Unit 3) Plant Growth and Development

That was Then and This is Now…

Then

"When spring came, the entire Brooks family, excepting the infant, was put to work in the making of a garden. Buffalo grass and weeds were removed, and the soil made ready for vegetable planting. All kinds of vegetables were grown – pumpkins, tomatoes, cucumbers, onions, beans, radish, lettuce, and cabbage. The cultivation of a liberal yielding truck garden meant health for all the family, besides providing a surplus that could be exchanged for more livestock, such as a pig and a dairy cow. In all this improvement, Hannah Brooks was the leading spirit, and ably supplemented the heavier work that fell to her husband." [1]

Roderick Cameron, Spring 1879

Now

"It's good to see the sunshine today. Our wheat, corn and soybeans really need some sunshine and rain-free weather. We'd like to mow our brome hay, too, but we need a forecast of five rain-free days and bright sunshine.

As I was scouting our crops today, I found some bean leaf beetles chewing up our young soybeans. Our wet spring delayed our corn and soybean planting and they are not as tall as they would be in a normal year. I called our County Extension Agent and described the bean leaf beetle damage on our soybeans. He suggested that with the damage I described, and the better weather forecast for the next several days, the beans should be able to overcome the damage and be okay without using an insecticide spray. He suggested I come back in three days and scout the field again. That was good news."

Bill Wood, June 2, 2009

Grain Sorghum Field
Credit: Anson Eaglin, USDA

Crop Field
Credit: Tim McCabe, USDA

Botany, the scientific study of plants, is one of the oldest branches of biology. To date, scientists have documented more than 400,000 species of plant life from tiny flowering plants less than one millimeter (1/25th of an inch) in length to sequoia trees reaching almost 275 feet in height.

Living organisms depend on plants to sustain life. In addition to providing food for consumption, plants produce the oxygen needed by plants, animals, and people through a process known as photosynthesis.

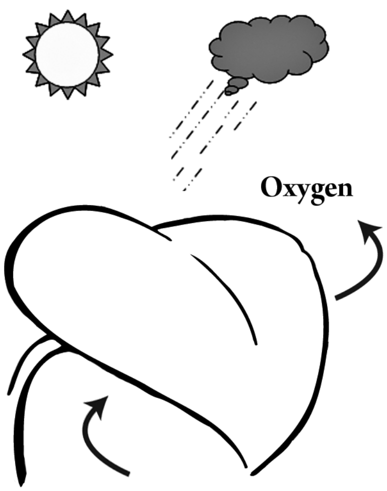
Photosynthesis

Photosynthesis is an essential process for sustaining life on Earth. One reason is because photosynthesis produces oxygen, which is released into Earth's atmosphere. While Earth's atmosphere itself is made up of many different elements, oxygen alone accounts for 21 percent. Nitrogen makes up another 78 percent, and the remaining one percent includes carbon dioxide, water, and other elements.

In addition to maintaining the normal level of oxygen in the atmosphere, photosynthesis provides nearly all the energy that sustains life on this planet, either directly or indirectly. Eating fruits or vegetables is an example of direct consumption of the energy stored in the plant materials. Eating meat or drinking milk are examples of indirect consumption as the energy stored in the meat or milk resulted from the animal consuming energy stored in plants.

Photosynthesis only occurs in plants, algae, and some species of bacteria. This unique process takes place when a plant uses energy from light to convert water and carbon dioxide into oxygen and other organic compounds. In other words, this process is how a plant produces its own food.

