Agronomy 541 : Lesson 5a

Shelterbelts

Introduction

Developed by D. Todey and E. Taylor

It is suggested that you watch Video 5A and complete the exercise in the video before continuing with the lesson.

The application of wind in agriculture is well known. Wind has been used regularly in agriculture throughout history. Most farms in the Midwest landscape were marked with a windmill as an energy source for pumping water from a well. Negative aspects of wind have required the use of shelters for various crops. While the old-fashioned windmill is used only for historical preservation, new wind generators are appearing on the landscape. And the use of shelters for crop protection is experiencing a resurgence.

What You Will Learn in This Lesson:

- How to apply generalized wind to flow around a shelterbelt.
- How a shelterbelt affects the environment and crops near.
- What a wind rose is.
- What wind climatology looks like.
Shelterbelts

Shelterbelts (Fig. 5.1) are extensively used in agriculture and for some general public use. Their most common uses are apparent as windbreaks seen providing some shelter to housing in open areas. Rows of trees dissipate and divert the flow of wind from whatever direction the trees are from the house. Reduction of wind for housing is most necessary during the winter to reduce heat loss from cold winds blowing past the walls of a dwelling. Highway departments sometimes use the same principle in planting rows of trees of bushes to reduce snow-drift across highways. These are fairly recognizable uses of shelterbelts or windbreaks. Other effects are more detailed and will be discussed in this section on shelterbelts.

![Windbreak protecting a sunflower field.](USDA-NRCS/ Univ of Neb. Publication EC 94-1772-X)

The purpose of these windbreaks is simply to reduce the wind speed downwind of the break. Windbreaks can be a row of trees, bushes or objects, such as fences placed to divert the flow of wind. Even tall crops, like corn, may act as a shelter to crops near them, which grow lower to the ground. Multiple cropping systems capitalize on this advantage. This purpose of windbreaks has been understood back to the 1400s. They are used extensively in portions of Europe to alter the microclimate for growing crops. More recently, planting of shelterbelts was encouraged in the Great Plains of the United States to alleviate the effects of droughts after the disastrous conditions of the Dust Bowl of the 1930s. Extremely dry conditions allowed soil to drift like snow causing huge soil loss. Since that time further advantages of windbreaks and shelterbelts have been discovered.

Wind is air moving as a result of a pressure imbalance (high pressure moving to fill in low pressure). Large-scale pressure fields provide the general background conditions for the wind direction. The position of high and low pressure systems in relation to the farm establishes the background wind direction. Smaller scale air motions, associated with the microclimate of an area, are produced by smaller pressure imbalances. Wind striking a solid object, such as a wall or building, is forced to flow around the object. Because a certain volume of air is trying to flow through the space occupied by the solid object, it must somehow be diverted. This produces several effects. Airflow is diverted around the object as the air tries to maintain its speed while being
squeezed around the object. Speeds increase around the periphery and over the top of the barrier. Near the upwind and downwind sides of the barrier, speeds are reduced (Fig. 5.2).

The speeding occurs in response to a build-up in air pressure upwind of the object. As the flowing air impinges upon the barrier, air piles up, similar to the backing-up of cars on a highway caused by slower-moving traffic. A corresponding area of lower pressure exists downwind of the barrier where a void is induced by the barrier. The small pressure difference across the barrier causes an increase in wind speed as the air attempts to correct the pressure imbalance (Fig. 5.3).
Wind breaks and shelterbelts work in much the same manner with one additional effect. Since these are usually comprised of rows of trees or large bushes, the barrier also has some porosity through the branches and leaves, which will allow some air to flow through through. The more rows of trees or denser the foliage, the more impermeable the boundary; the less dense the boundary, the more wind will be permitted to flow through the spaces in the shelter. Changing the character of the barrier can change the response of the wind flow around and through the shelterbelt.

Two zones are produced downwind of the shelter as effects of the shelterbelt, the quiet zone and the turbulent zone. The quiet zone is directly in the lee of the shelter where wind is essentially removed, hence the name (Fig. 5.2). Wind flow is reduced to very little as the wind is diverted around over the shelter. This zone extends to about 8-10h downwind. Beyond this zone, the background wind flow is not re-established, but more turbulent winds do occur. The diverted wind starts to fill the pressure void around the shelter, but does not until 8-10h downwind. Here increased turbulence causes more mixing in the air just above the surface. But the air mixed here does not interact with the ambient air flowing around the shelter. So more mixing occurs in this region, the background wind has not been able to re-establish itself. This turbulent zone extends to 20-25h downwind, where a reversion to the upwind effects exists. These two zones provide different micrometeorological conditions for crop growth as will be discussed.
Terminology differences between the names, shelterbelts, and windbreaks do exist locally depending on their use. Generally, there is not a difference associated. The terms are used interchangeably here. Snow fences are another terminology. All take advantage of the same meteorological effects to alter the microclimate depending on the purpose desired.
Shelterbelts

Positioning (Wind Climatology)

Placement of a shelterbelt should occur where it will divert wind the most effectively. If northwesterly winds are most common, a shelter protecting a field along its north and west border should be placed. This requires knowledge of the wind climatology of the area to understand where the prevailing winds are. In Iowa the prevailing winds change from season to season. Placement of the shelterbelt must occur where it will have the greatest affect for the purpose required. Not only is the prevailing wind direction important, but also the distribution of the wind speeds. As an example, if southeast winds occur 40% of the time, a shelter to protecting against southeast winds would seem helpful. But if southeast winds are generally very light (< 10 mph), then the shelter may not be necessary. while average temperature and precipitation data are often easier to obtain, detailed wind information such as this is necessary and often more difficult to access.

Observed wind distributions for a single site is usually displayed using a wind rose. A wind rose displays winds in a circular pattern according to their direction. The distribution of speeds is displayed by the length of indicators in each direction.

A wind rose is displayed below (Fig. 5.4). Wind direction is indicated from where the wind is coming. Directions on the rose start from north pointing directly up and continue clockwise as indicated. Frequencies of different speeds are indicated by the length of the respective wedge in each direction. The 360° of the circle are divided into twelve different categories. In this rose they are divided into equal 30° categories.

Study Question 5.1

What is the direction of most common (prevailing) wind?

Visit the NRCS website for monthly windrose normals for each state of the U.S. [www.wcc.nrcs.usda.gov/climate/windrose.html](http://www.wcc.nrcs.usda.gov/climate/windrose.html)
What is the direction of most common 5-9 knot winds?

