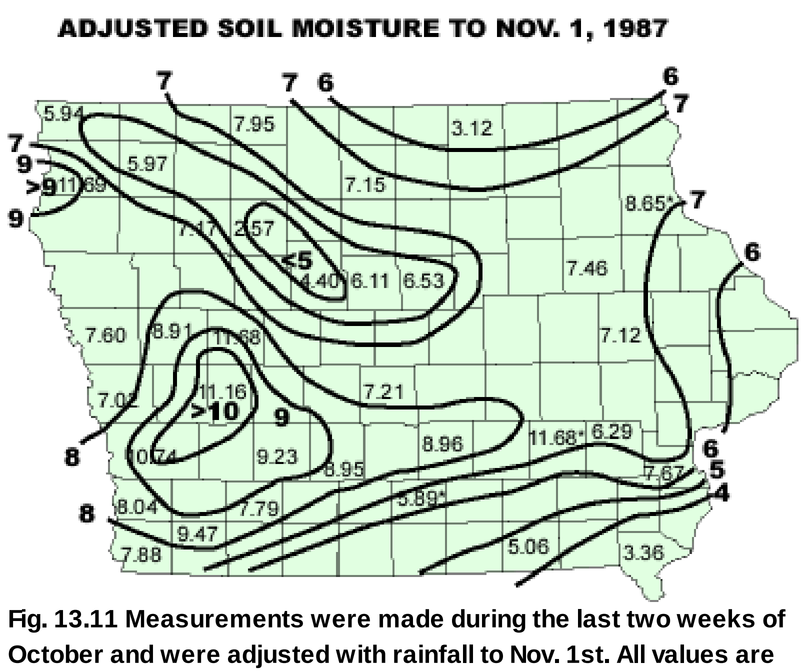

Fig. 13.11 Measurements were made during the last two weeks of October and were adjusted with rainfall to Nov. 1st. All values are

from fields under corn and soybeans unless values with *, which are values under alfalfa.

We can make some estimate of what the crop for the coming year will be according to the subsoil moisture in November. There is seldom a significant change in soil moisture between the time the soil freezes and the time that it thaws in the spring because water cannot infiltrate frozen soil. As soon as it hits the freezing point, water freezes near the surface ending infiltration.

What difference does it make if we get a lot of snow or a little bit of snow? The difference it makes is to the top inch or two of soil. After we get down into the soil five inches or so, the amount of snow doesn't really make much difference unless the snow happens to fall on unfrozen soil or soil that is barely frozen. Occasionally, the top inch or two of the soil will be frozen with 55°F (13°C) temperatures deeper in the soil under a blanket of insulating snow. Heat will transfer upward causing the soil to thaw and begin melting the snow from the bottom, taking up the water. For the most part, assume that snow doesn't make any difference after the first inch or two of soil. In the spring when the snow melts, the water from the snow melt runs off the frozen subsoil, leaving the soil in the spring with the same amount of water as on November 1. A second point is the relatively low water content of snow. A 12-inch (305 mm) layer of snow often has a water content near 1 in. (25 mm).

Spring rain may increase soil moisture. Iowa averages about an inch of precipitation in December, January and in February. If that precipitation happens to fall as snow, it might be a foot of snow each time. An inch of precipitation may show up as snow a foot deep. Precipitation in March is 2 in., in April 3 in., in May 4 in., and in June 5 in. June is normally the wettest month in Iowa.

Spring rains when soils have been dry in the fall, might raise the subsoil moisture up to normal levels or above normal. Historically, Iowa springs are not considered wet; however a number of years in the 1990's have been abnormally wet and interfered somewhat with planting.

Over the long run, we can begin to make an estimate of what the yield next year may be from the amount of moisture in the fall at the 5 ft. profile. Consider the extreme northwest portion of Iowa, and start off with a "wet case." A wet case is defined as 8-10 in. (203-254 mm) of water in the soil. A soil essentially filled with water, produces good chances that we will have high yield (Figure 13.12a).

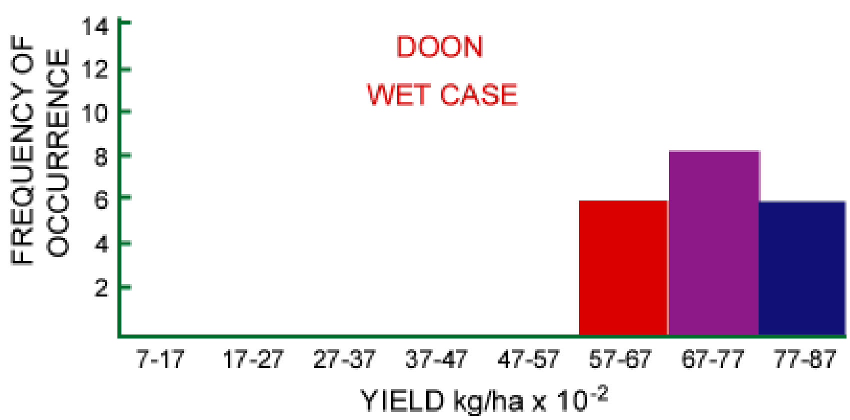

Fig. 13.12a Yields in northwest Iowa when spring soils contained 8-10 inches of water.

However, if we begin the growing season with 5-7 inches (127-128 mm) of moisture in the soil, it is almost rare to have a full yield. We expect yield to drop off by 30 percent on the average year starting off with half of a profile of moisture. Some years we might do quite poorly. Most years we would have a significant reduction (Figure 13.12b).

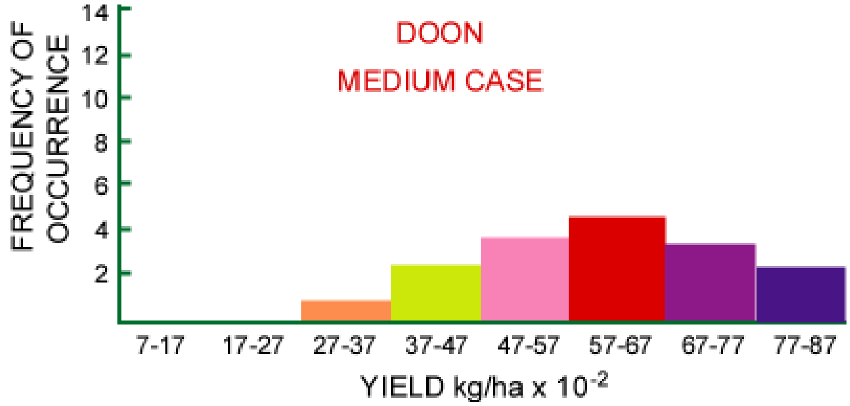

Fig. 13.12b Yield with the soil profile 1/2 full starting the season.

If we begin with only 3 in. of water in the soil at planting time, the expected yield is 1/10 to 1/2 of a full crop. Chance of a full crop is very slim (Figure 13.12c). The yield relationship to initial soil water is given by Shaw (1983). With low soil moisture in west Iowa, fields would only rarely yield their potential, and occasionally there would be crop failure. Most often, substantial reduction in crop yield would result.

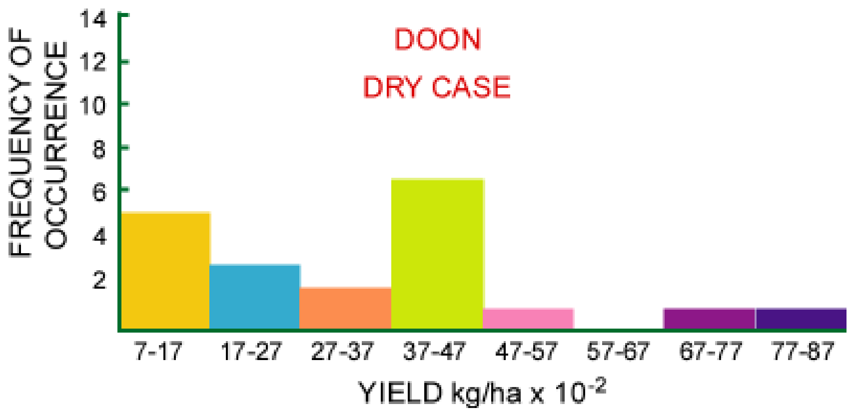

Fig. 13.12c Yield with 3 inches in profile.

Study Question 13.1

Starting the year dry, what percentage of the time would you expect western Iowa to yield less than 3700 kg/ha?

% Check Answer

In the east part of Iowa, the probabilities are different. If we start off with the wet case, we will usually get the potential yield for the field at Cedar Rapids (Figure 13.13a).

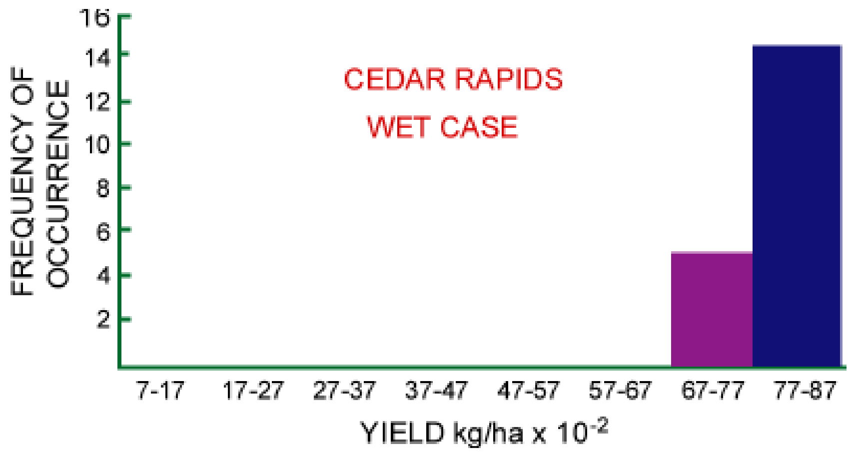

Fig. 13.13a Eastern Iowa yield with full moisture profile.

***Try This!* Selling Your Crop**
You are growing corn in Cedar Rapids, Iowa. You have just planted and the soil moisture is at field capacity. Quaker Oats offers you a price near at current Chicago price for your grain to be delivered at harvest. Should you:

- A: Take the offer
- B: Tell them to wait 45 days and ask again.
- C: Tell them to wait 90 days and ask again.
- D: Tell them they can buy your grain at harvest and pay the going price then.

Check Answer

Few people sell the entire crop in one deal. Suppose you sell 1/3 of your normal yield at a time. On a “great” year you may have a 4th lot of crop to sell at the very end. What offer do you need to sell some or your entire crop? See how you would do on a deer hunt where you may shoot 3 deer and have 3 bullets, on this hunt you will have 6 chances to “pull the trigger” on a deer… how will you score on your opportunities on the hunt and in the markets?

-CLICK HERE for the DEER HUNT-:

If we start off with a moderate amount of soil moisture, slightly dry, we will still usually get a full yield, sometimes reduced, and rarely significantly reduced (Figure 13.13b).

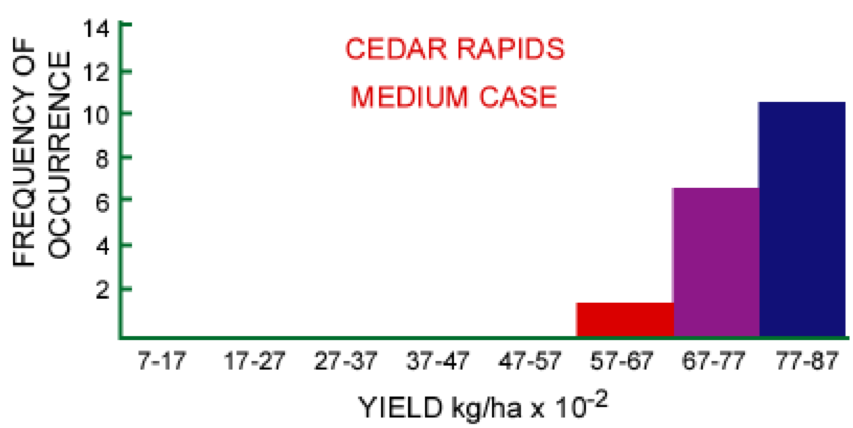

Fig. 13.13b Yield with a slightly dry soil profile.

If we start out essentially under drought conditions, we still would likely do fairly well in east Iowa. They would have had a failure if we would have included 1988 in this early prediction analysis.

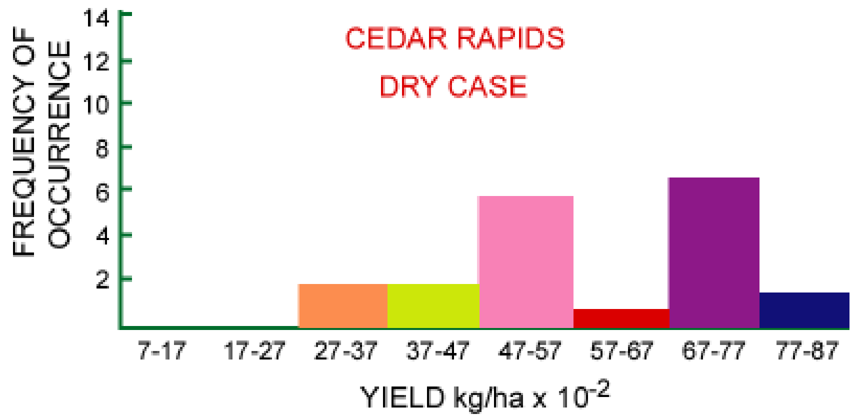

Fig. 13.13c Yield with a dry profile

Having taken an assessment of the subsoil moisture initially available to the plant, the next concern is how much moisture the plant needs and when it needs it. The stage of the crop and the evaporative demand of the atmosphere determine the time and amount of crop water need. Both factors were discussed in lesson 1. The atmospheric demand may be derived from pan evaporation (Figure 13.2). The average monthly pan evaporation for each month was depicted earlier.