Photosynthesis

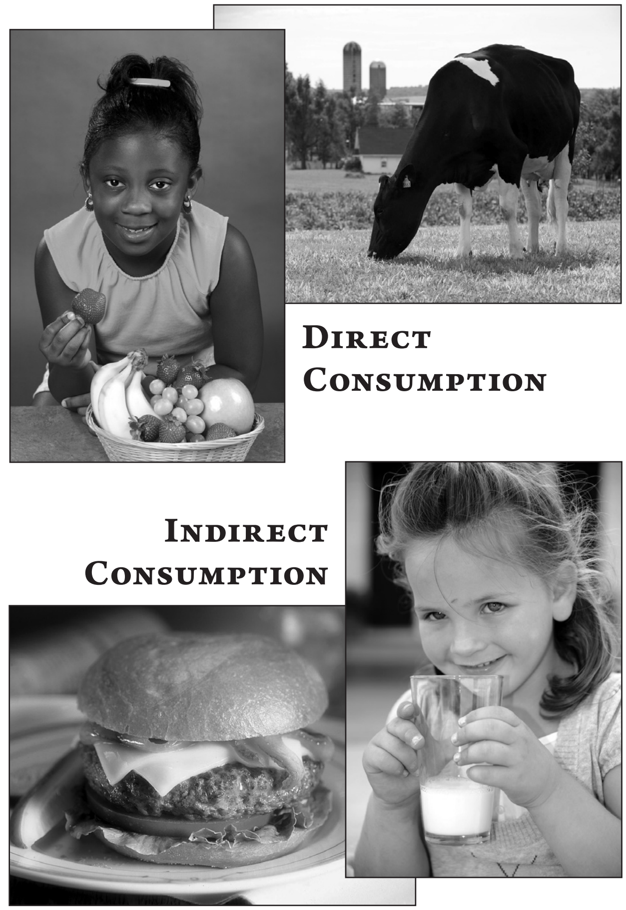


The photosynthesis process always begins with the absorption of energy from light. In plants, the light's energy is captured by chlorophyll, the green pigment contained in leaves and other plant tissue. Some of the captured energy is stored in the plant's tissue and used to complete the photosynthesis process. The remainder of the energy captured from light sources is used by the plant for other chemical and biological processes, such as producing sugar and converting it into starch, protein, oil, or other chemical compounds necessary for the plant to complete its life cycle.

Photosynthesis takes place in the cells of a plant. Carbon dioxide from the atmosphere enters a plant through its stomata, which are tiny openings on the undersides of the leaves. A chemical reaction takes place between the carbon dioxide and available water molecules. During this chemical reaction, the carbon becomes part of the plant's structure. The carbon is stored (sequestered) in plant materials until it is needed by the plant. The carbon is then converted into carbohydrates, ultimately resulting in sugars, starches, and cellulose, which are all used by the plant to maintain growth and development. When living organisms consume the plant or plant parts like seeds or stems, some of the carbon is

> ***Stomate (Stoma)***– a microscopic opening in the outermost layer of cells covering plant parts that have contact with the air, occurring most abundantly on the undersides of leaves. Plural: stomata.