Figure 5.4 displayed an overall wind rose for wind observations compiled over all hours and days for several years. Other display options are available to track winds at different times of the day or year. Winds change in direction and speed throughout the day because of changes in meteorological conditions throughout the day.

Average wind speeds throughout the year change as background pressure gradients change (Fig. 5.5). The diurnal profile of winds changes throughout the year, also. There is the regular day-night difference in wind. Notice how the wind speed does not drop off more to be nearly calm in seasons other than summer.

Fig. 5.5. Average speed of winds (mph) throughout the year (1969-78 data).

Fig. 5.6. Average speed of winds (mph) throughout the day for three different months illustrating seasonal changes throughout the year (1969-78 data).
Spatial variation of winds across the state indicate where the windier places exist in the state during the year (Fig. 5.7). These measure wind at the 50m level (the level used for calculation of wind energy assessment). This is much higher than normal observations are taken. But they do give a good representation of spatial changes in wind directions throughout the year.

![Fig. 5.7 Average monthly wind speeds in Iowa (50 m level).](image)

**Study Question 5.3**

Why are winds speeds higher in the northwest part of the state?

- Higher pressure gradients
- Flatter land
- Fewer houses

Check Answer
IN DETAIL : Observed Wind

Official weather records require anemometers to be placed at a level of 6 m (20ft) to observe wind speeds. Other conditions are placed on the measurement. For obvious reasons, the observation must be taken a certain distance away from other objects to limit the microclimate effect on wind direction. Wind speed is also an average of wind over a several minute period. Wind gusts are reported as five seconds or one minute depending on the shorter averaging period used. For wind power generation, winds are observed at a level of 50 m.
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Shelterbelts

Barrier Characteristics Affecting the Wind Flow

With the knowledge of the prevailing wind direction, other facets of the shelter can be adapted to change how the shelter diverts wind. Numerous characteristics of the shelter can be changed how the shelter works.

Height

The most important change in a shelterbelt can be related to height. The height of the shelter is so directly related to the extent of the wind effects that all related shelterbelt effects upwind or downwind of the barrier are described as a function of the height. Distances such as 8h downwind mean that the distance downwind of some effect is eight times the height of the shelter. This is a standard accepted in describing any affect of the shelter. This relationship indicates that height most directly affects the shelter effects. The shelter must be somewhat mature before becoming effective. But even low shelters do have an effect although, a shorter distance away from the shelter.

Porosity (Density)

Porosity of a barrier is defined as the ratio of open space within the barrier to the total volume of the barrier. A density measurement can also be used since it is the compliment (total solid volume to the total volume). Differences in the porosity or density of the foliage change the manner in which the wind is diverted or dissipated. A shelter with too little porosity acts as a solid barrier. This reduces the wind directly downwind of the barrier, but allows a quick reversion to upwind speeds downwind as the wind diverts around the barrier and fills the pressure void behind the shelter. A shelter with too great a porosity has little effect on the wind and causes very little pressure change across the barrier. A shelter of moderate porosity (about 40%-60%) seems to have the best shelter effect since some wind is allowed to pass through the barrier. A turbulent area is created downwind where wind speeds are reduced but smaller circulations prevail.

Van Eimern (1964) noted that very dense foliage reduced wind speeds at 10-15h from the shelter (Fig. 5.8). But a tree row with porosity of 50% reduced wind speeds a distance of 20-25h downwind (Fig. 5.9). The additional distance downwind is changed to a turbulent zone where winds are more chaotic as the energy of the straight-line winds is dissipated in smaller-scale eddies.

Fig. 5.8 A dense barrier is effective at slowing the wind near the shelterbelt, but not
far downwind.

Fig. 5.9 A less dense barrier allows more wind through the barrier, but reduces the overall wind speed farther downwind.

One subject of difficulty is assessing the porosity of a barrier. Since measuring the amount of volume is difficult, some estimating techniques are necessary. One of these is the use of nighttime optical measurements through the canopy to assess the porosity or density of a shelter.

**Width**

The greatest effect of added width (in the direction of wind motion) is to increase the density of the barrier. Depending on the purpose of the shelterbelt, certain widths may be recommended. Increasing the width of a shelter by 100 reduced the wind speed by only 15-18% (Wang and Takle 1996). Fairly narrow shelters can be effective without having to use too much cropland. The addition of more foliage reduces the total amount of airflow through the barrier. Some complex interactions within the boundary are the subjects of current research (Wang and Takle 1996).

**Length**

A standard of length is that the barrier (perpendicular to the wind flow) should be at least 10 times as long as it is tall to minimize the effect of wind flow around the edges of the shelter. A shelter of this length is sufficient to divert the winds around the edge and reduce the wind flow near the barrier. Too short a barrier would allow wind to divert around the barrier, causing speeding without sufficiently reducing wind at the barrier. Shelterbelts should be uniform horizontally for a long distance. Too short a shelter will allow flow around the ends. A non-uniform shelterbelt will force wind to blow through gaps in the foliage, such as where a tree may have been removed. These gaps will actually cause wind speeds to increase producing, damaging crops in these areas of jetting.

**Shape**

The effect of shape of the barrier is not well explained. A computer modeling study of shelterbelts (Wang and Takle 1997) found that little change in the wind field occurred for different shaped shelters, provided that the total density did not change. More vertical-sided shelters do alter the pressure difference across the shelter without changing the wind field significantly. An agreed-upon fact is that the density of the shelter should be most porous near the ground. The effect will change with wind direction and as the shelter grows and matures. Smooth or shelters that are streamlined do not work as effectively in the wind.
Direction of wind

The effect of a shelterbelt varies dramatically depending on the direction of the wind. Obviously, a north-south oriented shelter will have little effect on winds from the north or south except for some channeling effects along the tree line. But how winds with differing amounts of westerly component change the effect cannot be predicted without computer modeling efforts or actual measurements. Whether the wind strikes the shelter at an angle or head-on will impact what the effects of the shelter will be. The turbulent exchange behind the shelter will be effected in these cases. The complete effects would have to be observed in the field.
Shelterbelts

Effects on Crops

The obvious response of the shelterbelt is to reduce the wind speed in the quiet zone of the shelter. Here wind is greatly reduced and winds are relatively calm (Fig. 5.10). Further downwind, straight-line winds will be reduced, but winds will not be calm. More turbulent winds exist in the turbulent zone. Further downwind, straight-line winds re-establish their predominance. There will be some associated effects with the wind speed reduction and increased turbulence in these areas. Physical damage to crops can occur by sandblasting of crops by wind-blown soil cutting plants. Reduction of wind speed reduces the possibility of this occurrence.