The total evaporation out of a pan totals 47 in. in the southwest and central portions of the state for the growing season. It is 43 in. in the northern portion of the state.

Pan evaporation tells us something about potential water loss and water use for a crop. It does not tell us the actual water use of the crop, just the potential. Who says that a crop should use water the same as a pond? Or the same as an evaporation pan? Suppose a crop has perfectly good subsoil moisture, right up there at 10 in. of plant-available water in the top 5 ft. of soil. Will the plant be able to use the water as if it were a pond of water? Of course not.

When the crop is first planted, it draws little water from the soil. There is a little sprig of green when it first emerges. That little sprig of green with a little root system that extends an inch or two is not drawing a significant amount of water out of the large bulk land in the field. There is limited evaporation from the soil surface. The total evapotranspiration is likely to be only a fraction of the pan evaporation.

When the crop is more than 6 ft. tall and has its maximum leaf area, it uses a great deal more water than it did before. A chart (Figure 13.14) gives an estimate of the amount of moisture used by the corn throughout the season, as introduced in lesson 2 (Figure 2.3). According to Table 13.1, beginning at a planting date in early May until June 5, most of the potential water use is evaporation from the soil.

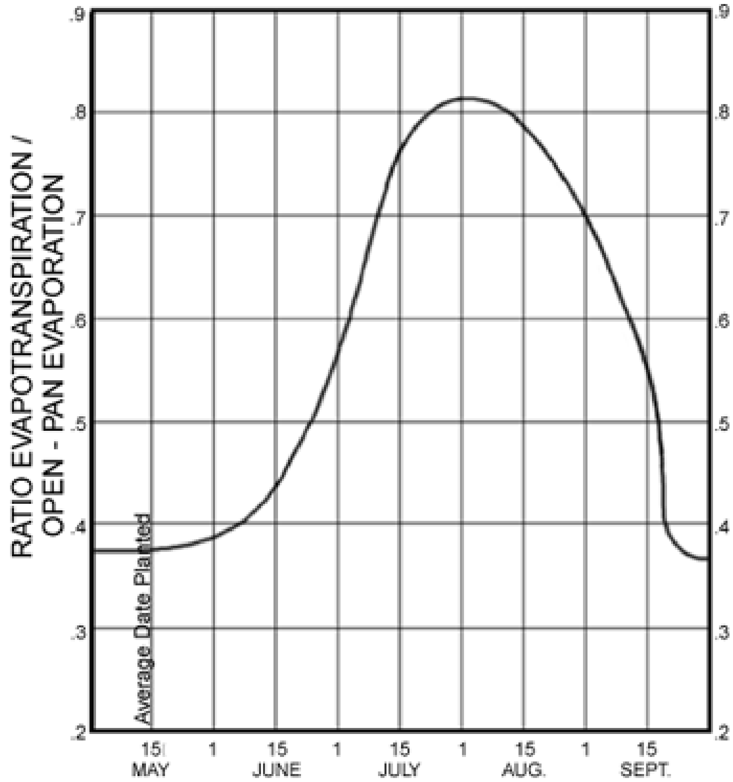

Fig. 13.14 Ratio of corn use of water to open pan evaporation through the growing season.

Table 13.1 Crop stage and relative water use (portion of pan evaporation)

Crop	Factor	Date/Stage
Corn	0.3	emergence
	0.6	July 1
	0.75	July 15 to silk
	0.83	after pollination
Soybean	0.6	40 days after planting
	0.9	60 days after planting (when canopy closes)
	1.1	70 days through leaf turning

The small plants transpire a limited amount. We assume that evapotranspiration is something less than .4 of the amount that is evaporating from the pan. If you know the evaporation from the pan, the amount of water evaporated from the land in May is less than .4 of the amount that evaporates from the pan. On a day when the soil surface is wet, the amount is greater and, when very dry, it is less.

Once the crop area begins to become substantial (approaching the end of June or early July), it uses half as much water as would be used by the pan. On August 1, corn reaches its maximum use, about 0.82. If a pan used 0.33 in. of water during a hot August day, which is not uncommon, the crop would use something on the order of 0.25 inch of water.

As the crop begins to senesce, the water use drops back to under 0.4 again. The only water used after maturity is evaporating from the soil itself with none being lost by the crop.

Soybeans produce a similar picture. Ten days after planting soybeans, total water use is mostly evaporation from the soil (around 0.3 of the pan evaporation). This increases linearly up until 60 or 65 days after planting when it peaks at about 105 percent of pan evaporation. Soybeans use more water than corn at the peak of the year. If you take a circular plot of soybeans that's 6 ft. across, it will use more water than a pan of water 6 ft. across. In other words, it will use about 5 percent more water from about day 65 through about day 95. Then, as the leaves begin to turn, soybean water use drops off substantially. By comparison, corn can use 82 percent of the water that is evaporating from a pan. Soybeans can use 105 percent of the amount of water evaporating from a pan.

I've been consistently saying "can" use. They will only use that amount of water if that amount of water is available to them. If the water is not available, they can't use it. Actual use will vary somewhere between 0 and 82 percent of the pan's evaporation for corn. The charts that we've been looking at give what is known as the potential evapotranspiration. This is expressed often if you see it written in the literature, as just PET, potential evapotranspiration. The ideal total (life cycle) water use for corn and soybean is almost identical, but the time of use differs (lesson 2, and the crop calendar introduced in lessons 1 and 2 provides confirming data).

The potential evapotranspiration must be evaluated if environmental stress and resulting strain on the productive system is to be anticipated. The PET in relation to realized or actual evapotranspiration (AET or just ET) is a well-known measure of strain in the production system.

If you know both PET and AET, theoretically you know the crop production. This theory is based on the concept that if the plant is evaporating water at the rate of the actual evapotranspiration ratio to the potential evapotranspiration equals 1 (AET/PET = 1), there is no stress. If the actual and the potential are the same, the crop will grow at its optimum rate, assuming that you have good soil, fertilized properly, and good pest control. Growth is not being reduced from the potential by what we would call water-stress induced yield loss. But the actual evapotranspiration, as you remember from our very first discussion, is seldom equal to the potential. The Iowa crop calendar charts PET and AET in the various districts in Iowa (Shaw and Benson, 1987).

When a yield estimate is made, based on the water stress method, it is by taking this ratio of actual evapotranspiration to potential evapotranspiration. Why would actual be less than potential? If there is no soil water there, the actual is 0, whereas the potential is still based on what would evaporate out of a pan of water. The amount of moisture in the soil has some control over the AET.

When subsoil moisture becomes limiting, and the potential to use water is fairly high, the plant that would be using one-quarter to one-third of an inch of water on a stressful day, does not have that much water available to it. So it can't use it. If that water is not available, what is going to happen to the plant? The atmosphere is demanding one-quarter inch of water. The roots cannot supply that to the plant. What happens to the plant? It wilts. Or the plant has some adaptation to overcome the wilting.

The soybean plant is well adapted to water stress. When the soil cannot provide the water at the rate the atmosphere is demanding it from the leaves, the leaflets will often fold together. Sometimes all three leaflets fold together so it almost looks as if there is only one. They are vertical rather than horizontally displayed. So there is a change of display of the leaf. Also, if the leaflets are tightly put together, we have the effect of a reduction of leaf area. Instead of having three leaflets, we have the equivalent of one or two.

Corn does a similar thing with its individual leaves. If the leaf is not supplied with the water equal to the demand of the atmosphere, the wilting on the leaf does not cause the entire leaf to wilt initially, but just a few cells known as buloform cells. As these cells wilt along straight lines going the length of the leaf, the leaf begins to curl into a cylinder. Some say it looks like a **pineapple field** when corn leaves all over the field have entered incipient wilting. In this case the buloform cells have wilted to the point the leaves are rolling.

That is one of the functions that we have with the crop adjusting so that the actual transpiration is less than the potential. If it cannot meet it, rather than just wilt, dry up and die, the leaves may change their exposure to the sun and the leaf area may change by rolling and moving together.

The bluegrass in lawns typically folds in half with just one set of buloform cells. Rather than roll up into a cylinder as a corn leaf does, they fold in half displaying in the gray outsides rather than the green inside.

Corn does somewhat has this same thing. Many times you'll say, "Oh, the field is looking gray and it's getting grayer." Then you know you're close to having leaves at the firing point if you haven't already reached it. That is, that they're not going to recover from that day's wilting episode.

(1) Leaf Area and Exposure. That's mechanism number one, if we want to look at it that way. When the actual evapotranspiration is not going to meet the potential, the leaf area and/or exposure may adjust in some way.

(2) Stomata. Number two is the apertures in the leaf; that is, the holes that let the moisture out. They are called stomata and were described in lessons 7 and 9 and in Agronomy 501.

In every leaf surface there are a certain number of pores in that leaf that can only be seen with high magnification. In most plants, stomata influence water loss. Very little water escapes from the waxy leaf surface. Most of the water lost by a leaf diffuses as a vapor through these pores (stomates).

Stomates on most plants exhibit an evaporation control mechanism. They are an anatomical device on a plant that can open and close. The stomate aperture can change. On more than half of the plants in nature, if the roots cannot provide the water at the rate that the atmosphere is demanding it, the stomates begin to close. The aperture in them begins to constrict to become very narrow. With closed stomates, water loss may be less than if the stomates are open. The stomates can be open, or they can close. For the most part, this appears to be a turgor response. That is, as the leaf begins to wilt, one of the first responses is that stomatal aperture begins to restrict water loss.

The restriction of water loss from the stomate is called resistance and will often be indicated by an "r", sometimes an rs, meaning the resistance to water loss by the stomates.

More than half of the plants in nature have stomates that seem to restrict as water becomes limiting. In the Iowa woods on a hot spring day, there are many little plants which at midday will often wilt. Although there is ample moisture at their roots, they're not used to as much sun as gets through the canopy before the leaves are there. They don't have stomata control, so the plants wilt. That changes the leaf angle from horizontal display. Quite often they'll lose leaves during the day because they are not provided with the amount of water that they need. They don't have a well-developed stomate control mechanism to control water loss from the plant.

Most agricultural plants, including alfalfa, corn and soybeans, have effective stomate control of resistance to water loss. The two mechanisms are in place, the changing of the leaf area and display in some way, and the control of water loss by the stomates.

If the stomates become restricted and resist water vapor loss, then the plant may not wilt as readily and may survive through stressful times of day when the potential for water loss is high. The stomatal resistance is not always the factor most limiting to water loss and thus may not always influence water loss.