Consuming Energy Stored in Plants

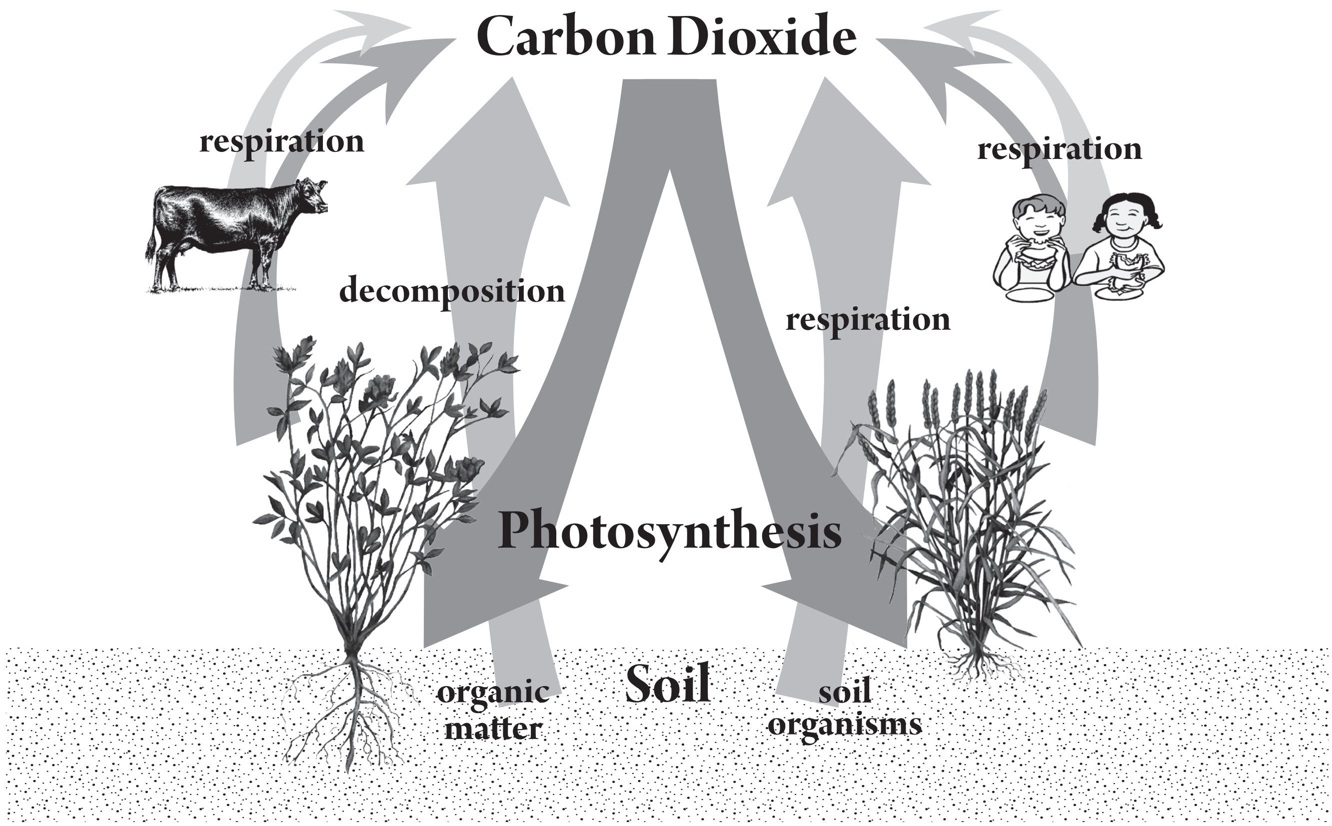


Credits: Clockwise from top left: Peggy Greb, USDA ARS; Midwest Dairy Association; Midwest Dairy Association; The Beef Checkoff

Carbon Facts

In the carbon cycle, carbon circulates through the air, soil, water, and living organisms.
Carbon sequestration is the process of storing carbon.
The organic matter in the Earth's soil contains twice the amount of carbon present in the atmosphere. [2]
Agricultural crops that produce higher amounts of crop residue, like wheat or corn, leave more organic matter containing carbon in the soil than crops that leave less plant material in the fields after harvesting.

The Carbon Cycle



Sources: KFAC, Nebraska Ag in the Classroom

released back into the atmosphere as carbon dioxide. Other carbon atoms remain stored in the soil as the remaining plant material decomposes.

During photosynthesis, the chemical reaction between the carbon dioxide and water molecules separates the hydrogen and oxygen atoms in the water molecules, leaving oxygen as a byproduct. Since the plant does not use the oxygen, it is released into the atmosphere through the stomata and made available to other living organisms.

Plant Growth

Plants sustain life on earth by producing the oxygen that living organisms need to survive. They play a critical role in the food web, transferring energy to other living organisms as they are consumed (eaten). However, the specific purpose of each individual plant is to produce its own food so that it can reach maturity and reproduce.