![Fig. 5.10 Wind speed reduction downwind of a barrier as a function of upwind speed at three different levels.](image)

Radiation

The main effect of the shelter on radiation is immediately adjacent to the shelter. A N-S oriented shelter would have radiational effect varying throughout the day. An E-W oriented shelter would be somewhat different depending on latitude and time of the year. Net radiation would be changed because of the reduced evaporation discussed below.

To the south of the shelter, an increase in radiation would occur because of reflection of radiation from the shelter.
Air Temperature

With the reduction in wind, less turbulent mixing will occur near the shelter. Turbulent mixing is the process which happens during the day when warm air from the surface rises and is replaced by the cooler air aloft. During a sunny, windy day, turbulent mixing is very strong. The wind speed reduction of the shelter reduces the amount of turbulent mixing involved, allowing air temperatures near the surface to increase. This increase adds Growing Degree Units, which can hasten the maturity of a crop. These effects are most pronounced in the early and late parts of the season. Evening temperatures are usually warmer from the additional heat gained during the day. During particularly calm nights, the temperatures can be cooler since the reduced wind flow does not allow mixing of warmer air aloft down to cooler air near the surface.

Crop Temperatures

The reduced amount of wind and turbulent mixing in the quiet zone will produce an effect on crop temperatures. With a reduced capability to remove heat from the leaf surface by wind, leaf temperatures will increase. Early and late in the season this is an advantage because it will increase the growth rate during climatologically cooler periods. Increasing the leaf temperature can be a difficulty during high temperatures and possible water stress times. This possible problem is alleviated by the additional soil moisture found here because of reduced evaporation. The reduction in wind speed reduces the amount of evaporation. As will be discussed in lesson 12 wind blowing across a leaf evaporates water. Reducing the wind speed blowing across a leaf reduces the total amount of air blowing across and, thus, the total evaporation potential is reduced. This ultimately can reduce water use and stress in a crop. The converse of reducing wind speed is that excess heat may not be removed by the wind and leaf temperatures may rise.

Soil Temperatures

With the decrease in evaporation and increased air temperatures in the protected area of a shelterbelt, soil temperatures respond similarly to air temperatures, especially early in the season. Soil temperatures are usually higher because since the reduced mixing of heat away from the surface allows more heat to enter the soil.

Study Question 5.4

How would soil temperatures be affected just to the north of an E-W oriented barrier?

- Higher
- Lower
- Same

Check Answer

Frost

Damage to crops because of occurrence of frost is somewhat complicated by several factors in a shelter. The reduced mixing in the quiet zone can allow leaf surface and air temperatures to become much colder than the air above because of radiational cooling. Mixing the warmer air above down can be done by the wind. Since wind is reduced in the shelter, this does not occur. Frost can then be more likely in the shelter under clear calm conditions late in the growing season. This can be counteracted by some effects. The increased temperature and moisture content in the shelter could maintain enough heat to protect against frost. The additional number of GDDs accumulated (as discussed above) could accelerate crop development enough for it mature sooner.
than the rest of the field, reducing the potential frost damage. Again the overall situation is complicated by many factors.

**Carbon Dioxide**

Possible crop damage, because of carbon dioxide reductions in the crop canopy, were theorized in some shelterbelt research. The concept was that the reduced mixing of ambient air with the crop canopy with air in the shelter would reduce the carbon dioxide concentration sufficiently to limit plant growth. Field measurements have since indicated that only slight decreases occur and that plants are not physiologically harmed by this decrease. The only noted carbon dioxide changes occurred at night when CO$_2$ is released. This extra CO$_2$ is trapped by stable atmospheric conditions as a consequence of strong temperature inversions over the field in the sheltered area.

**Precipitation**

Little change in liquid precipitation is noted except for some possible differences immediately adjacent to the shelter. More important to the total precipitation is the depositing of drifting of snow. The shelter can be modified to create snowdrifts at the barrier or to spread them evenly downwind of the barrier. Where snowmelt is a large component of the water for growth (in the dry areas in the western Plains), the barrier can produce some additional water for the field.

**Humidity and Evaporation**

Generally, humidity levels are higher in the protected area of the shelter. The reduction in mixing behind the shelter reduces the amount of water carried away by mixing moist surface air with drier air aloft. Since the air is more humid near the plant, the moisture gradient between the plant and atmosphere is reduced, and less evaporation and less plant water use will occur. Reducing the water loss by evaporation can conserve limited water for plant growth and to conserve moisture for high stress times.

Early season soil moisture is more readily available in the shelter since the evaporation is reduced. During the spring this can lead to quicker seed germination, growth and emergence and more rapid crop development. There is some question as to whether this quicker growth might deplete the available soil moisture faster by its rapid growth. But there seem to be indications that the water use efficiency of sheltered crops is higher than in non-sheltered crops.
IN DETAIL : Temperature Profiles

As discussed in Lesson 3, the atmosphere responds to heating from the surface of the Earth. Thus, temperature profiles will respond to changes in the heating between day and night.

During the day in the growing season temperatures near the surface are warmer than temperatures aloft. During the night, this situation reverses (Figure 5.11b). On calm nights, this can produce an extreme temperature inversion near the surface. When the wind is blowing, mechanical mixing will bring down warmer air to the surface, keeping temperatures higher.

In the quiet zone of the shelterbelt, inversions are a common occurrence because of the reduced mixing in the lee of the shelter. Outside the protection of the shelter, this would not be the case.

Link back to Lesson 3b to review temperature profiles and radiation.
Shelterbelts

Effects on Yields

Most of the meteorological effects of a shelterbelt produce conditions conducive to increasing yields. The worst scenario in most cases is that little yield effect is found. With few exceptions, yields are increased in the sheltered areas of windbreaks. A few limited yield reductions of a few percent have been reported, while some large yield increases have been recorded Table 5.1 (van Eimern 1964).

While many of these are from smaller-scale specialty crops, increased yields from soybeans have been shown from several studies. Differing opinions exist on whether there are preferential areas or types of year (wet versus dry) that show preferential response to shelterbelts. Major midwestern crops of corn, soybeans, and winter wheat showed at least 15% yield increases due to shelterbelt effects.