IN DETAIL : Maps of The Plant Available Soil Moisture

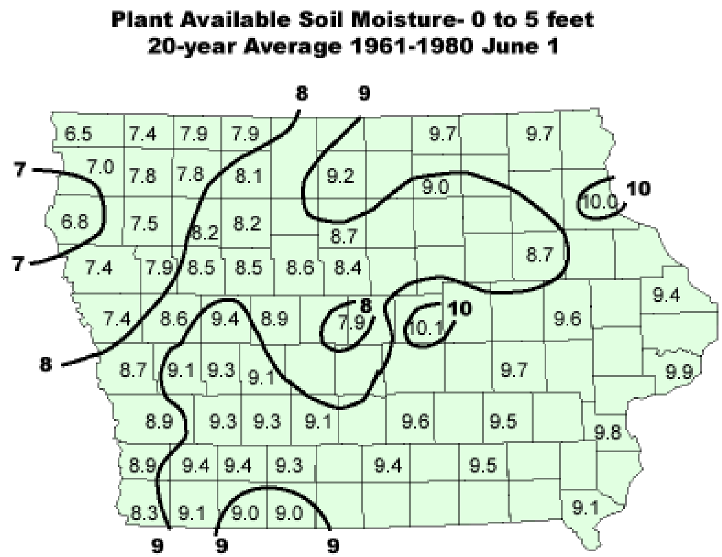

Fig. 13.3

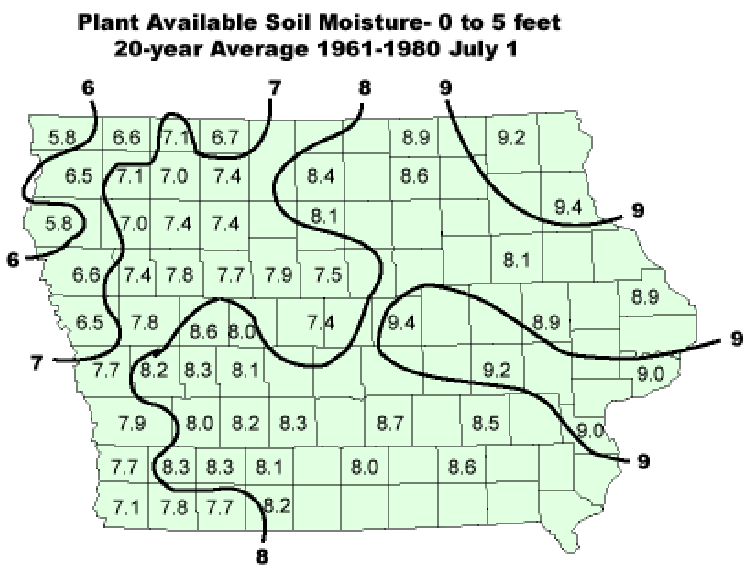

Fig. 13.4

Plant Available Soil Moisture- 0 to 5 feet
20-year Average 1961-1980 August 1

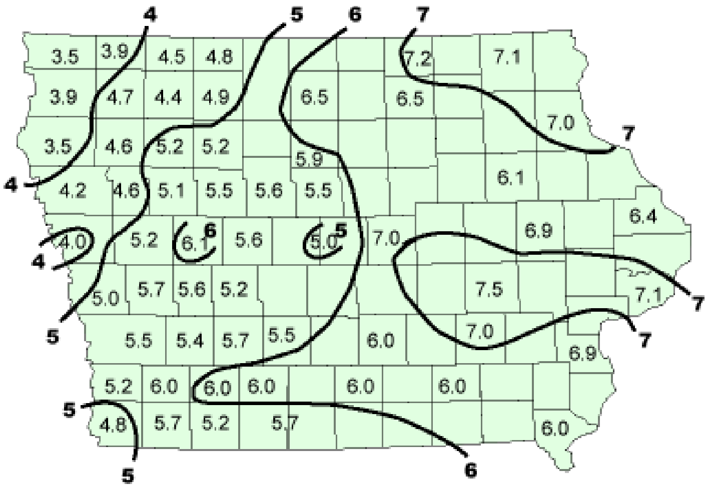

Fig. 13.5

Plant Available Soil Moisture- 0 to 5 feet
20-year Average 1961-1980 September 1

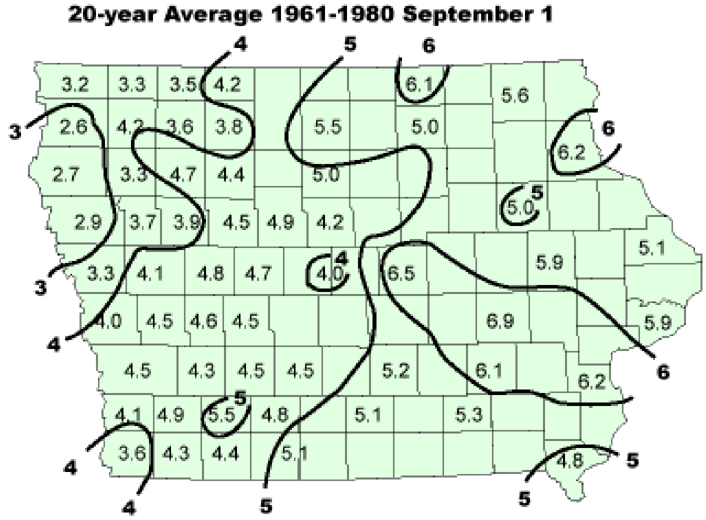

Fig. 13.6

Plant Available Soil Moisture- 0 to 5 feet
20-year Average 1961-1980 October 1

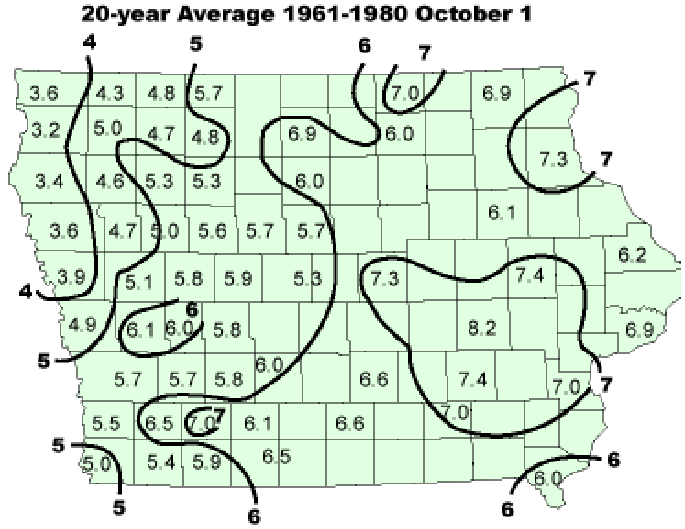

Fig. 13.7

Plant Available Soil Moisture- 0 to 5 feet
20-year Average 1961-1980 November 1

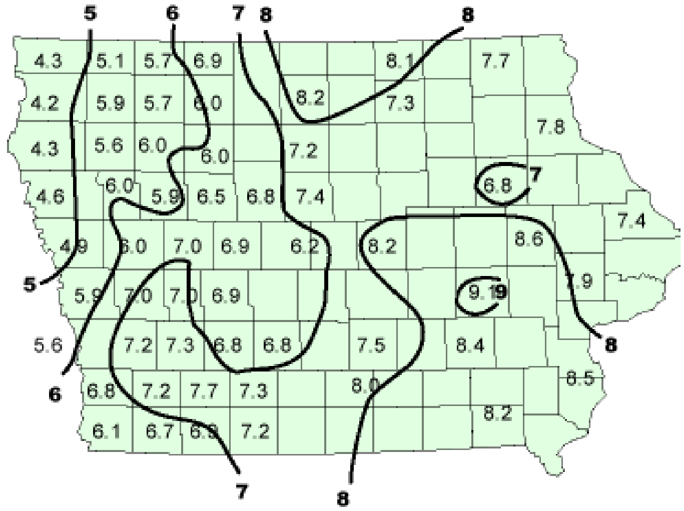

Fig. 13.8

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Soil Moisture and Crop Yield

Water Loss and Yield

So far we are talking about the water loss from the plant. It should be obvious that the water loss from the plant should have something to do with the yield of the plant. Let's look at it a little bit.

Figure 13.15 represents a cut on the edge of the leaf. A little hole in the bottom of the leaf represents a stomate, maybe a hole in the top also. At the stomate water vapor comes out of the leaf.

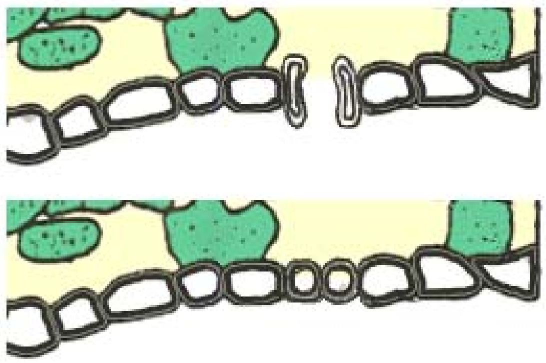

Fig. 13.15 Stomatal adjustment to restrict water loss when the plant is under stress.

Inside the leaf are cells, not necessarily organized as in the figure. At the top of the leaf they are organized more as a palisade layer. Near the bottom of the leaf a spongy configuration might be typical leaves. The cells are inside of the leaves. We assume that the cell surfaces are wet, or essentially wet, and evaporating freely. As the water evaporates from the surface of the cell, it can escape through the stomate and out into the atmosphere. Second, it is assumed that the relative humidity within the leaf is 100%. Neither assumption is strictly correct.

When a plant is growing (adding dry weight), it is taking carbon dioxide from the atmosphere, which enters the plant through these same stomates. The carbon dioxide finds its way to the edge of a cell that has chloroplasts in the cell. The carbon dioxide is absorbed and converted into sugars and eventually starches, proteins, and all of the things that are important to plant growth.

Much of the path of the carbon dioxide coming into the plant is identical to the path of water getting out. In the air spaces inside this thin leaf, the water and the carbon dioxide are moving in opposite directions through the stomates. Carbon dioxide from the atmosphere gets inside the leaf and finally into the cells. Water from the surface of the cell ultimately gets out of the plant.

In the past, physiologists actually said that water loss is "just a necessary evil", that the water loss doesn't really do any good for the plant. That is not strictly true. But there is still some measure of accuracy to this. All this water loss by the plant doesn't have much direct effect on the plant under most cases. It's just that water is going to get out if we're going to let carbon dioxide in. I guess physiologists were justified in saying that it is just an unfortunate circumstance that to get carbon dioxide in, you have to let water out.

Not all plants do this, of course. Plants adapt. Some plants do not open their stomates in the daytime. They keep them closed so that the water can't get out. Then they open the stomates at night and let in the carbon dioxide. Of course, that doesn't do much good because photosynthesis can only occur when there is light. These plants take in some carbon dioxide at night and store it away in some manner. Then the next morning they close the stomates as the sun comes up. That first little bit of light lets photochemistry occur and use the carbon dioxide that the plant brought in during the night, and the plant grows a little.

Plants that have adapted to not lose water by closing their stomates during the day and instead let the carbon dioxide in at night usually grow quite slowly. Of course the plant that would be familiar as a general group would be cacti. Many cacti do this. Crasula is another group of plants, as could be told from the name, that does the same thing. These are usually succulent plants with thick leaves, maybe with photosynthetic thick stems. The "hen-n-chicks" plant common to flower gardens is an example of this group of plants (Figure 13.16).

Fig. 13.16 Hen-n-chick plants.

Agricultural crops don't do this. A plant that "just survives" is not useful in agriculture; a highly productive one is needed. Plant stomates need to be open in the daytime when the light is available to grow rapidly. Hence, these plants use a great deal of water.

The amount of water that the plant uses depends on the demand of the atmosphere. The demand of the atmosphere is indicated by the amount of water evaporating from a pan. That's an indirect measure, but a good one.

A more theoretical measurement is to say that when the relative humidity of the atmosphere is low, the atmospheric demand will be high. If the atmosphere was full of water, there would be a water molecule occasionally headed into the leaf. If the plant was full of water, there would be a water molecule occasionally headed out. These would balance. That's what's happening with those plants that open stomates at night when the humidity is high. But when the humidity is low, very rarely would there be a molecule of water from the atmosphere headed into the plant. Relative humidity inside of the leaf is assumed 100 percent. While the actual might be 99.6 percent, the assumption is saturation.

In some plants, such as salt desert plants that grow in the deserts of Nevada, Idaho, China and Russia, the relative humidity inside the plant may be 85 percent. These are extraordinary plants that can grow in the desert with their stomates open in the daytime and still not lose much water. Halogeton, introduced to the U.S. from Russia, is such a plant.

If the humidity is 100 percent inside and the humidity is 50 percent on the outside of the leaf, which is typical for mid-day in Iowa, moisture flows rapidly from the humid area inside to the dry outside. It is not just the difference in this humidity that drives the water. In fact, humidity is not a good measurement for understanding this process because relative humidity is temperature dependent. The leaf and the air are seldom at the same temperature. It is a rare thing for a leaf temperature and air temperature to be the same. In the sun, the leaf may be warmer than the air, particularly if its stomates are closed or partially closed. In the sun the leaf might heat up several degrees (5°-10° C) warmer than the air.

If the leaf is a lot hotter than the air, this will drive the water off more effectively just as if you were boiling water on the stove. The difference in temperature between the leaf and the air is of importance. An equation for the amount of water lost from a plant would consider the density of the water inside of the leaf (ρ_L), minus the density of the water in the air (ρ_a). The air temperature and humidity determine the density of water vapor in the air and the density of water vapor in the leaf. If the air is cold and the humidity is low, then ρ_a would be a small number. If the leaf is hot, and we assume the humidity inside the leaf is 100 percent, ρ_L would be a large number. At high leaf temperature, moisture loss will depend on the square root of the wind, which we will call V. The more wind there is, the less external resistance to water loss. The larger the leaf, the greater the external resistance. This factor varies with the square root of the dimension of the leaf (D).

Leaf dimension was discussed in lesson 12. Corn leaves, soybean leaves, and alfalfa leaves are of differing shapes, not only different in size. If we calculate the leaf dimension, and put the dimension in the water loss equation for each crop, the equation is functional.

According to the leaf evaporation equation [Equation 13.1, same as Equation 12.4], larger leaves reduce the magnitude of the computed amount of evaporation.

$$\mathbf{E = L\,\frac{{}_s\rho(T_L) - RH \times {}_s\rho(T_a)}{r_i + R_a}}$$

Equation 13.1

and

$$\mathbf{R_a = K_2(D^{0.35}\ W^{0.2}/\,V^{0.55})}$$

The larger the leaf is, the lower its evaporation per unit area, not the lower its total evaporation. If a leaf has an area of 10 square centimeters, and using 10 grams of water, while another leaf is much larger, 100 square centimeters of leaf area, may only use 0.6 of the water. If the area is 100 times bigger, the leaf will use 60 times the water, not 100 times the water. The effect of dimension may be as biologically important as leaf area.

A large leaf "can be" more efficient on water use. Being a large leaf, it also heats up more in the sun because the larger the dimension. We have conflicting adaptations on the leaf, and mentioned in Lesson 12a. A leaf experiences different demands depending on the difference in temperature between the air and the leaf according to the dimension, the wind speed, and the evaporation from the leaf. Under some conditions, the small leaf may have the greater efficiency of water use because of the leaf temperature functions.

That also explains the great argument that we had on the campus between Dr. Curtiss and Dr. Clumb. One thought that wind made soybeans use more water. The other thought that wind made soybeans use less water. They were both correct because it was a function of the dimension and wind and the resistance of the leaf and all of these things happening at the same time.

If the plant is freely losing water, it is freely taking up carbon dioxide. The typical model that is used for estimating yield states, "When the stomates close so that the plant is not using water, it is also not gaining dry weight because it is not taking up CO_2." The estimate is that the yield is approximately equal to (it would be more mathematically correct to say "a function of") the actual evapotranspiration divided by the potential evapotranspiration. This would be strictly true if the only thing affecting the actual was the stomate aperture. To the extent that the leaf angle and the rolling of the leaves influences this, it messes up the relationship. Nevertheless, this is the basic equation used in most yield estimates called physically based estimates of yield.

The actual evapotranspiration ratio to the potential determines what the yield will be. This value can be estimated very well.

The strain on the mature plant when it cannot meet its transpiration demand does not have any effect on yield. If the crop cannot meet the potential for evapotranspiration in the first few weeks of its life, it will have some deleterious effect on the plant. But there is a long time for the plant to recover and compensate for the effects of the early stress. Amount of stress produces several times the yield-reducing strain at pollination time as occurs early or late in the crop cycle (Figure 13.17).