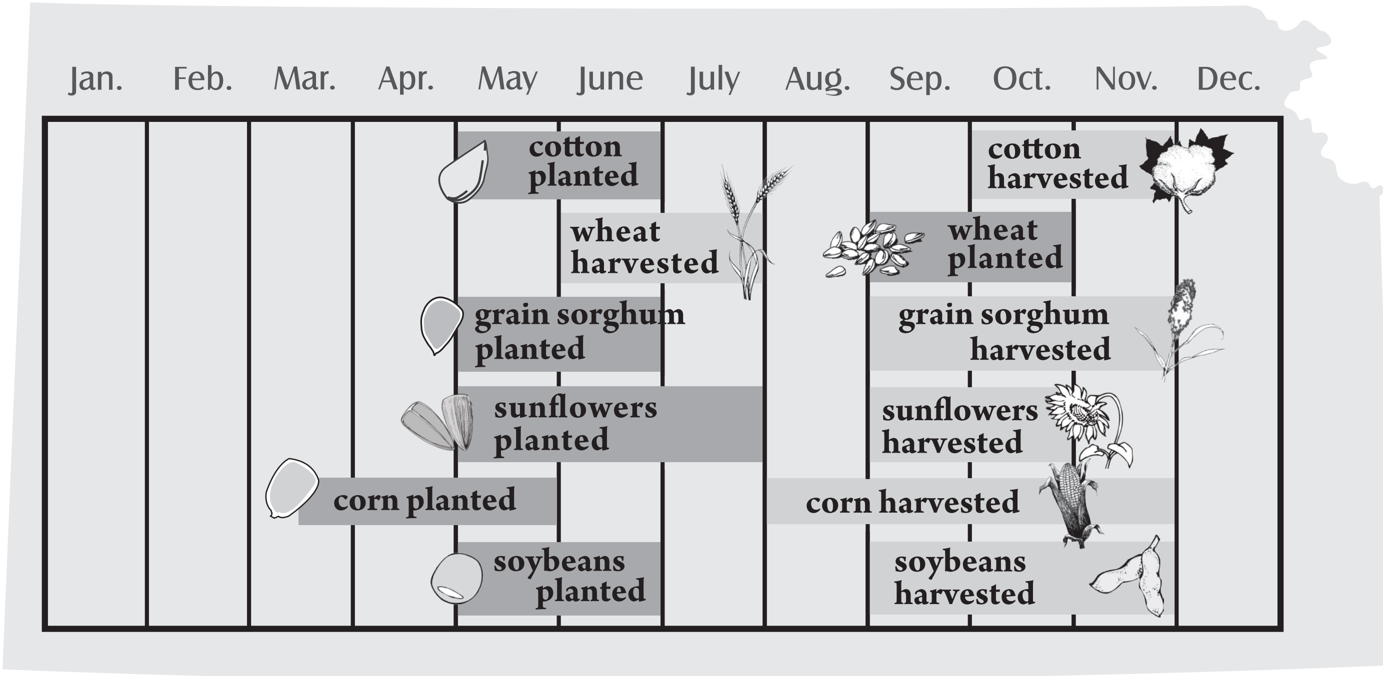
Since sunlight provides the necessary energy for photosynthesis, it is one of the most important influences on a plant's growth. However, several other factors also influence the rate of plant growth. These include the temperature of the air and the temperature of the soil the plant's roots are growing in. These factors help determine when agricultural crops will be planted and when those plants will be ready for harvesting. For example, seed producers calculate the necessary number of days of optimal air temperature (the temperature at which a plant will grow best) for a specific plant variety to reach maturity. Agricultural producers then choose between plant varieties, matching the season and conditions with the "growing degree days," referred to as "growing degree units" or "heat units."

Rather than maintaining consistent air and soil temperatures year-round, Kansas experiences four distinct seasons: spring, summer, fall, and winter. The spring season brings mild weather and higher rainfall so most plants will grow faster during the spring. Once the soil warms up enough for the seeds to germinate, crop producers plant spring crops, including corn, soybeans, grain sorghum, sunflowers, fruits, and vegetables. During the summer season, warmer temperatures continue to encourage plant growth. Many plants also mature and produce seeds or fruit, like wheat, cotton, and tomatoes. The fall season brings cooler temperatures, and there is less sunlight available for photosynthesis due to the shorter days. Most spring-planted crops mature and are harvested during the fall months.

The Growing Season in Kansas

The normal frost-free period shortens from 200 days at the southeast corner of the state to only 154 days in extreme northwestern Kansas. The shortening of the growing season is due to the rise in altitude from 679 feet above sea level in the southeastern corner of the state to 4,039 feet above sea level at the highest point in western Kansas. From the southern to northern border of the state, the change in distance from the equator (latitude) also affects the length of the growing season. On average, the growing season shortens about one day for each additional eight miles north of the southern border of the state of Kansas.

Timeline for Planting and Harvesting Kansas Crops



Source: KFAC

Plant Life Cycles
Annual – a plant that completes its life cycle in one growing season. Examples: sunflower, wheat, corn, potato, marigold, tomato.
Biennial – a plant that requires two growing seasons, with a period of dormancy in-between, to complete its life cycle. Examples: carrot, onion, red clover, parsley.
Perennial – a plant that lives for more than two years. Examples: alfalfa, asparagus, rose, daisy.

Despite cooler temperatures, however, annual crops like winter wheat are planted early in the fall and begin growing before going dormant during the winter months. During the winter, the soil stores water from precipitation (mainly ice and snow), which is stored in the soil until the spring. Once temperatures start warming up, the water is available to plants as they resume growing. Perennial plants also go dormant during the colder weather and start growing again in the spring.