While the yield increases can be large, the bottom line to the farmer is the economic benefit of shelterbelts. These include the loss of land to production, the expense of planting the shelter, the growth time, and the continued upkeep. One positive aspect is inclusion payments for planting of shelterbelts in the CRP program. Brandle et al. (1992) found economic benefit for planting shelterbelts when yields were increased by less than the 15% reported above. Conditions exist where yield increased as low as 6-7% produce economic benefit. Some of the other management considerations and economic and ecological benefits of shelterbelts will be discussed in the Crop Management course (531).

Other management publications can be found at: http://www.unl.edu/nac/brochures/ec1763/index.html

Where these effects occur in the field is dependent on shelter positioning. Since the meteorological conditions vary by position with regard to the shelter, this result is to be expected. Figure 5.12 displays several field relationships in relation to the position of the shelter.

![Fig. 5.12 Expected meteorological and yield effects around a shelterbelt.](image-url)
This assumes a regular prevailing wind. These can change with changing wind patterns.

A list of publications about shelterbelts can be found at http://www.unl.edu/nac/pubs.html
### Table 5.1

<table>
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<th>Ref.</th>
<th>Crop</th>
<th>Location</th>
<th>Years tested</th>
<th>% Benefit</th>
<th>Notes</th>
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<td>Bates (1911)</td>
<td>Zea mays Wheat</td>
<td>Kansas and Nebraska</td>
<td>---</td>
<td>7-42</td>
<td>Noted that greatest benefit of shelter occurred in years of highest rainfall</td>
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<td>Gagarin (1949)</td>
<td>Rye, grain</td>
<td>Kamennaja Steppe, USSR</td>
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<td>Savi (1949)</td>
<td>Wheat</td>
<td>Sardinia</td>
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<td>Omsk, Siberia</td>
<td>5</td>
<td>21</td>
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<tr>
<td>Blender (1955)</td>
<td>Rye, grain</td>
<td>Peine, Germany</td>
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<td>6</td>
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<td>Rye, straw</td>
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<td>Potatoes</td>
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<td>French beans</td>
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<td>Aleksandrov (1955)</td>
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<td>Voronez, USSR</td>
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<td>14 (38)</td>
<td>Parentheses refer to yield in the dry year of 1954, when sheltered plot benefitted from extra melted snow.</td>
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<td>Dry bean, yield per plant</td>
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<td></td>
<td>Dakotas, Alaska</td>
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<td>Dryland</td>
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</table>
Shelterbelts

Windbreaks for Snow Management

As mentioned above, shelterbelts can be used to control the drifting of snow. The need to modify the snow placement has two benefits:

1. reducing the drifting of snow across roads and paths which need to be shoveled. This is the most obvious and is often used on farms and along roadways. Where large open spaces exist upwind of a road, a great deal of snow can be collected and deposited making clearing of snow difficult and time consuming.

2. purposely drifting snow where the melt-water will provide moisture for crop growth. Some crops in the western Plains, such as winter wheat depend on the cover of snow during the winter and the moisture provided during the spring thaw. When annual precipitation runs 10-15” per year, maintaining the melting of 1” or more water equivalent of snow can add a large percentage of moisture to a field.

http://www.unl.edu/nac/brochures/ec1770/index.html
Wind as an Energy Resource

Legislation in Iowa requiring the use of renewable, clean energy sources has spawned the creation of wind farms to generate electricity for Iowa power companies. Numerous farms are operating all across Iowa, and even more single wind generators are in operation in various sites. Information about Iowa wind energy can be found at [http://www.energy.iastate.edu/Renewable/wind/wem-index.htm](http://www.energy.iastate.edu/Renewable/wind/wem-index.htm). The sites active in Iowa and other states can be found at [http://awea.org/learnabout/publications/factsheets/factsheets_state.cfm](http://awea.org/learnabout/publications/factsheets/factsheets_state.cfm). Average wind speeds throughout the year have been modeled for the state of Iowa. In other states, such as California, wind power is quite common. Huge wind farms have been developed to take advantage of windy areas in these states.

![Wind electrical generator](image)

Fig. 5.13 Wind electrical generator.

Try This!

*Create a wind rose using wind data.*
A summer day may start with crystal clear blue skies. By noon there may be some white puffy clouds forming. By late afternoon thunderstorms may form. These two cloud types are called cumulus and cumulonimbus cloud, the latter of which produces precipitation. Necessary for their formation is a moisture source or humidity in the air. Clouds and precipitation will be discussed along with their relationship to humidity in the atmosphere in this section.

**What You Will Learn in This Lesson:**

- How relative humidity is calculated.
- What the differences are in several moisture measurements.
- About different cloud types and their formation.

**Reading Assignments:**

- pg. 92-99—Aguado and Burt
- pg. 132-143—Aguado and Burt
Humidity

The amount of moisture in the air seldom changes during the day unless there is rain. A front could also transport an air mass with a different moisture content. The indicators on the columns in Figure 5.14 show that there is the same amount of water in each picture. The amount of water up and down the column does not change, but the size of the container does. The reason is clear and illustrates that very warm air can contain more water than can very cool air. This is indicated by a smaller container. The amount of actual water in the air stays fairly constant through a 24-hour period. If the temperature is 68°F (20°C) with a humidity of 42% and the temperature cooled by about 20° to 50°F (10°C), the humidity will rise to 77%. The "rule of thumb" is good; temperature changes of 20°F (11.1°C) changes the humidity by a factor of 2.

Your personal comfort at a given temperature depends on the R.H. For crop and meteorological purposes, the actual amount of water in the air is important, such as the "absolute humidity" grams of water in a volume of air. The supplemental text discusses several relationships of water and air; specific humidity, R.H., etc.

Study Question 5.5

What is the relative humidity at 50°F and 7.27 grams of water vapor per cubic meter?

%  

Check Answer
Many things can be figured out from this little chart. If the temperature outdoors is near freezing, humidity is near 100%, and a little fog is seen, why do plants need so much water in the greenhouse? In the greenhouse with a temperature of 68°F (20°C), the same amount of water is in the air as is outside. But it is only 28% relative humidity inside the greenhouse, where it is 100% outside. Therefore, the plants in the winter in the greenhouse will use many times the amount of water that those same greenhouse plants would use in the summertime when the temperature outside is about the same as it was inside in wintertime. Heating the greenhouse to 86°F (30°C) would produce a relative humidity of 16% when it was actually foggy at 32°F outside. This concept is applied in the following example (Fig. 5.15).