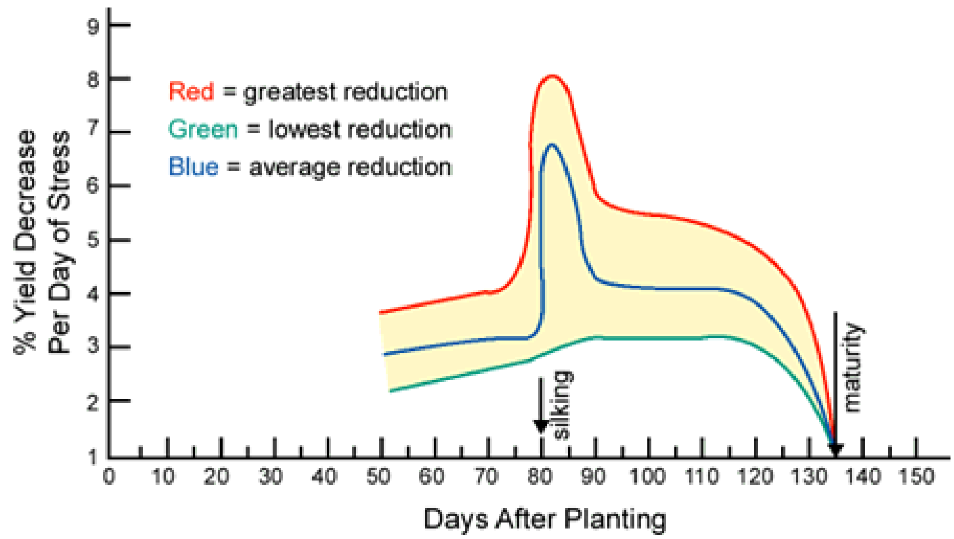

Fig. 13.17 Percent yield reduction for stress over the season for a corn crop.

Stress level is computed for Figure 13.17 from atmospheric water demand and plant-available soil water. There is yield decrease for each day that the plant is under stress. Stress can be estimated from observed strain of the crop. The strain is observed as rolled up corn leaves or the folded leaflets of soybean. A stressful day fifty days after planting (the corn is rolled up) will perhaps reduce the yield of the crop up to 3 percent. Stress must occur the entire daylight time. If the strain is evident for only 6 hours, one-half day of response would be assumed.

At silking, 7 percent or 8.5 percent of your corn yield can be lost per day that the leaves stay rolled.

You say, "Oh, yes. I can lose a lot more than that if the thing is wilted and rolled up right at the day that it's supposed to be pollinating. I might lose everything." That is true for a field; the stress response is the average for the county. If it's at silking time for the county...some fields aren't silking the same day as others, and some parts of your field aren't silking at the same time as others. We're not talking right now about the individual plant. We're talking about a large field or a county, township or something for the yield over a moderately large area, or what a farmer would call a ridiculously large area.

The average response is shown by the center line of Figure 13.18.

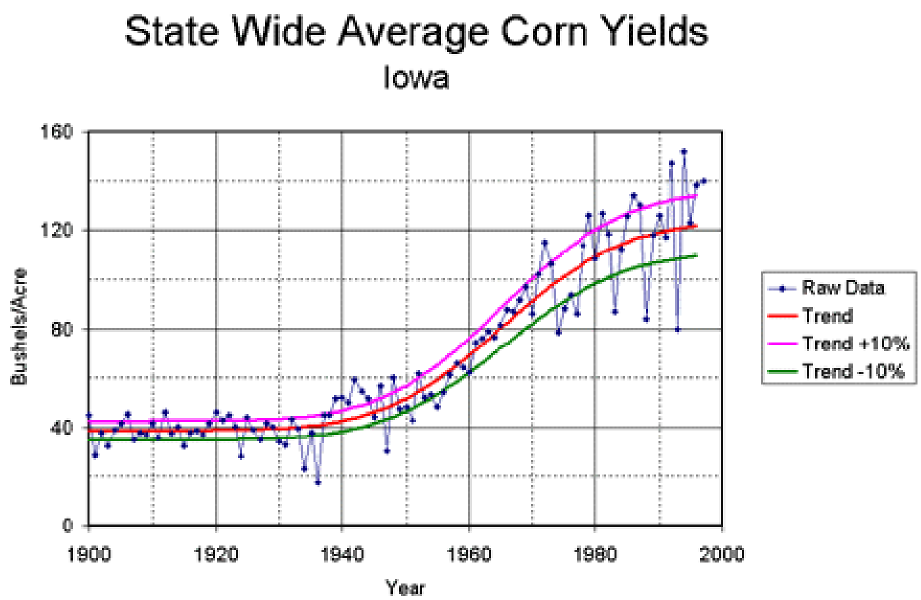

Fig. 13.18 Iowa actual and trend corn yields.

The lowest loss is the lower line (Figure 13.18). The highest the loss could be is the upper line, at least that we have observed. Of course, as the crop approaches maturity, this chart says it's 135 days after planting, or after silking we're some 50 or 60 days later, strain doesn't impact yield. At maturity, it doesn't make any difference if water is limited to the plant. It drops off to 0 yield reduction there.

Reduction in yield based on the stress can be quantified by the time that the stress occurs. Figure 13.19 is an average stress map between 1961 and 1980 (Shaw and Felch, 1972).

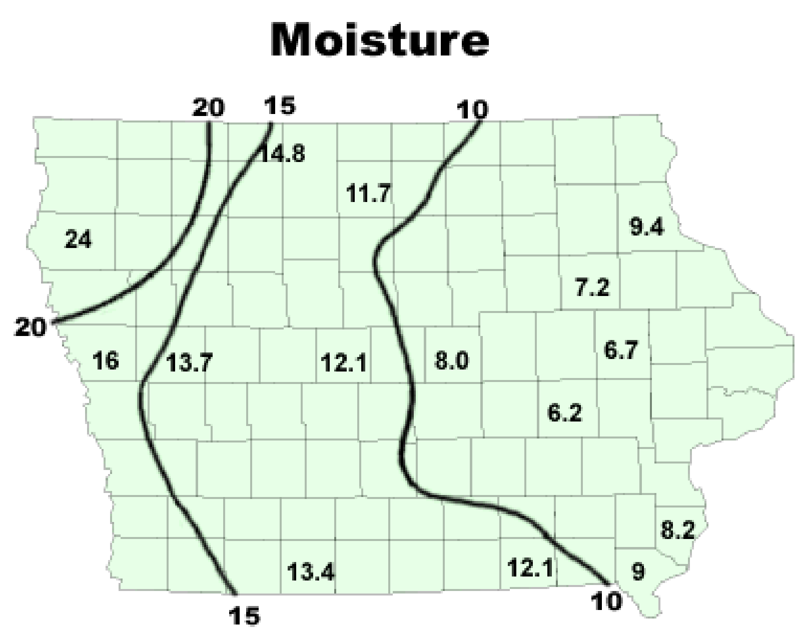

Fig. 13.19 Average soil moisture stress.

The 1954-1970 average was 22 units of stress in Lyon County, 9 in Lee County, and 6.7 or so in Cedar County. By 1980 the averages were 20 in Lyon, 6.5 in Lee, and 3.5 in Cedar. The latter decade reduced stress because of increased precipitation.

The stress difference alone can account for the long-term yield differences between Cedar and O'Brien

County. Soils can be good in O'Brien and Clay County. But over the long run, the yields historically will be less because of these stress units that are accumulated in western Iowa as opposed to the stress units that are accumulated in east-central Iowa.

A rule of thumb is, 50 accumulated stress units reduces your crop by 50%. One example might be to look at what some people in central Iowa will remember as a traumatic year --1977. Sixty-five stress units accumulated in Greene County and slightly less in Boone, Story and Carroll. It was stressful in much of the state, but extremely stressful--crop failure stressful--in Greene and Boone County.

A few places didn't have stress. In Cedar County accumulated stress was 1, causing a near-record yield in 1977. In fact, some fields had all-time record yields while other fields farther west experienced total crop failure. This was all nicely accounted for by the stress evaluation. It was accounted for by the ratio of the actual evapotranspiration to the potential evapotranspiration, adjusted by the time that it occurred. This value is called the weighted stress index. It is weighted by the time or date that it occurs. The amount of stress each day multiplied by that number that would produce the cumulative stress value.

This method provides a pretty good model of what will happen to crop yield if the limiting factors are temperature and water only. The effect of sunshine is not included in this evaluation. Crops need sun to grow, live, and do well.

Measurements from Ames during the drought of 1988 are displayed in Figure 13.20. The year began with 7 in. of plant-available water in the soil. This value would be somewhere between moderate and a wet case. A fairly favorable outlook existed for 1988. Some rain early increased the moisture to 8 in. of plant-available water in the soil in late May. Then in June and early July the crops drew moisture out of the soil rapidly, lowering the moisture to 3-4 inches of plant-available water in the soil by July 1.

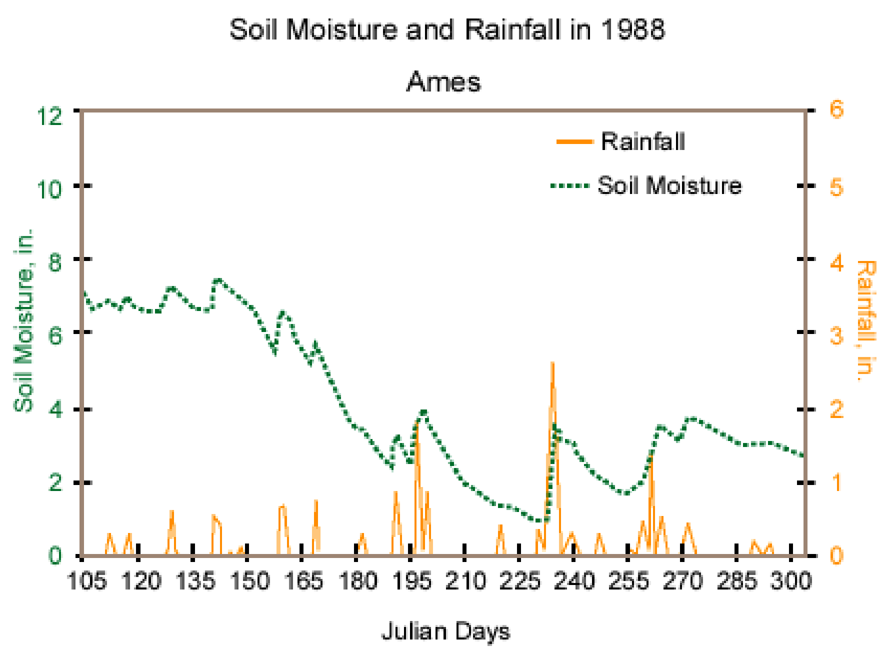

Fig. 13.20 Rainfall and soil moisture for the 1998 growing season.

Plant-available water of 3-4 inches will cause the crops to stay rolled up all day long. At 3 in. of water in the soil, the leaves aren't going to unroll all night either. At 2 in. of water in the soil, a significant amount of leaf loss will occur. Central Iowa reached that point by August 15. A significant number of the leaves fired and were lost from the plants.

Some rain occurred in late August but this rain was too late for most crops. The drought was over. From about August 10 through September and October was fairly normal. But normal isn't good enough to recover from the drought in June and July. Remember that June is usually the wettest month. If June rain fails, a drought is almost inevitable.

In 1988 an El Niño had just ended (the 1987 El Niño). There was a post-El Niño drought condition. It was early in the spring. It was harsh. It removed subsoil moisture quite rapidly. A Corn Belt-wide drought disaster developed.

In some of the places in Iowa, it wasn't a disaster. At a few locations in west Iowa, particularly in northwest Iowa, individual farmers reported the highest yields they'd ever had. There was an interesting weather pattern that year. What moisture was received in May and June came from the west. The western portion of Iowa had the first shot at it.

Shaw Stress Model

Dr. Shaw, from Iowa State University, developed a model called soil moisture and moisture stress prediction for corn in a western Corn Belt state. Billed as predicting the stress, the paper predicts yields as well. The Shaw (1982) paper is a complete description of how to use water availability, water stress and evaporation to calculate crop yield with plenty of sunshine. The paper and principles were previewed in Lesson 2.

Sometimes it would be desirable to learn how to work crop models in great detail. That is not intended in these lessons. It is, however, important to understand the mechanisms that are being modeled. By the time you get to the last page of this model, you will be able to estimate crop yields with respect to the crop's exposure to stress.

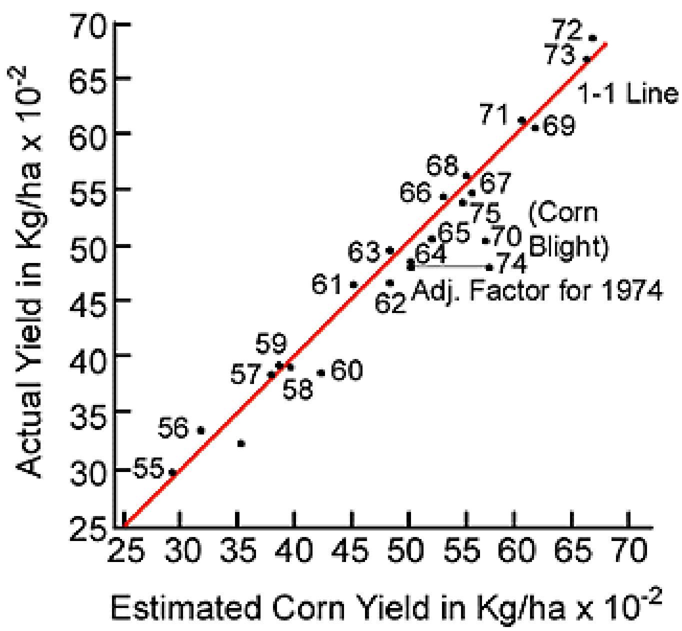

Fig. 13.21 Actual vs. estimated yields using the weighted stress (Shaw 1983).