Parts of a Plant

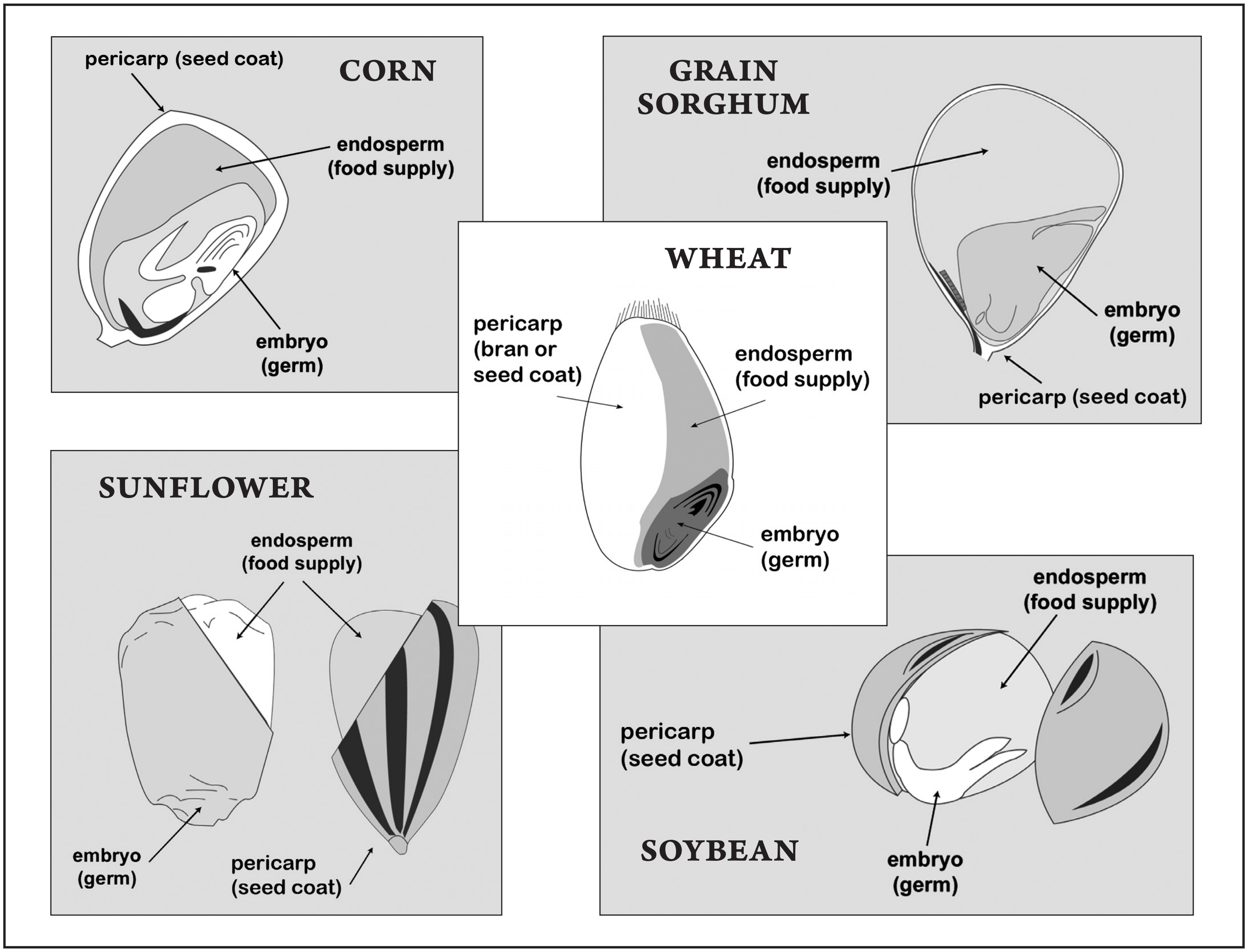
Seeds

All of a plant's growth is aimed at achieving maturity and being able to reproduce, even though many plants are harvested before they reach maturity. Most plants reproduce by producing seeds. Since each seed can only produce one plant, plants produce many seeds to ensure the survival of their species.

Each seed has three parts: the pericarp, the endosperm, and the embryo. The pericarp is the seed coat, or the protective covering that surrounds the entire seed. Inside the pericarp, the endosperm, the largest part of the seed, serves as the food source for the embryo

Seed Collection
Credit: Jack Dykinga, USDA ARS

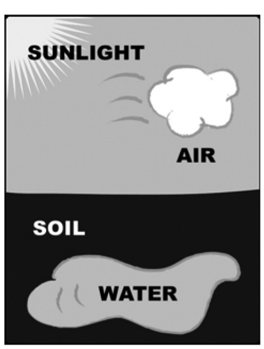
Seed Parts



until the embryo can produce its own food. The embryo, also known as the germ, is the only living part of a seed. This is where a new plant first starts to form.