This applies to home heating, also. Humidifying the heated air inside the house is necessary to feel comfortable, to protect wood from drying out, and to reduce static "shocks" from rubbing feet across carpets and touching metal.

While relative humidity is the most quoted measure of moisture in the air, dewpoint is another measure of the amount of moisture in the air. Dewpoint is defined as the temperature at which dew would form if you cooled the air, on the temperature at which saturation would occur. Thus, dewpoint is an absolute measure of the amount of moisture in the air, while relative humidity is a relative measure. The amount of moisture in the air is compared to the amount of moisture the air could hold (at saturation). The dewpoint is the number most often used by meteorologists because it is an absolute measure of how much moisture is in the air. Some common dewpoint numbers are easy to remember. Dewpoints near 60°F (15°C) begin to feel humid; ones near 70°F (21°C) produce the most uncomfortable conditions during the middle of the summer and are often a precursor to thunderstorms.
Cloud Formation

One very important humidity application is in the discussion of cloud formation. Clouds form whenever the amount of moisture in the air is such that the humidity goes above 100%, or the dew point is reached. When you see your breath in the winter, you are forming a cloud. The air, expelled as you breathe out, is usually near saturation, almost 100% humidity. This moist air is cooled by coming in contact with the cooler air reaching its dew point. Condensation forms all around your face as a cloud, as we say "seeing our breath". Breath can be seen at a temperature in excess of 90° F (31.6°C) in the jungles where the humidity is 100%. In the Midwest these conditions usually occur with temperatures near freezing. When we suddenly cool the air that we are breathing out to the dew point, we see the cloud that was formed. When the humidity reaches 100% dew will form on plants, grass, or other objects if there is something for dew to condense on.

Above the surface no large objects exist. Here a small particle of dust, pollen, or salt (if near the ocean) in the atmosphere would be sufficient to start some moisture condensing on it. The moisture would grow on this little particle, referred to as the condensation nuclei, to the point that we would have a small drop of water, called a cloud droplet. If this drop becomes large enough that its weight is significant compared the bombarding from all the molecules in the air, it may start falling toward the earth. The particles need to become a certain size before gravity has a significant enough effect on them that they begin to fall toward the earth.

Clouds form for various reasons. Usually it is because air is lifted and cools. Normally, in the atmosphere for every 1,000 feet increase of elevation, the temperature may drop by 5 or 5½° F (Fig. 5.16). Many other conditions exist. These will be discussed later.

![Fig. 5.16 Average vertical temperature change in the atmosphere under normal heating conditions.](image)

Clouds occur at various levels in the atmosphere. Ranging from near the surface to 70,000 ft. Cloud composition varies; whether it is water, ice, or a mixture is a function of the surrounding temperatures.
Clouds are classified according to how they are formed. There are two basic types:

1. Clouds formed by rising air currents, named cumulus clouds. These clouds are, typically, piled up and fluffy. Air is rising; as if it is bubbling up into something. Sometimes these clouds will be flat on the bottom and look like a bubble on the top. The looks are not deceiving. That is precisely what is happening with their formation. Imagine a bubble of air coming up through a swimming pool. When it gets near the top, it leaves a bubble or foam on the surface of the water. It is flat on the bottom where it contacts the water. Similarly, air rises up through the fluid of the atmosphere when it may form a cloud. Also where it can no longer keep going up further because of the temperature and moisture relations of the atmosphere, a fluffy, rounded cloud is formed (Fig. 5.17).

2. The second type of cloud is formed when a layer of air is cooled to the saturation point without localized vertical movement. In this case a widespread area is lifted slowly, causing a large sheet of clouds. These clouds are called stratus (Fig. 5.18), meaning "sheet-like". Stratus clouds are formed under conditions where the air is stratified, and they exist something like a sheet across a large area. That is why the stratosphere is called the stratosphere because the air does not mix all around and churn. The atmosphere is layered in stratosphere.
Cloud tops, even on thunder clouds can rise up to 70,000-75,000 ft (22,500-24,200 m). Cirrus clouds and some other types of clouds reach that height quite often.

A second designation is given a cloud according to height or if a cloud is precipitating.

Clouds' names are descriptive. "Nimbus" in a cloud name designation means rain. There are "fracto-" (meaning "fragment"ed clouds), where the wind breaks clouds into pieces, "alto-" meaning middle. But all of the names have meanings. They do not seem to have changed very much from the original cloud classification. The designation is applied to the cumulus or stratus types to further describe clouds. First we will apply the height designation.

The high clouds, clouds that are above 20,000 ft. (6000 m), are almost always ice clouds. There are three basic types:

1. The cirrus clouds, sometimes called mares tails, are wispy, fibrous clouds that occur around 25,000 ft (Fig 5. 19). There is something to be learned from those clouds called mares tails. When there are mares tails in the sky, we quite often see trails behind a jet flying overhead, condensation trails. Cirrus clouds are high level clouds.
2. "Cirrocumulus" clouds, occurring (Fig. 5.20) between 20,000 to 25,000 ft. (6000-8000 m), are patchy clouds that often make patterns referred to as a mackerel sky. They are always thin; they never really make shadows on the ground, although they may cut down the intensity of the sunshine. The cumulus elements are very small, resembling the scales of a fish, hence, the term "mackerel sky".

3. "Cirrostratus" clouds (Fig. 5.21), a great sheet of ice particles above the surface, may look like wind-blown gauze. The sun or moon is always visible through this thin layer of ice crystals. Some photos show a halo around the sun or around the moon. Sometimes there is a double halo when the temperature is 40° F (4° C). These halos are the product of refracting and reflecting light through the crystals. It has been said that when there is a halo around the moon or around the sun, there is going to be a storm. It is the same thing as watching the condensation trails in the sky. A warm front is probably on the way, the moisture is building up in the air, and the clouds form in the upper atmosphere creating the halos.
In the middle of the atmosphere, clouds are basically stratus or cumulus types. The bases of these clouds average about 10,000 ft. (3200 m) above the earth.

1. The "altocumulus" clouds (Fig. 5.22) are patches or layers of puffy clouds or sometimes rolled clouds at middle levels of the atmosphere. They again do not consist of ice crystals. The cloud elements are larger than cirrocumulus and can form in larger arrangements, also, up to 6000 m.