Figure 13.21 gives estimated yields which are related to actual corn yields. The model data generally fall on a straight line. During the year of a blight, yield was sharply reduced. Except for the blight years, the water stress model gives a good result in Iowa.

Shaw (1983) gave a relationship of the weighted stress to corn yield. The relationship is not universal; that is, it changes with location and soil type. For a Nicollet silt loam in Iowa, the equation is:

Yield = 9682 - 118.6ws **Equation 13.2**

Where yield is expressed as kg/ha and ws is the total weighted stress for the season. The yield may be

Where yield is expressed as kg/ha and ws is the total weighted stress for the season. The yield may be converted to bu/A by dividing yield by 62.73.

The expression (Equation 13.2) was valid in 1980. However, the yield potential has improved since that date. Accordingly, the expression should be used to find yield reduction, or the value 9682 should be changed to reflect current potential yield (in kg/ha). Also note that the term "118.6" is related to the stress resulting in no yield (9682)/118.6 = 81.6 stress total for crop failure.

Study Question 13.2

Note the usual stress in East Iowa and in northwest Iowa from Figure 13.19. In northwest Iowa, what is the "expected" yield for an "average" year for corn grown on a Nicollet silt loam soil?

- 117 bu/A
- 126 bu/A
- 136 bu/A
- 145 bu/A

Check Answer

It is good enough that we can also publish a map of the same nature that is Yield Reduction.

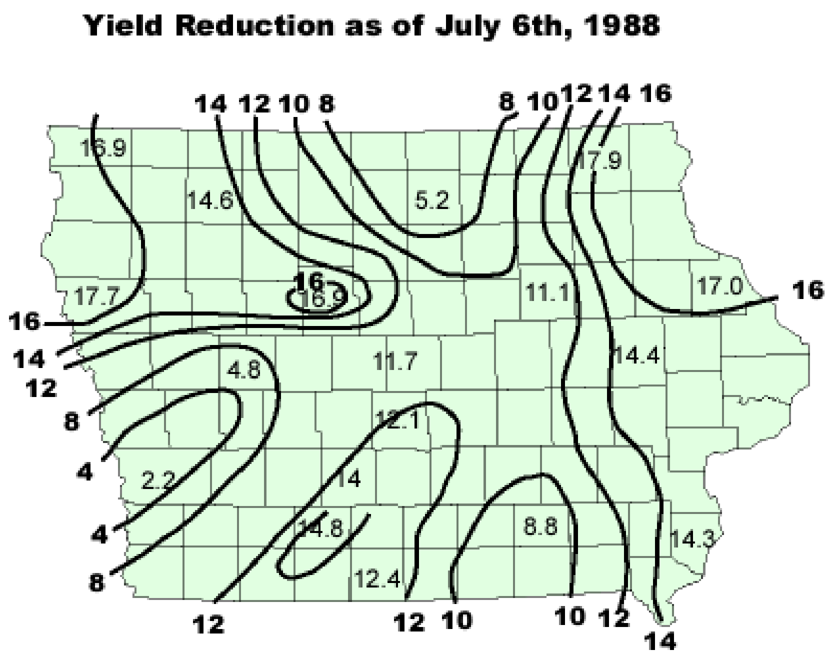

Fig. 13.22 Yield reduction as of July 6, 1988 using Equation 13.2. Click the image for other dates.

Figure 13.22 is a copy of the map published July 6, 1988 that indicates 10 percent of the yield in central Iowa had been lost, 17 percent of the yield in the northeast, 17 percent in the northwest, 2 percent of the yield in the southwest and 11-12 percent in the bulk of the center of the state. The model begins with potential yield and estimates reductions. A more accurate adaptation of the model is to use trend-line yields and average stress for a basis of comparison. Seasonal stress may be expressed as a deviation from the normal and anticipated yield similarly expressed.

Each week a map based on the water stress is produced anticipating yield loss to date. The model yield loss for

1988 anticipated that harvest would be some 30% below the trend line yield. Soybean yield was set at 32%

1988 anticipated that harvest would be some 30% below the trend line yield. Soybean yield was set at 32% loss.

At the end of the season, the predicted loss was within 1% of the actual loss. This was desirable. It gave people some advantage in knowing in August what the yield was going to be, not just for Iowa but in the Corn Belt. The tragedy could be assessed on your farm. If you happened to have a fairly good yield, you could assess what the markets might do with 30 percent less corn available. People in Iowa, at least those who believed my radio broadcasts and had faith in this model, knew what the yields were going to be on August 1 rather than wait until harvest time. It turned out that the yields didn't degrade further because of the average weather thereafter.

Average rain in August is less than the crop needs. The crop has to rely on subsoil moisture to have actual evapotranspiration be anywhere near the potential. That is a point to keep in mind. If June rains fail, the crop is hurt, because July and August normally don't rain enough to compensate.

During the last five or six years, July and August have occasionally brought heavy rains. But these were El Niño influenced years. This reduces much of the stress on the crop.

The Shaw paper begins with an understanding of how to picture plant-available moisture in the soil. Figure 13.27, which you will find on page 1 of the Shaw handout, represents the moisture in the top 5 feet of soil.

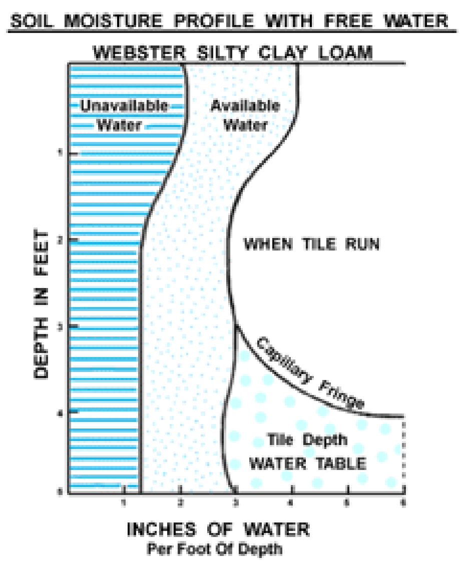

Fig. 13.27 Normal Iowa soil at field capacity.

At the left of Figure 13.27 is unavailable water. If soil was perfectly dry perhaps an inch of water in a foot of soil could be added. In a pan with soil a foot deep, pour the equivalent of inch-deep water and the soil will take up that water. The soil will still be dry. It will appear dry to your hand and to the plant. It can take up the first inch of water in a foot of soil and not have anything available at all to a plant.

Add another inch of water to the pan and perhaps the plant can get some. If the soil contains quite a bit of organic matter, still there is none available to the plant. It will still, after the water has had time to distribute well in that foot-deep soil in the pan, appear dry, almost powdery.

Add another inch of water (having added 3 in. of water into a pan that has 1-foot deep soil) and the soil will now just start to feel moist.

Add another inch, and the soil will become muddy. You can make a ball with your hand, and it will stay in the mud ball. This is at field capacity. In this foot of topsoil, of the 4 in. of water, 2 in. is available to the crop. As the

crop grows it removes 1 in. of water over a period of four or five days. When the soil just begins to feel dry to crop grows it removes 1 in. of water over a period of four or five days. When the soil just begins to feel dry to you, it is half gone. The plant can then go on another four or five days, withdrawing the next inch of water and you will think that it is bone dry. There are still 2 in. of water that could be driven out by heating in an oven.

Deeper into the soil, the subsoil, the water-holding capacity is less than the topsoil. The total plant-available water in the top 5 ft. usually is something on the order of the 10-11 in. (as discussed before).

A rainfall event that drops more water than the soil can hold, will introduce water which will sink down through the soil to a lower depth until it reaches the water table. Then, 5-6 in. of water per foot of soil will exist at the water table. Hopefully, there will be a tile or something there draining this off.

Water will rise from the water table. This is called capillary water (Figure 13.27). If you have a pan of soil and the soil slopes, you fill it with water until there is a puddle. The water will soak upward, making it extremely wet for a little bit above the water level. It will make the soil moist, perhaps, all the way to the top. A capillary rise occurs just because the soil particles are close enough to each other that you get a little capillary effect of water standing between the particles of the soil.

This is the picture of the soil condition. If the soil is dry, no plant-available water may exist except at 3-5 ft. where there are not many roots. An inch or two of rain might add some plant-available water at the top that does not soak down. The roots soon use that or it evaporates out the top, and only the plant unavailable water is left in the soil.

With that we will conclude our look at modeling the soil demand and atmospheric demand as they influence the plant. There is one last factor to keep in mind. If the subsoil moisture is less than field capacity, the plant under a high demand atmosphere, will not be able to get all of the water that it needs, and the stomates will restrict. The student will consider water stress and crop production risk in the following section.

IN DETAIL : Yield Reduction

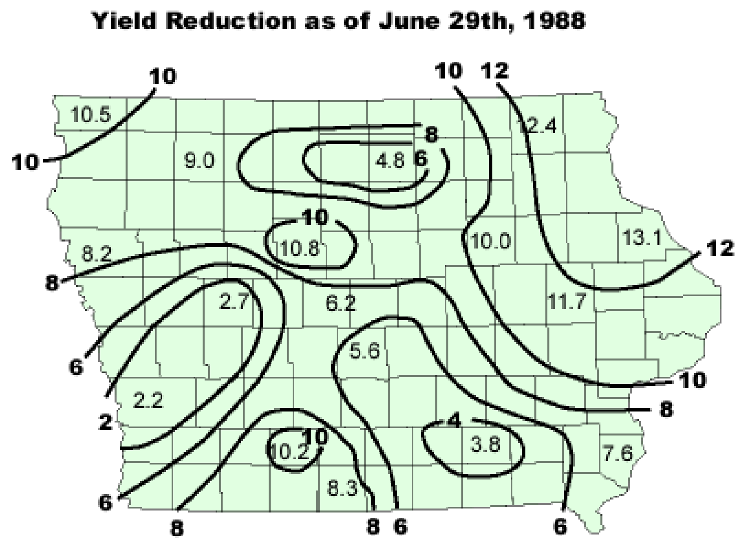

Fig. 13.23

The completed percentage of yield reduction by the end of June was substantial in eastern Iowa. West central Iowa received timely rain.

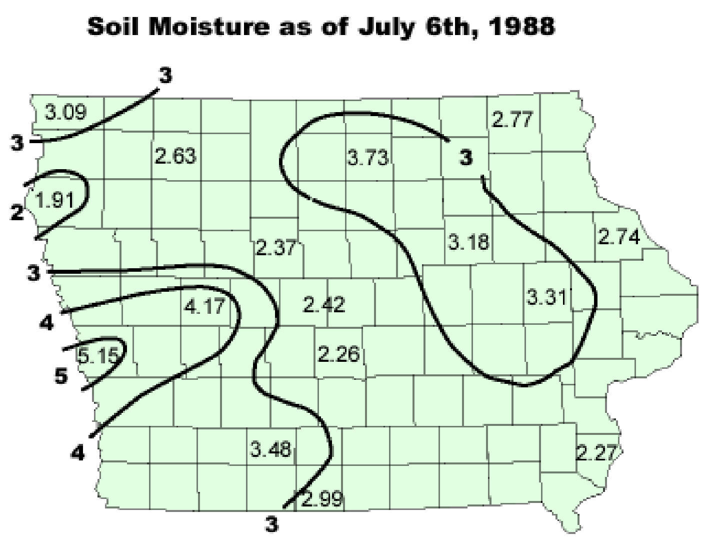

Fig. 13.24

The sub soil moisture was 60% to 70% depicted by July 6th and corn leaves stayed rolled throughout the 24 hr period in some locations. lower leaves died in northwest and east central Iowa.

Yield Reduction as of July 6th, 1988

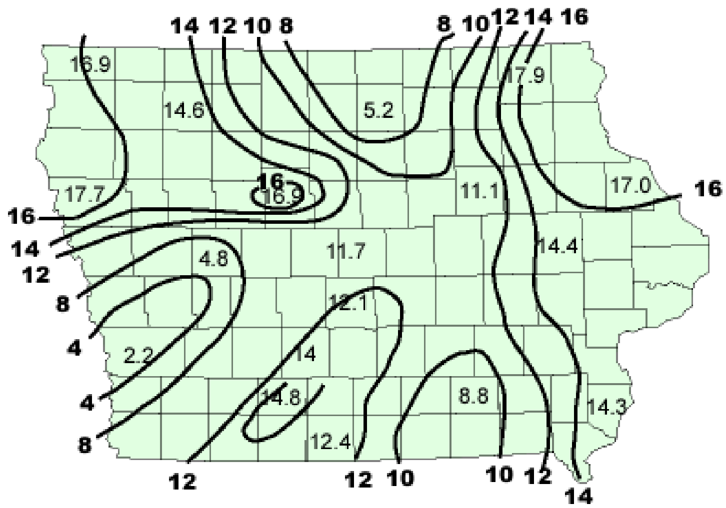

Fig. 13.25

Yield reduction advanced significantly during early July.

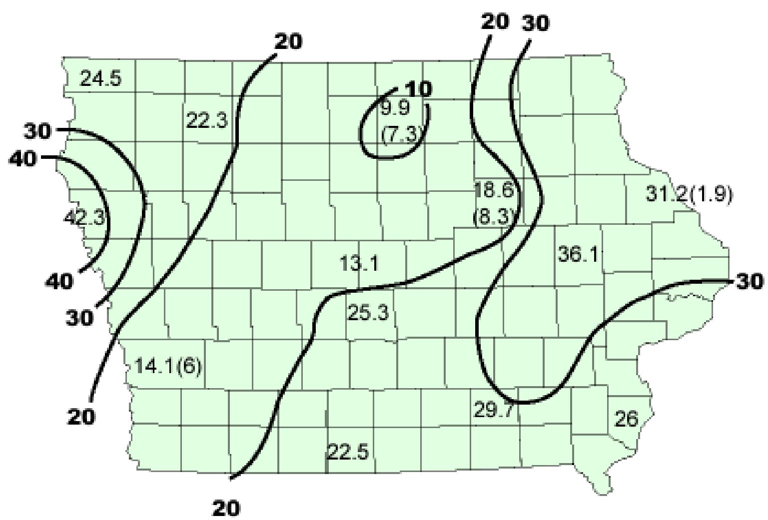

Fig. 13.26

By the end of July 1988 weather patterns returned to near normal and the estimated yield loss as of July 29 was the final yield loss for the season.