All seeds are dormant, or inactive, for a period of time. This allows the seed to delay growth until the proper growing conditions exist. The essential components of plant growth are air, sunlight, water, and something that anchors the plant's roots, like soil. When these components reach optimal levels, the seed germinates (begins growing a new plant).

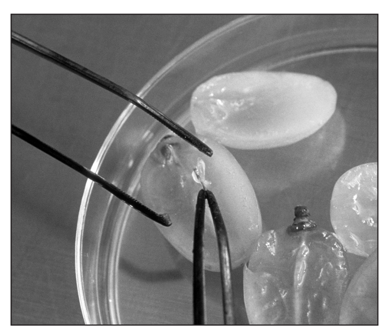
Plant Growth Factors



Source: KFAC

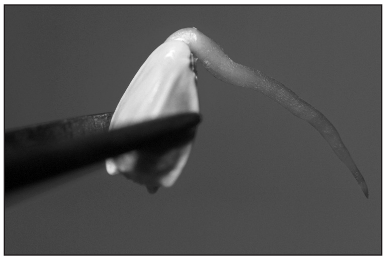
Germination

Germination begins when the seed absorbs moisture. The moisture softens the pericarp, which eventually cracks and allows water and air to reach the embryo. Using the food stored in the endosperm, the embryo begins growing and develops one or two cotyledons. The cotyledons provide food for the developing plant until it is capable of producing its own food. Working against gravity, one end of the embryo grows up towards warmth or sunlight. This new plant growth, called the "shoot," pushes through the soil surface. Once it emerges from the soil, the shoot elongates and develops into a stem. Stems have cells that generate new living tissue, including leaves. Once the first leaves emerge and begin producing food for the plant, the cotyledon dries out and stops supporting plant growth and development.



Grape Seed Embryo

Credit: Jack Dykinga, USDA ARS



Safflower Seedling– Two Days Old
Credit: Keith Weller, USDA ARS

Sunflower Cotyledon
Credit: National Sunflower Association

Emerging Corn Plant
Credit: Lori Abendroth, Iowa State University

Monocots and Dicots

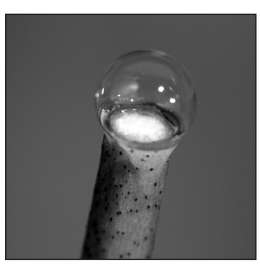
Cotyledons (seed leaves) are part of a plant's embryo. A cotyledon stores food that is used during germination. Depending on the plant species, the cotyledon either remains in the seed or emerges following germination.

Monocots (monocotyledons) are plants that produce an embryo with a single cotyledon. Following germination, the embryo produces a coleoptile. A coleoptile is a pointed protective sheath of plant tissue enclosing the emerging embryonic plant in monocots. When the coleoptile reaches the soil's surface, it stops growing and the embryonic leaves (first true leaves) penetrate the top of the coleoptile. Monocots have long narrow leaves with parallel veins, fibrous roots, and the parts of the flowers are arranged in threes or multiples of threes. Wheat, corn, grain sorghum, grasses, onions, tulips, daffodils, and orchids are examples of monocots.

Dicots (dicotyledons) are flowering plants with two cotyledons. The two cotyledons may emerge from the soil when the seed germinates (soybeans) or remain below the surface of the soil (peas). Dicots have broad leaves with branched veins, taproots, and the flower parts are arranged in fours and fives or multiples of fours and fives. Examples of dicots include sunflowers, soybeans, pinto beans, potatoes, tomatoes, peas, and pumpkins.

Stems

Both plants and animals are complex organisms comprised of many types of cells. However, only plant cells contain cellulose, a sugar that gives plant cells thick walls. Cellulose allows plants to stand upright, even though they do not have an internal or external skeleton. About 33 percent of all plant matter is cellulose, even though it varies between plant species. For example, the cellulose content of cotton is 90 percent, while the cellulose content of wood is 50 percent. [3]



Cotton Stem
Credit: Peggy Greb, USDA ARS

The cellulose in the cells of a plant's stem enables the stem to support the plant's leaves and flowers. At the same time, the stem provides a tube-like structure that the plant uses to move water and food from place to place. All stems serve the same primary functions – supplying water and nutrients to the leaves and carrying the sugar manufactured in the leaves to storage in seeds, roots, and stems. A secondary function of stems is to display leaves, flowers, and fruit.