2. "Altostratus" clouds (Fig. 5.23) are dense veils of gray or blue which often appear to be striped. The sun and the moon do not form a halo in a middle cloud because these clouds do not have ice particles in them.
Low clouds are clouds near the ground. There is a difference between fog and a cloud that is just at ground level. The difference depends on how they are formed. Fog is due to local cooling of a cloud that settles down to the ground. Low clouds are formed by lifting processes in the atmosphere which lift already very moist air slightly to cause condensation. We will find a lot of interesting things happen on this. When you are driving in foggy weather in Iowa, sometimes the fog is in the valley bottoms. Other times the fog is on the hilltops, and the valley bottoms are clear. So this really does differentiate the conditions under which fog and clouds were formed. When they were formed, was it because of surface cooling, or was it because of a layer of air that was below the dew point?

1. Cumulus clouds (Fig. 5.24) are the ones often associated with fair weather. They are regularly seen as puffy clouds which have the shapes that we love to lay on our back on a sunny summer day and watch the clouds move and change. On the days when a cold front has come through and brought dry air and comfortable conditions, the fair weather cumulus clouds appear.

![Fig. 5.24 Cumulus clouds](image)

2. "Stratocumulus" (Fig. 5.25) are the regular masses of clouds, gray, dark shading and do not produce rain unless they start to thicken and change into a rain cloud. As the name indicates, they are a layered
cloud with cumuliform elements.

Two forms of clouds produce precipitation.

1. "Nimbostratus" (Fig. 5. 26) are the true rain clouds. They are a dark layered cloud (low-based cloud) with a shaft of rain seen coming down toward the ground. They have a wet look to them. They are often accompanied by some low clouds that are moving along beneath them, usually quite quickly as the wind blows under these clouds. These little clouds are called "scud" and move along quickly underneath the rain clouds. "Nimbo" is an added prefix meaning "rain".

2. A special form of a cumulus (Fig. 5.27) cloud is a cumulonimbus cloud (cumuliform with rain). This type differs from regular cumulus clouds because of its huge vertical development. They form in very unstable conditions transporting huge amounts of moisture high into the atmosphere. The height of these can range from near the surface to 70,000 ft (22,500 m) in the most extreme cases. The great storm that produced the huge floods with 15" of rain in 1993 had its top at 60,000 ft (19,350 m). They are well
known for their anvil shape caused by spreading of the cloud by the jet stream.

![Cumulonimbus Cloud](image)

**Fig. 5.27** Cumulonimbus, a cumulus cloud with great vertical development and rain.

**Try This!**

[Click here to do an exercise on clouds.](#)
I watch these things very closely. Jets are always flying over Iowa. If they fly over your area, at times you will notice that there are jet trails, or condensation trails, in the air. Sometimes the jets are flying over but the trails do not persist; they dissipate. If dry conditions exist all the way up in the atmosphere, the condensation trails seem to dissipate quite quickly. Some days you will notice that the condensation trails persist, spread with time and become more extensive. This condition indicates that moist air has moved into the upper atmosphere. Generally, one can assume that a warm front will pass by within the next 36 hours after the condensation trails begin to persist and spread. I saw an interesting event one summer day when I was in Colorado. The day was perfectly clear. The planes were flying early that morning into the airport at Denver. The low ones, of course, were not making condensation trails but the ones at high altitude were. The first plane across the sky left a trail, and it began to spread. Soon 20 or 30 planes had flown by and the sky was completely cloud-covered. We may even have some climate modification due to condensation trails putting more clouds in the upper atmosphere, at least under certain atmospheric conditions. So, the mares' tails, cirrus clouds usually at 25,000 feet, with temperatures always below freezing, are always ice particles.
Humidity and Clouds

Precipitation

From the two precipitating types of clouds, cumulonimbus and nimbostratus, fall precipitation. There are basic types of precipitation: rain, snow, dew, and frost. Snow is frozen precipitation but is not the basic category. Frozen and non-frozen precipitation are perhaps better terms for precipitation types.

Rain comes in various sizes of droplets. Sometimes there are very large droplets that some people say "could fill a teacup with one drop," and others that are very small or fine, almost misty. Raindrops come in all sizes, just like spray droplets from an agricultural sprayer. They have different falling and settling rates, just as expected with spray from an agricultural sprayer. The rain drops are almost always formed on a bit of salt, dust, pollen, or something that serves as condensation nuclei to get them started. They always form when the temperature is at or below the dew point in the area where they are forming.

But let us consider how droplets grow. Initially, they grow by water vapor condensing on their surface. Eventually, they grow large enough and begin to fall. A large drop will fall faster through the atmosphere than will small drops. Accordingly, a large drop catches up with small ones and captures them as they fall until the drop reaches its maximum size. A raindrop can reach only a certain size. It cannot get any bigger than that because if it gets bigger, it deforms as it falls, gets flat on the bottom, becomes cup-shaped on the sides, and little pieces break off of it as it falls. A small droplet will fall, bump into larger ones, then grow, and continue to fall faster and faster as it grows. After reaching a certain size, it grows by impacting with and capturing other drops as it falls (Fig. 5.28).

Snow always forms as ice crystals that grow. The temperature must always be colder than the dew point by at least a little bit so that crystal growth may occur. Temperatures must also be below freezing. Sometimes cooling of raindrops occurs quickly and water does not freeze immediately. This is called super-cooling of water. There are some interesting things happening in super-cooling of the atmosphere.

There are frequent questions about what type of precipitation is falling. Is it snow, graupel, sleet, or freezing
rain? All of these classifications occur in the state of Iowa. Here is the situation that often produces these. Sleet or little beads of ice graupel occur when there is a warm front moving into the area. Warm air pushing in over cold air that is already present. As this warm moist air is lifted over the cooler air near the surface. The moisture condenses and it begins to rain. Then the rain falls through the freezing air that is already near the surface, when it has been in the air long enough to freeze, ice pellets may fall to the ground. If these drops of water are below freezing, but have not yet changed to ice, the drops of water freeze when they hit something at ground level that is colder than freezing, like the windshield of your car or the soil. They freeze instantly because they are super-cooled. Being super-cooled, as soon as something disturbs them greatly, the raindrops freeze instantly, creating glaze or freezing rain. The temperature structure associated with these is in Figure 5.29.