Agronomy 541 : Lesson 13a

Soil Moisture and Crop Yield

Water Loss and Yield

Modeling Risk Analysis

Although weather patterns are erratic, they are not random. Accordingly, crop production risk can be assessed more accurately than by simply using the distribution of “good and bad” years. The risk of a drought that reduces crop yield to less than 90% of the trend yield is 1 in 6. However, during El Niño years, the risk is closer to 1 in 20. The risk of a yield-reducing drought is greater if subsoil moisture is lacking and the chance is less if moisture is plentiful at planting time. The risk of frost damage to a crop in the spring is less if the crop is planted somewhat “late.”

Decision risk analysis considers the changing chance of adverse conditions with time, place and circumstance from an economic standpoint with as many risk factors considered as practical. “RISK” is a demonstration production risk analysis program developed as a thesis project by R. Stefanski (1988) at Iowa State University. The program is a knowledge-based system that considers observed crop water stress for Iowa during the past 90 years. The risks associated with soil type and subsoil moisture at planting time are computed using the “Shaw ” water stress relationships. The effect of the planting date on expected yield and of hybrid maturity class on yield are included according to “expert opinion” (Dr. G. Benson and others at Iowa State University served as consultation experts in the development of the expert system).

The risk of fall frost damage is computed from the chance of a freezing temperature for any given location and date. The yield loss because of late frost is computed according to crop development stage on the frost date (Ortiz-Valdez, 1983).

If the soil is dry at planting time, the risk of drought injury is naturally greater than if moisture is at favorable levels. Very early planting makes possible a long growing season, but also increases the risk of spring freeze damage. A long-season hybrid planted late may not reach maturity by the end of the growing season, but if the fall frost is late it may yield very well.

The “expert” system program considers all of the risk factors and weighs them against one another. A 50% chance of freeze and a 60% chance of drought do not “add” to a 110% chance of crop failure. Risks do not sum directly. Consider the risk associated with a series of coin flips: There is a 50% chance of flipping a “tails,” but only a 12% or 13% chance of 3 tails in a row (Figure 13.28)

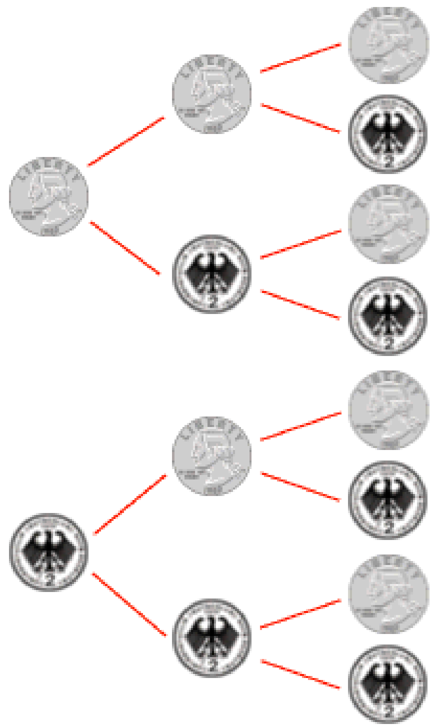

Fig. 13.28 If a coin is flipped three times, there are 8 possible outcome combinations: all H, all T, and 6 HT combinations.

The chance of rain during the next 36 hours is related to the chance of rain during each of the three forecast periods of 12 hours each. Naturally rain is more likely at some time during the 36-hour period than for any of the individual forecast periods. If the chance of rain is 50% tonight, 50% tomorrow, and 50% tomorrow night, the chances are much like that of the coin flip. There is a 1-in-8 chance that it will rain in all three periods and 1 in 8 that it will not rain at all.

Study Question 13.3

Forecast: 30% chance of rain tonight, 40% tomorrow, 60% tomorrow night. What is the chance of rain at some time during the next 36 hours? (Remember the 36-hour chance is greater than the chance for any one period.)

% Check Answer

USING RISK

To use RISK you will need to connect remotely to one of our computers. First, you will need to connect to the Iowa State network through use of a **virtual private network (VPN)**. The first time you do this, you will need to follow the **installation instructions**. Each subsequent use only requires you to **login**. Once you have connected to Iowa State's VPN, you will need to initiate the remote desktop connection by downloading, unzipping (extracting), and then launching the file provided here. Login using your ISU netID and password (the same information used to access these materials or Blackboard Learn).

To start RISK, go to **Start > All Programs > MS Agron Software > Risk > Risk**. Follow the steps as they appear on the screen.

When presented with a choice, run the “Risk” option.

Select “One Combination” of input options
Select “Northwest” Iowa
Select “soil Yield Potentials”
Select “Sac silty clay loam”
Select “2-5%” slope
Select “Field capacity” planting time moisture
Select “April 20th” as planting date
Select “Full” hybrid maturity class
Select “No” corn was not grown last year
Select “soybeans” as last year's crop
Enter “45” Bu/a soy yield
Enter “3” price of corn
Enter “.1” price of nitrogen
Enter “100” other production costs per acre
Enter “100” desired return
Select “No” do not print

Note: The chance of full yield (148 bu/A) is 13%. The “worst” (1-in-100 chance of doing worse) is 74 bu/A. The likely yield (67% choice) is better than 116 bu/A. This is found by punching “F3” twice to highlight “economic”, then tapping “F4”.

Study Question 13.4

Analyze the nature of the production risk for full, medium, and short season hybrids for years with plant-available moisture at 50% of field capacity and years with water at field capacity at planting time.

Tap “F10” to return to the main menu of RISK. Select all combinations, Northwest, soil yield, Marcus silty clay loam, soy last year @ 45 bu/A, corn @ $3, N @ $.1, additional @ $100, and $50 return.

Study Question 13.4 (a)

Identify the planting date and maturity with the highest expected $ return:

- April 20 Full
- April 20 Medium
- May 29 Short
- May 16 Medium

Check Answer

Study Question 13.4 (b)

Identify the combination with the best chance of returning more than $329/A

- May 16 Full
- April 20 Medium
- April 20 Full
- May 3 Full

Check Answer

Study Question 13.4 (c)

The combination with greatest risk of losing $

- June 10 Full
- May 29 Full
- May 16 Full
- June 10 Medium

Check Answer

Study Question 13.4 (d)

The least chance of losing $

- April 20 Medium
- April 20 Short
- May 16 Medium
- May 16 Short

Check Answer

Press “Space Bar” to continue. Then Return to change a variable. Select “Soil Moisture” and set it at 50%.

Study Question 13.4 (e)

Compare results-which combination now has “lowest risk” of loss?

- [ ] April 20 Medium
- [ ] May 3 Medium

Check Answer

Tap “Enter”.

At a soil moisture near 50% of field capacity, there is an 8% chance of 148 bu/A as opposed to the 13% chance when moisture at planting time was high. The lowest yield (1-in-100 chance) is only 30 bu/a as opposed to 74. The likely yield is better than 103 bu/A.

It is intended that you become fully comfortable with the concept of production risk analysis. You should identify the maturity class that fits a given situation of the environment and is conducive to your “Risk Preference.”

If you buy lottery tickets, you don't object to a “long shot.” If you buy a lot of lottery tickets, you are a risk-loving person. Hopefully, your business decisions are based on the management of risk such that a worst case does not “cost the farm.” A risk-preferring producer may choose a maturity that could yield 165 bu/A or as low as 100 bu/A with an expected yield of 140 bu/A. A risk-adverse person would prefer the 150 bu/A maximum cultivar that would also be expected to yield 140 bu/A and not be as likely to fall below 120 bu/A.

Now proceed through the system to evaluate individual combinations. Select “Combinations,“One combination.”

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Introduction

Developed by E. Taylor and D. Todey

It is suggested that you watch Video 13B and complete the exercise in the video before continuing with the lesson.

Podcast Version **Full Podcast List**

Lightning is an extremely powerful force in the atmosphere. The consequences of a lightning strike are astounding. Consider that the temperature of lightning is approximately 10,000° C, while the surface temperature of the sun is 5500° C. The effect of a lightning strike is shown in Figure 13.29. A replacement flag is being held in the hole because the original flag exploded into several little bits of melted metal about the size of large buckshot. The causes of lightning and a discussion of hurricanes are included in this lesson.

Fig. 13.29 Golf course green after lightning strike.

What You Will Learn in This Lesson:

- How lightning is formed.
- How lightning is monitored.
- About the climatology and details of hurricanes.

Reading Assignments:

- pg. 287-293—Aguado and Burt
- pg. 323-333—Aguado and Burt

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Lightning

Lightning is associated with any thunder in a storm. It is produced by a charge difference within a cloud, between clouds, or between the clouds and the ground. This charge difference induces a flow of **electrons** from the negatively charged site to a positively charged one. A naturally occurring charge difference exists between the ground and the atmosphere.

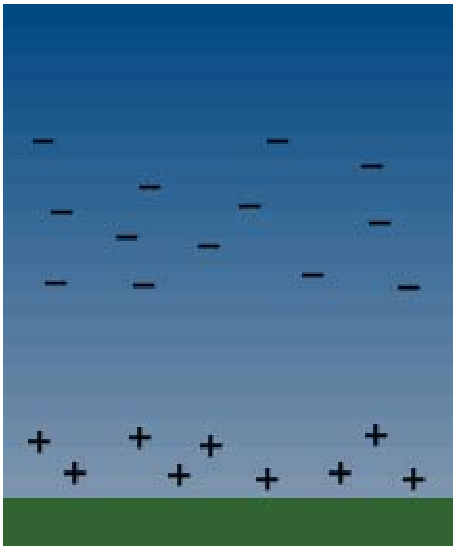

Fig. 13.30 Ground-atmosphere charge difference.

The charge difference does not produce lightning under normal conditions because the air is an excellent insulator. During a thunderstorm, the charge difference is increased. The charge build-up is caused by interaction of raindrops and ice in the cloud. This is not well understood, yet. But **ice must occur** in the cloud for thunder and lightning to occur.

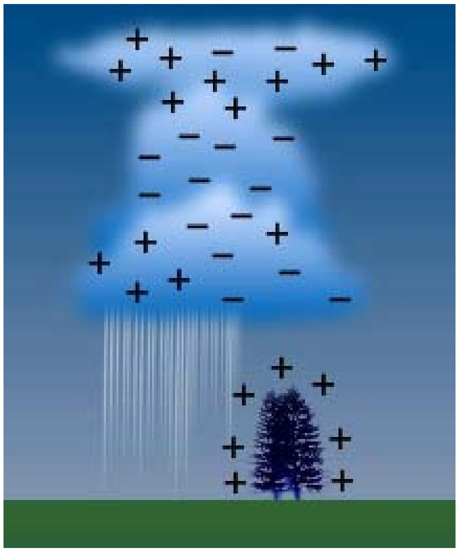

Fig. 13.32 Thunderstorm charge difference.

Note that the charge difference is greatest where an object protrude higher into the air than other objects, such as a trees, poles, or even a person standing in the middle of an open field. When a thunderstorm develops, the charge difference increases to a point, overcoming the insulating effect of the air. A discharge occurs moving electrons to balance the charge between different areas. This can occur in the cloud, between clouds, or with the ground. About 65% of all discharges are between clouds. Of most interest and concern are those strokes that strike the ground. These strokes follow a several step process. When the normal potential difference increases to about 3,000,000 volts/meter, the attraction between the oppositely-charged regions is overcome.

IN DETAIL : Ice and Storm Process

The formation of ice is necessary for rain to occur in the middle of the continent. Growth from a **condensation nuclei** to a cloud drop and rain drop is far too slow to form rain. Without ice formation, it would take days for clouds and rain to form. But the formation of ice on freezing nuclei at very cold temperatures speeds the process to less than a few hours. Once ice begins to form in a cloud, rain can form.

When a cloud begins to glaciate (freezing) is easy to monitor. The cloud outlines go from a sharp contrast at the edge of a cloud to less distinct. Ice will scatter light less effectively than the water in a cloud, producing the pictured effect (Figures 13.31a & 13.31b)

Fig. 13.31a Example of an ice cloud

Fig. 13.31b Example of a water cloud

Once the ice process starts, water vapor deposits on the crystal, usually forming snow. The growth of the crystal proceeds. Eventually, the crystal starts to fall colliding with other crystals and liquid water. The crystal grows with water depositing and freezing on the crystal, forming hail. This can continue and form large hail, or it may fall and melt producing rain. But all rain in the Midwest starts frozen.

Rain in tropical climates can form without the ice process. Without the ice process, no thunder and lightning are created.

Close Window

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Lightning

Lightning Discharge

Lightning to the ground starts with a relatively thin leader stroke from the cloud, which starts to branch out toward the ground. When it reaches near the ground, surge of positive charge reaches out to the leader, producing the lightning stroke. Once the channel has been ionized, the actual flash of lightning may occur many times. You can see this, looking at a lightning stroke. After the first strike, the channel will flash numerous times as the electrons flow in several distinct pulses differing by only hundredths of a second. If the wind is blowing, the charged path can move along with the wind. The distinct flashes will appear the move slightly. There may be a damage path on the ground where the lightning strike passed. The lightning will continue until the charge difference has been reduced. The total time included may be up to one-half a second for the life cycle to transpire.