![Fig. 5.29a. Liquid precipitation freezes before reaching the ground.](image)

![Fig. 5.29b. Liquid precipitation cools below freezing but does not have time to freeze. Precipitation freezes upon contacting the surface, which is below freezing.](image)

If particles or small ice crystals in the warm air layer, above 32°F (0°C) up high in the atmosphere, fall through the cold air lying near the ground, freezing precipitation or glaze takes place.

This is why it is so hard to forecast. If there is only a cold air layer, there would be only ice pellets or even snow falling. But the presence of a warm layer above the cold air causes forecasting problems. If precipitation begins just within the warm air, only rain would occur. Further into the cold air there would be only a narrow band, sometimes 2 miles wide, sometimes 20 miles wide, where the freezing rain conditions occur. That band may go on for several hundred miles parallel to the front. But it is still narrow, making it very difficult for forecasters to know exactly where that band will be. We know that we can forecast conditions of mixed frozen precipitation somewhere along that line.

Ice storms are always associated with the glaze, the super-cooled moisture, hitting the branches, or ground, and freezing there. It does a lot of damage to power lines. The super-cooled rain will crystalize upon striking an object. If the object is cold the glaze formed with persist. Many people may be aware of such storms, especially those living in northern Iowa.

Hail storms have an interesting inception. In a thunder storm there is a rapid uplift of the air. The air is rising because of buoyancy like a helium balloon that is filled with gas. If you let the balloon go, it rises because the gas inside it weighs less than the gas in the air. That is what is going on in a thunder storm. The air is unstable. A warm bubble of air near the ground starts to rise up through cooler air. As it rises, it cools, but it not as much as the air around it if the conditions are unstable. It rises very rapidly many miles into the atmosphere. The updraft may be so strong that some rain falling out of this area may get entrained or pulled back into the
updraft. Then it is blown back up high into the atmosphere by this uplift (Fig 5.30).

![Diagram of updrafts lifting air into the storm](image)

**Fig. 5.30** Updrafts lift air into the storm. This condenses into the clouds and precipitation is seen. Mixing of the updrafts and downdrafts recycles ice, creating large ice chunks called hail.

You can see an example of this entrainment if you have your vacuum hose blowing instead of sucking and hold the hose pointed up into the air with a beach ball over it. The ball will stay in the vertically moving air because where the velocity is greatest, the pressure is least. This is a phenomenon called Bernoulli's Principle; where there is high velocity, there is low pressure. Something that gets near a stream of air will be drawn into the stream of air and will stay there. As with the vacuum hose blowing straight up, a beach ball will stay trapped in the air flow.

Droplets of rain act similarly. When a drop is lifted high in the cloud, it freezes and starts to fall. It may get entrained again, go up, start to fall, go up, start to fall, go up again, and accumulate more and more layers of ice until there is a hail stone that is so heavy that it cannot be lifted (Fig. 5.30). It will fall to the earth as a hail stone whatever size is appropriate for the amount of wind that there has been associated with that storm. Stranger vertical motion can produce larger hail. Baseball and softball size hailstones that fell on central Iowa in May 1998 needed updrafts of 80 mph to sustain them (Fig. 5.31).
Fig. 5.31 Hail stone of 10" circumference which fell on Ames, IA in May, 1998.
Humidity and Clouds

Dew

Dew is important in agriculture, horticulture, and agronomy because so many pathogens require free moisture to develop. Dew is slightly different from other precipitation in that it doesn't fall from the sky. It comes from the air but forms on surfaces. When the temperature is right and there is moisture on the leaves, diseases will grow. Diseases will grow on soybean pods and reduce the value of the soybean yield for seed. When there is damage, the soybean cannot be used for seed, but must be used as grain for food processing or animal feed. Tomato plants may have disease outbreaks on them because there is a pathogen in the area and with occurrence of dew. There is dew on a spider web in Figure 5.32, making it a beautiful lacy thing. But dew does not fall.

Dew forms locally because the surface is cold enough that it is below the dew point. The air around the surface contributes the moisture to form the dew. Often the moisture that is in the air comes from the soil right in the vicinity. Soil is evaporating water slowly. If the soil is warmer than air temperature, it is evaporating a considerable amount of moisture into the atmosphere in that bottom foot or so above the ground. A ground fog could form, or skies may stay clear. If the sky stays clear, all the way to outer space, we can end up with a situation wherein we have radiative cooling of the ground and of the surface. If temperatures are below the dew point, the moisture evaporating from the soil, leaves, and the vicinity will condense on the cold surface, causing dew to form.

There are places in the world where it seldom rains. One that has been known for thousands of years was written about in the Bible. The Bible in the Old Testament says, "As the dews upon Mt. Carmel...." The dews at Mt. Carmel in the Israel, Palestine area are produced by moist air from the Mediterranean which comes in almost every night. The air is cool over the mountains. It does not rain or create fog very often, but heavy dew forms on the side of that mountain. The dew supports a heavy vegetation for an arid area which does not have rain. In some accounts, all moisture that would ever accumulate was dew up until the time of Noah and the Ark. Then it started to rain and flooded them. That was the first rain known, by some accounts, in that part of the earth. The dew had kept the vegetation alive.
Dew can be significant in keeping vegetation alive. It is significant on the desert coast of Chile and Peru. There are some plants there that probably have not had an inch of rain in 10 or 20 years. Yet, the plants grow and thrive because of overnight high humidities and dew that forms there.

Scientists can estimate the amount of dew that will be forming. There is a dew model which was one of the first weather models about which was published.

Frost forms much like dew except that the surface is colder than freezing, so it is ice crystals form. The water vapor in the air goes from a vapor state to a solid directly without being a liquid. More about dew and its relationship to disease will be discussed in lesson 7a.
Humidity and Clouds

Water Cycle

Eventually all of the precipitation that falls flows into lakes, the ground, or the ocean evaporates into the air. Rain is either stored in the ground in ponds or lakes, runs off to be stored in the ocean, or evaporates into the air to produce precipitation again. This cycle is known as the hydrologic cycle (review the first page and the water cycle interactive).

A great deal of water is stored in the land in Iowa. The top 5 feet of soil at field capacity will contain 10 inches of water. This is a great deal of moisture. When the Corps of Engineers builds dams, even for flood control, a dam holds 2-3 inches of moisture in a watershed. In other words, a three inch rain in a watershed (or drainage area into a lake) falling on frozen ground would fill an empty lake. People talk about a dam as a flood control measure because it will hold that 3 inches and keep it from going down river and flooding the community below the dam. But ten inches of moisture can be held in the soil. That is three or four times the water holding capacity in the soil than in any of the reservoirs and dams built around the state.