One of the features of lighting is that it can often be forked and have several branches. Sometimes the branches extend to the ground; sometime they extend to the cloud during a cloud-ground strike. The direction of the stroke can change at times. Lightning can be described as going like a river. All the little tributaries drain to the main stem or all the branches drain electrons into the main stroke (Figure 13.33). If it is branched near the ground, it's ground-to-cloud lightning. The cloud is positively charged and the earth is negatively charged. This is the opposite of the usual condition depicted above. If the lightning is branched the other way, then the lightning is from the cloud to the ground, with a positively charged ground and negatively charged cloud. The electrons flow like a river downstream.

Fig. 13.33 Forked lightning progression.

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Lightning

Lightning Effects

Some of the effects of lightning are quite interesting. The golf course naturally renovated the green shown. In renovating it, they picked up everything off it, sifted it and rebuilt the green from scratch. Greens are primarily sand with fine grass growing on it. Several white lines are seen radiating from the pin in the figure. Part of one of those lines from the green is displayed in Figure 13.34. The intense heat of the lightning melted the sand to a glass substance named fulgurite. ("Fulgu" means lightning) Fulgarites are found many places on the earth, where lightning strikes and passes through silicon dioxide (sand).

Fig. 13.34 Fulgurite

Lightning and thunder can be used to judge the distance to a thunderstorm. Judge the distance to a thunderstorm by counting. The speed of sound is about 1,100 ft. per sec. or 1 mile in about 5 seconds. For each five seconds from the time you see the lightning flash until you hear the thunder, is a mile.

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Lightning

Lightning Safety

Lightning was, until recently, the primary hazardous severe weather in our country. The reduction in lightning deaths is probably due to the reduction of people working outdoors. Still 75-100 people are killed annually by lightning. As mentioned, the greatest charge difference seems to occur with objects, which stand above their surroundings, poles, trees, housetops, and people in the middle of an open field. The idea is to stay under some protection when lightning is around. But that protection must not be a potential lightning attraction, such as a tree. If caught in the open, a person should crouch down in a ball. Spreading out flat increases the area you are exposed to lightning. Farmers sitting on tractors used to be a prime candidate for being struck. Enclosed cabs and better forecasts are probably reasons for the decreased number of farm deaths.

To learn more about lightning safety go here.

Are cars or a metal building, a wise place to be? Yes, they are. It's the nature of electricity that it stays on the outside of things. If you have a tin can with an electrical charge on it, the electrons, the negatively charged particles, repel each other. Excess electrons on the move as far away from each other as possible. As far away from each other as possible is on the outside of the can. Electricity does not travel inside of a tin can. It travels on the outside of a tin can. Electricity does not travel through the center of a wire. It travels on the outside of the wire because it moves to get as far away from itself as it can. Electricity will not go inside of a metal building. It will stay on the outside. The only possible damage is if it was such a powerful bolt of lightning that it punched a hole in the building, or burned some of the metal away.

The automobile is the same situation. The electrical charge will stay on the outside. The airplane is the same situation. The electrical charge will stay on the outside of the metal container. You are, generally, safe from the electrical discharge of lightning in an automobile.

A police car somewhere in Iowa was sitting still at the side of the road was struck by lightning. It destroyed the radio in the police car. It blew out all of the tires on the police car, and it gave the officer inside the car a headache from the noise. He was not injured other than a headache and ringing ears. A car, which doesn't have metal on the roof, such a true rag-top convertible does not provide the same safety.

If you live in a rural area that has aerial telephone lines, the most dangerous thing that you can do is call your friend over in the next section and say, "Isn't this a terrific lightning storm? Are you getting it over there too?" Lightning can enter your house through the wiring. Some of the lightning deaths, reported in our country, are people struck in the ear by talking on the telephone. Telephones do have lightning arresters on them by law to protect against minor lightning discharges. A direct hit right outside your house will ignore the lightning arrester and will come right in the phone wire. The same can occur with electrical or cable TV wires. If the lightning charge enters a line, it can travel a distance and damage electrical appliances or damage TVs through the cable.

There is a danger with the plumbing. During a storm is not necessarily the time to go take a shower. Houses used to have lightning rods on them. Very few homes have lightning rods any more that are formally installed. Why? Internal metal plumbing acts as a lightning rod. The lightning rod on the top of your house is the vent to the plumbing, which comes to your sink, your bathtub or your commode, or whatever you have that is vented. The electricity will travel down the metal pipe past the sink as it follows the plumbing to the ground, where it will harmlessly be dissipated. Still, you could be on the path if you are showering or using the water from the tap. If you only have plastic pipes on the roof of your house, you don't have lightning rods.

One or two times people will find one or more large circles in a field, perhaps in an alfalfa field or a soybean field, where all the soybeans are dead. One place called out the newspaper and the sheriff, because clearly they'd had a UFO land. The ground was obviously burned. Digging around in the ground produced some things similar to the fulgurite. They were not exactly like it because, being a fairly good Iowa agricultural soil, it had a low sand content. It isn't uncommon at all to find in fields a large necrotic place where the **lightning has damaged the crop**.

A few years ago beetles were destroying the pine trees in Florida. There was a great deal of concern about controlling them. They tried to control them, but there was concern about the use of chemicals. It turned out that the beetles had always been there. It wasn't a big outbreak of beetles; it was a big outbreak of lightning. The lightning had damaged the pine trees. The pine trees, being almost dead, weren't producing a great deal of resin like healthy pine trees produce. When a beetle would dig a little hole in the bark, no resin would come out to drown the beetle or to clog the hole. The beetles would live under the bark around the tree. Soon the tree would be dead and the beetles were blamed. However, they found a few trees that were just as dead and looked just alike, except not having any beetles. Investigating them carefully indicated lightning in the area had weakened the trees.

IN DETAIL : Field Lightning

Fig. 13.35

Fig. 13.36


Fig. 13.37


Fig. 13.38

Close Window

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Lightning

Lightning Detection

To observe and report lightning occurrence, a lightning detection network has been developed (Figure 13.39). The towers at these locations observe lightning strikes and detect the direction from the tower. Then by use of triangulation, the site of a lightning strike is obtained. These are plotted on maps to depict the density and location of lightning strikes (Figure 13.40).

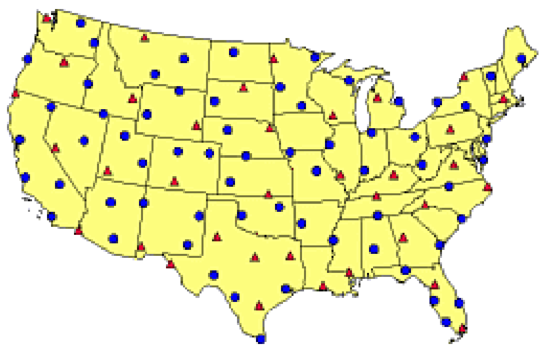

Fig. 13.39 Locations of lightning detection stations.

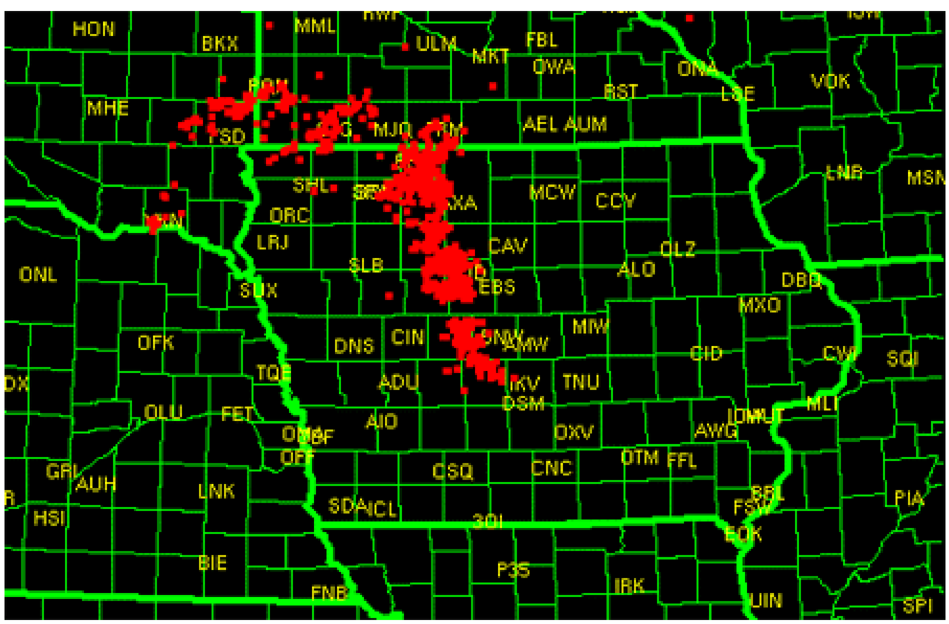

Fig. 13.40 Lightning strike frequency over an hour period.

Satellites are even used in lightning detection. Discharges from storms can be tracked at night using visible satellite imagery (Figure 13.41)

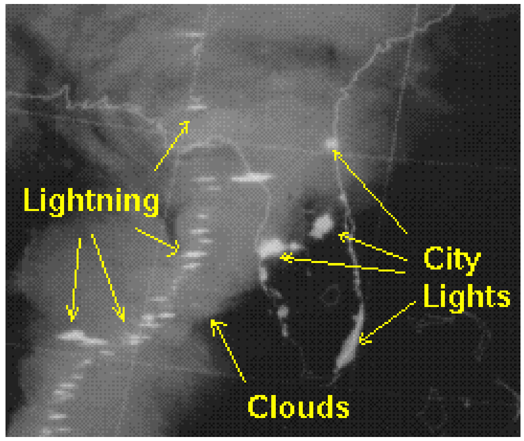

Fig. 13.41 Satellite night detection image.

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Hurricanes

Another severe storm and great cause of life and property damage is hurricanes. Hurricanes are quite different in their formation because of their tropical nature (as opposed to the extra-tropical storms in the Midwest). The floods that are associated with them cause the greatest loss of human life, probably not just in the United States but around the globe as well.

Hurricanes are named differently depending on where they occur. In the Western Hemisphere, they are called hurricanes. In the Eastern Hemisphere they are called typhoons. This applies to Australia as well, where books often say they are called Willy-Willies. In the Indian Ocean, they are called cyclones. Hurricanes form in a single warm air mass. The particular areas have uniformly warm water and air. This combination of heat and high humidity produces instability and rising motion. Tropical areas straddle the Equator in the easterly trade winds. Hurricanes do not form right on the equator because the Coriolis effect is minimal near the equator. If fact, they will not form within 200 miles of the equator for this reason. The Coriolis effect causes them to spin counterclockwise in the northern hemisphere and clockwise in the southern hemisphere. Notice the rotation is similar to the rotation around areas of low pressure.

In lesson 7, **figure 7.30** depicted the general wind flows around the world. The greatest heating of the earth is over the equator, the rising air over the equator gives rise to low pressures there and high pressures in the sub-tropical highs. The air moving from the sub-tropical highs toward the equator turns easterly, becoming the trade winds, converging at the equator. The convergence area is called the Inter-tropical Convergence Zone (ITCZ). The ITCZ is not always right on the equator. It is only over the equator a couple of times a year. It follows the sun, following the area of maximum heating, which is slightly north of the Equator during the Northern Hemisphere summer. It is in this zone that you're most likely to have formation of hurricanes.

Thus, the tropics are the hurricane formation areas on the Earth. Your text (pg. 142) shows where hurricanes form around the globe. Of most concern to the United States are usually the hurricanes, which form in the Atlantic or Caribbean and move over southeastern and eastern parts of the country. The western part of the country can be susceptible at times. Usually, the colder water off the west coast defends the coast against hurricane penetration there. The most numerous hurricane area and area of strongest hurricanes is over the Western North Pacific.

Since the ITCZ follows the sun, the maximum time of hurricanes in the Northern Hemisphere would be summer. Since the heating of the ocean occurs very slowly, the time of maximum ocean temperature occurs in August and September. The time of Southern Hemisphere maximum would be six months later. The time of the greatest number of hurricanes corresponds with this (Figure 13.42) As mentioned, very warm water is necessary for the formation of hurricanes. Until the water temperatures reach critical levels, hurricane formation is less likely.

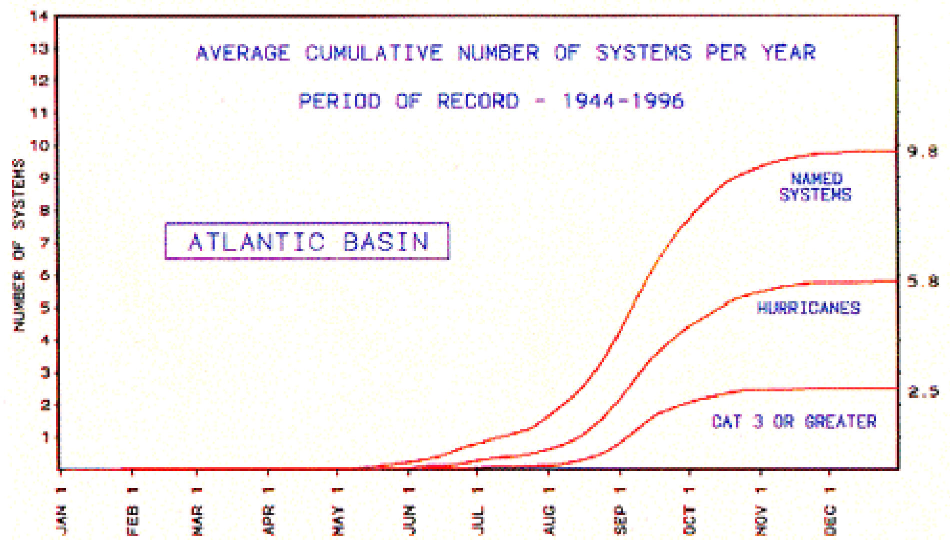

Fig. 13.42 Cumulative numbers of named tropical systems, hurricanes and strong hurricanes averaged over 43 years.