Now let us look at what happened in the flood that we had in Iowa a couple of years ago. Assuming that there was about 5 inches of water in the soil and that the dam was about half empty, the lake would hold 1½ inches. If suddenly, a 5-inch rain falls, some of that will soak in. Three inches of a 5-inch rain will soak into the soil, and there will still be room for some in the soil. Two inches will run off, of which 1½ inches can be held in the dam, filling the dam. Some water is let out of the dam at all times. Water engineers let as much run down the river as they dared. They let half an inch of it run down the river, while holding the 1½ inches in the dam (Fig. 5.33).

What really happened in 1993? Iowa started off with 10 inches of moisture already in the soil. If any rain fell, none could be held there. If 5 inches of rain fell, 5 inches would go into the dam. The dam could hold only an inch and a half. In one instance 15 inches of rain fell, all going into the dam. We had what is called a 100-yr flood. Actually, there was not one chance in a hundred of having a hundred year flood. There was one chance in 17. The reason the chance was so high, when they figured it would happen only once in a hundred years, was assuming the soil would hold another 5 inches of water. The soil would hold none, so it was really a 20-year flood for years when the soil was already filled with water (Figure 5.34).
Our crops require about 25 inches of water for the year. If our crop starts off the year, like it did in 1995, with 10 inches of water in the soil, we have more than a third of the water that is needed for the entire season. That amount can see the crop through a fairly dry period any time in the season. If rainfall gets a little bit spotty or occasional, 10 inches of water already in the soil, can give us a lot of buffer. It is better than almost any other place on the earth. We are really blessed in Iowa to have soil that will hold 10 inches of water. Very few other places will do that. Some of our Iowa soils will hold 12 inches of water. Some places in Iowa, the crop roots go down more than 5 feet. Sometimes corn and soybean roots will go down 7 feet. That means they have 14 to 16 inches of water available to them to see them through harsh times.

Sandy soils do not hold 10 inches of water. Sandy soils hold 5 inches of water at most. Some damage occurred in 1995 as soil and crops began to get dry in July. In August some of the sandy areas were depleted of water, producing some firing of the crops because not enough water was available to them at that time.

Water storage in the soil, in the topsoil and the subsoil, is about 10 inches. In the ground water, deeper than 5 feet in the soil, about 2 inches of water can be stored per foot of soil. But the plants do not draw it out of that depth. It remains there unless it is drained out by a well or by a deep-rooted tree. For the most part, crops do not influence the ground water level, below 5 feet.
Humidity and Clouds

Cloud Seeding

An episode happened one year in Yellowstone Park during the winter. There were geysers and hot pools producing clouds in the area. In the place I was standing, the sky was perfectly clear. I could see a cloud to my right and one to my left that were associated with some hot pools and some geysers. The temperature was near 0° F (-17.8°C). The guy that was with me decided that he wanted to smoke. He lit a match. I noticed that the smoke from the match was growing, like the condensation trail of a jet plane. I said, "Light another of those matches." He lit 2 or 3 more matches and soon he had a cloud that was maybe 20 feet in diameter from just lighting those matches. Eventually that cloud got up to about 30 feet in diameter. Actual little snow flakes could be seen falling from the cloud. By lighting his cigarette, he started weather modification and started a miniature snow storm that day by Old Faithful Lodge in Yellowstone.

Super-cooled water in the air is the kind of thing that cloud seeding is taking advantage of. Sometimes the atmosphere is so clear, even though there is enough water to produce rain or snow and the temperature is right, that it just does not start. It is below the dew point and below freezing, but there is nothing to make it create a cloud or droplets. If you put a little bit of silver iodide salt in the air, or the smoke from the match that my friend lit, you can start moisture condensing on the particles. Pretty soon you can have a storm. Rainmaking could be a real thing, especially if you get something small like one match to start a large event as a chain reaction.

Rainmaking and cloud abatement are practices utilized in many areas to hopefully alleviate dry conditions.

By seeding the clouds, a plane might be able to get the clouds to form droplets of water large enough to fall as rain or mist and clear the fog, a measure often used to clear fog at airports to make them available. Sometimes cloud seeding is used to clear the Panama Canal so ships can see to get through by causing mist or rain to fall which will clear the atmosphere of fog.

This has been the most successful aspect of rainmaking, fog clearing. Many times people during a drought year have tried to do rainmaking in various parts of our state or of other states. For a long time it was thought that rainmaking and cloud seeding was just nothing more than a shyster or someone trying to gyp people. We found out that when there are clouds that look like rain clouds come in three types. There are clouds that if seeded with silver iodide, can produce some rain; there are clouds that if seeded, would produce less rain because so many little droplets of moisture are formed that they would never get to the ground; and there is the type of cloud that if seeded does nothing.

It turns out that these clouds occur in equal numbers, particularly in North Texas where these studies were being done. The researchers seeded every cloud that came by. They found out that sometimes they got rain and sometimes they did not. If they did not seed the clouds, sometimes they got rain and sometimes they did not. But they did not realize that there are three kinds of clouds that all look the same to our eyes. With the invention of an instrument called the nephelometer that can measure the nature of the cloud and the structure (size and distribution) of the water droplets in the cloud, we finally had the ability to differentiate the three kinds of clouds. We see what kind of cloud it is. If it is the kind that rainmaking will help, the clouds can be seeded if more rain is wanted.

Assignment 5.1
Lesson 5 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 5b

Humidity and Clouds

References


Agronomy 541 : Lesson 5a

Shelterbelts

Introduction

Developed by D. Todey and E. Taylor

It is suggested that you watch Video 5A and complete the exercise in the video before continuing with the lesson.

The application of wind in agriculture is well known. Wind has been used regularly in agriculture throughout history. Most farms in the Midwest landscape were marked with a windmill as an energy source for pumping water from a well. Negative aspects of wind have required the use of shelters for various crops. While the old-fashioned windmill is used only for historical preservation, new wind generators are appearing on the landscape. And the use of shelters for crop protection is experiencing a resurgence.

What You Will Learn in This Lesson:

- How to apply generalized wind to flow around a shelterbelt.
- How a shelterbelt affects the environment and crops near.
- What a wind rose is.
- What wind climatology looks like.