Study Question 13.5

What is the earliest occurrence of a category 3 hurricane?

Check Answer

Study Question 13.6

What is the average number of hurricanes for the season?

Hurricanes Check Answer

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Hurricanes

Hurricane Structure

The structure of a hurricane is shown on page 148-149 of your text. Hurricanes rotate counterclockwise, similar to a low pressure system in the Northern Hemisphere. Their formation is based on the Coriolis force. As rising motion occurs, air that flows in toward the center of the low. The Coriolis force turns this wind to the right, producing a counter-clockwise circulation. Because the Coriolis force does not exist at the Equator, hurricanes cannot form there. Hurricanes form at 5-10° latitude and move parallel or away from the Equator. Since the winds of a hurricane are 75 mph or greater, they do entrain quite a bit of air. The pressure is low at the center of a hurricane, drawing air readily into it. The circulation produces spiraling bands of clouds which rotate in toward the center of the hurricane. The center of the hurricane is called the eye, which is surrounded by an area of strong convection called the eyewall (Figure 13.43). The eye likely forms because of centrifugal force. When we have a low pressure, we start to bring air in from the edges. Because it's low pressure, it's attracted there, and so we'll have wind drawing this air in toward the center.

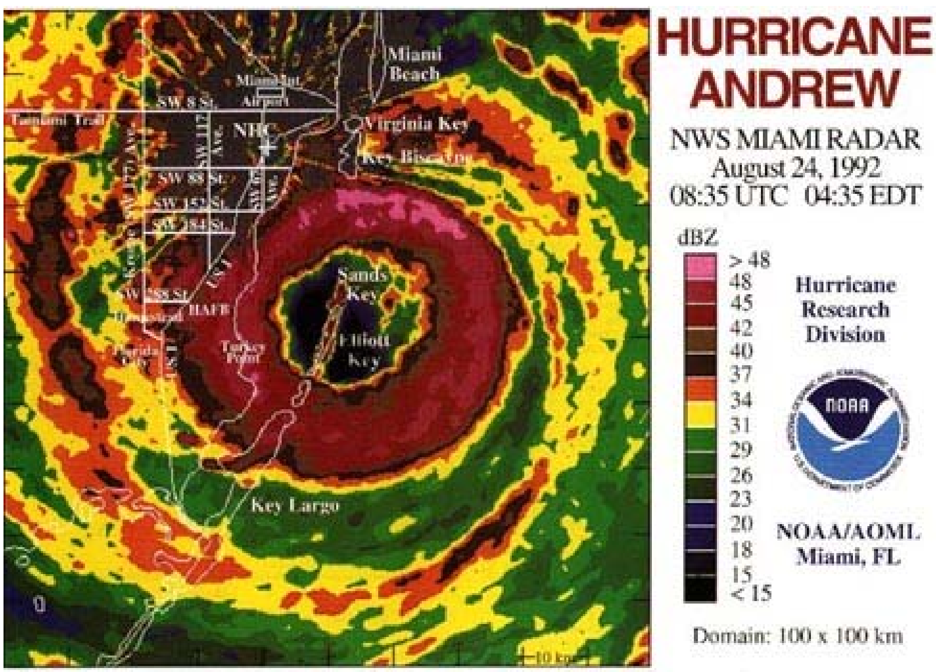

Fig. 13.43 Radar image of hurricane Andrew. Notice the intense radar reflectivity around the eye.

The center of a hurricane is a relatively calm eye (Figure 13.44) with air descending down the middle of it. Often the sun can shine down there if the sun is high enough in the sky. It would be rather calm because the wind is blowing down, and going over and joining the sides rather than blowing up.

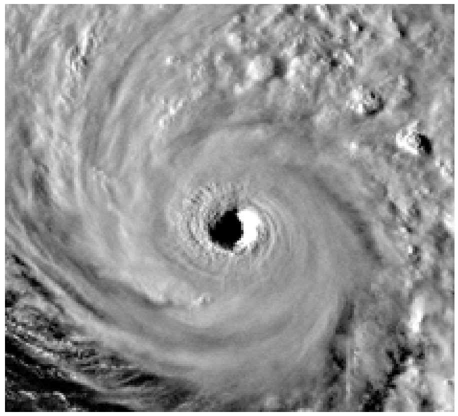

Fig. 13.44 Satellite image of the hurricane's eye.

Apparently quite a few people historically have said, "Oh, the storm's over." Going outside during this, they were struck by the eyewall on the other side of the eye. The wind, coming from the other direction, has caused considerable loss of life since they did not realize that there is an eye associated with a hurricane.

The hurricane forms out of a single air mass. The warm, moist air mass is the driving force for the hurricane. The rising motion in the hurricane lifts warm moist air. As the warm air cools and condenses moisture into drops it causes rain. The condensation of moisture releases heat that causes further lift in the atmosphere. The huge amounts of energy released powers the hurricane. As soon as the hurricane goes over land, it will almost instantly cease to be a hurricane. There is a little more friction as the hurricane goes over the land, but the largest effect is that the hurricane no longer has the energy supply that it needs. A hurricane can cause damage over land, but it generally weakens its wind flow very quickly.

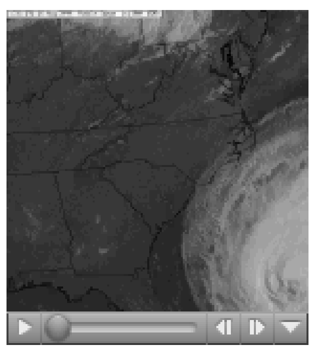

Fig. 13.45 A 60 hour visible satellite loop of Hurricane Bonnie (1998).

Hurricane formation goes through several stages. The typical path of the Atlantic hurricane is to generate somewhere between Africa and the central Atlantic. The formation starts as a low pressure disturbance, called an easterly wave. As it moves westward it may become a tropical depression. As the winds strengthen to greater than 34 mph it becomes a tropical storm. If it continues to strengthen to greater than 74 mph, it will be a hurricane. At any time crossing the Atlantic it may become caught in the westerlies and move into the central Atlantic. It may continue a westward movement and cross the islands of the Caribbean. Hurricane tracks from the active year of 1995 are pictured in Figure 13.46.

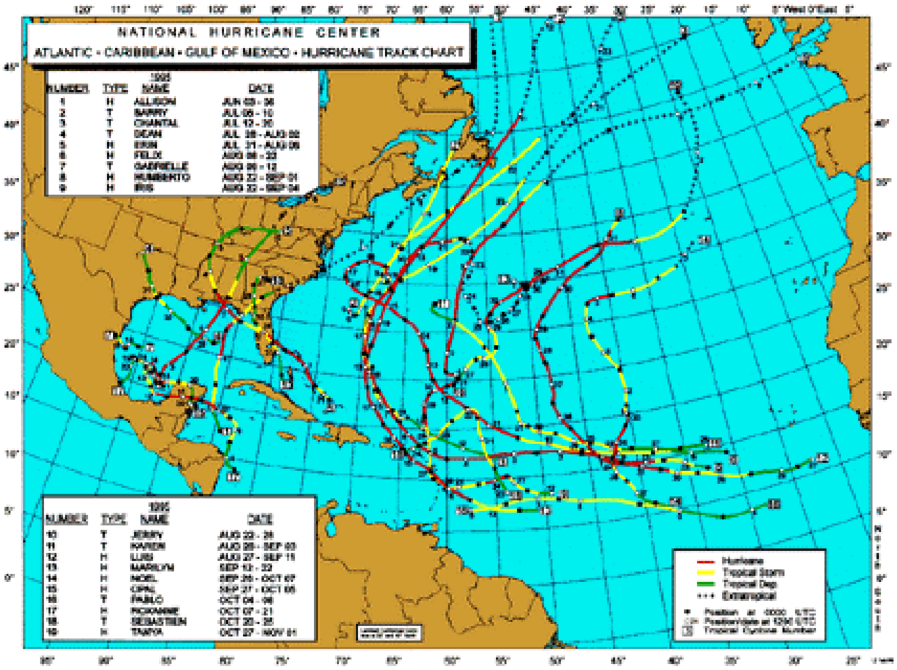

Fig. 13.46 Life cycle and tracks of all named tropical systems of 1995.

At times they may continue west and hit Florida or over to hit Mexico rather than move and follow the warm water. They may cross the Gulf of Mexico and hit locations on the Gulf Coast. More miss the United States than hit the United States.

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Hurricanes

Hurricane Forecasting

In the early part of the century, hundreds and thousands of lives were lost in hurricanes in Galveston, TX, Key West, FL, and others. There was no hurricane warning system. The hurricane warning system was established by the military and the National Weather Service, (called the United States Weather Bureau) in 1938. Before that, about the only warning that a hurricane was coming was the barometer dropping, and the type of clouds that were showing up in an area. People had to learn to know if there was a severe storm coming by watching the signs around them. There was great loss of life because hurricane tracking was based on ship reports near hurricanes and no warning system was in place. With the advent of satellites, observing hurricane formation and tracking became much easier as they were able to be tracked throughout their life-cycle.

Another major improvement in long-range forecasting was produced by Dr. William Gray of Colorado State University. His forecasting system is described, based on wet years in Africa and the state of the ENSO (Gray 1998).

The main point of interest with his hurricane forecasting has to do with the rainfall in Africa. Numerous factors are involved in what the hurricane season will bring (Figure 13.47). Two of the major ones are the state of the ENSO and rainfall in Africa. El Niño conditions (lesson 10b) tend to suppress hurricanes while La Niñas tend to promote hurricane activity. Rainfall in the Sahel of Africa is very important, an extended drought during the 1960's to 1980's limited the number of hurricanes. But rainfall has returned in the last 10 years assisting in producing hurricanes.

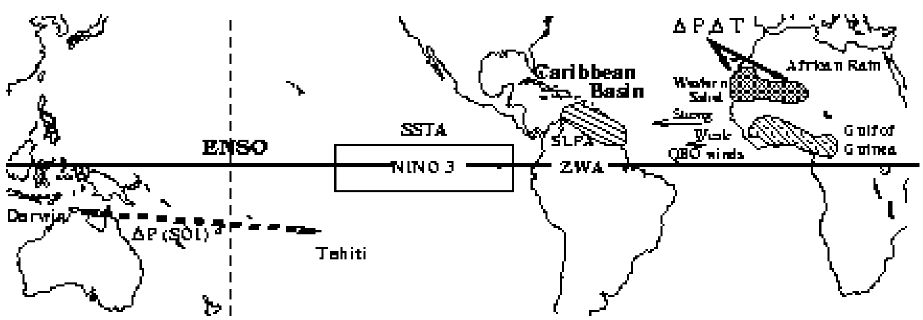

Fig. 13.47 Factors involved in hurricane forecasting (Gray 1998).

We've had really an extended droughty time, the deserts have been extending in Africa, there have been a lot of problems happening of that nature, but in the meantime people had been noticing all the beautiful real estate available along the Gulf Coast and the Atlantic Coast, and nobody lived there. There are beautiful beaches, a beautiful place, why don't we live there? Why don't we build a hotel? Why don't we build a summer home there? Nobody could think of any reason not to except the people who had lived there back in the thirties and forties, and they said, "Well, the reason that nothing is there is that everything that was put there has been washed away."

During the dry period in Africa development along the coast of Florida and the Gulf Coast progressed rapidly. The land was inexpensive allowing rapid development. Meteorologists kept saying it was not wise thing to develop flood-prone areas being concerned about hurricanes striking the area. There was little concern because few hurricanes were occurring. Rain has started in Africa again. People are starting to find out that they live in a hurricane-prone and flood-prone area along the coasts of Florida, along the Gulf Coast, along the Atlantic Coast. Much more damage will be seen in the near future if we indeed have seen a return to the normal rainfall or above normal rainfall in western Africa. Several recent large hurricanes have born this out.

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

Hurricanes

Hurricane Dangers

Several dangerous conditions exist with a hurricane. Winds can be a problem with stronger hurricanes as sustained winds of greater than 100 mph occur with much higher gusts. This is usually close to the center of the hurricane. Of more concern near where there hurricane make land fall is the storm surge. The strong winds build up water, sometime 10-15 ft. above normal tides pushing water inland. Often this surge with the heavy rains can cause severe flooding near land fall of the hurricane. Heavy rain can occur anywhere inland as the tropical system brings huge amounts of moisture inland. Even after the storm weakens in wind strength, it can produces inches or feet of rain on occasion. Another problem, which is not minor, is the number of tornadoes spawned around the outside of the hurricane. As the hurricane comes to shore, they say, well the damage will be...they always want to know right where it's coming ashore, in other words where the eye is coming. That isn't always where the greatest damage is. Sometimes the greatest damage is 60-70 mile away from the eye where the tornadoes are. These things all need to be watched, not just where the hurricane comes ashore.

Assignment 13.1

Click here for Assignment 13.1

Lesson 13 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?

Agronomy 541 : Lesson 13b

Lightning and Hurricanes

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Agronomy 541 : Lesson 13a

Soil Moisture and Crop Yield

Introduction

Developed by E. Taylor and D. Todey

It is suggested that you watch Video 13A and complete the exercise in the video before continuing with the lesson.

Podcast Version **Full Podcast List**

In this lesson, the student will:

1. Review a crop yield/water stress model (Shaw's Model).
2. Use an "Expert System/Knowledge-based" model to determine risk of reduced yield for years when initial soil moisture is at low, moderate, and high levels.
3. Estimate "pan evaporation" from temperature data to evaluate potential evaporation.