Cucumber Vines (Stems)
Credit: Stephen Ausmus, USDA ARS

Although they serve the same functions, stems vary widely in appearance and traits. Stems may be herbaceous (soft) or woody. Stems may grow above ground or below ground. Stems may also grow horizontally or vertically. There are round stems, square stems, three-sided triangular stems, stems that are somewhat flat, grooved stems, barrel-shaped stems, ball-shaped stems, stems covered with spines, and smooth stems.

Some stems have unique characteristics, such as the waxy layer on the outside of the stems of the big bluestem grass plant. The blue-colored wax helps prevent water loss during the growing season, but as it wears off, the stems appear more brown or red in color. An onion bulb is an example of a flattened underground stem, with scale-like leaf bases surrounding a center bud. The stem and leaves of an onion or garlic plant may not look like those of typical plants, but they have the same cell structure as other stems and function in the same ways.

Onion Bulbs
Credit: Jeff Vanuga, USDA NRCS

Leaves

After germination, the first true leaves of a plant form from the shoot (young stem). Then, as the stem grows, leaves develop at regular intervals around it. In some plants, additional stems develop as branches off the main stem. The arrangement of the leaves on all the stems maximizes the amount of available light reaching the leaves and thus available for photosynthesis.

Soybean Seedlings
Credit: Lynn Betts, USDA NRCS

Growing Wheat Plants
Credit: Julia Debes

Leaves are used to help identify and classify plant species. There are two basic types of leaves: compound and simple. A simple leaf is an undivided leaf. A simple leaf may have indentations, such as those found around the edges of an oak leaf, but those indentations do not reach the center vein of the leaf. Plants belonging to the grass family of plants, including wheat and corn, have simple leaves. Other plants with simple leaves include cotton, sunflowers, pumpkins, apples, and sweet potatoes. In contrast, a compound leaf is subdivided into more than one blade (called leaflets), each with a separate attachment along a vein in the leaf. The entire leaf has a single attachment to the stem. Plants with compound leaves include soybeans, peanuts, potatoes, tomatoes, alfalfa, and black walnut.

Simple Leaf: Corn

Credit: Gene Alexander, USDA

Compound Leaf: Soybean

Credit: M. Nash, National Soybean Research Laboratory

Leaves can be classified in many ways, including the way the leaves are arranged around the stem, the shape of the leaf, whether the veins in the leaf run parallel to each other or radiate out from a central point, and according to distinctions at the edges (margins) of the leaves.

Healthy leaves are critical to photosynthesis. During hot and dry periods, the stomata on the leaves close to conserve water for the plant. If the conditions persist, the plant draws water and nutrients back to the lower leaves, then the stems, and finally, down into the roots – all to ensure the survival of the plant despite harsh conditions. Some plants, including grain sorghum, can temporarily shut down growth and seed production while waiting for precipitation.

Plant Canopy – Soybeans

Credit: Scott Bauer, USDA ARS

The Plant Canopy

The plant canopy is the area of ground covered by a plant's foliage. The plant canopy shades the ground beneath the plant's leaves, suppressing the growth of undesirable plants (weeds). When several plants that are planted near each other grow at a uniform rate, the canopies of the individual plants may fully cover the ground. Referred to as the "closing" of the canopy or "full cover," this creates a microclimate. A microclimate may be warmer, colder, wetter, or drier than other areas around it.

When sunlight is intercepted by the plant canopy and does not reach the ground, the temperature of the soil decreases and the amount of water the soil retains increases. Since undesirable plants (weeds) need sunlight for photosynthesis, those plants are unable to maintain plant health or grow large enough to compete with the desirable plants for the water available from the soil.

> ***Microclimate*** – the climate of a confined space or small geographic area, including the temperature, humidity, wind conditions, and precipitation.

Roots

Once germination is successful, gravity causes one end of the seed's embryo to grow downwards, forming roots. Roots anchor a plant and allow it to remain in one place during its entire life cycle. The roots of vascular plants also absorb water. In vascular plants, tiny root hairs grow into the soil. The root hairs are coated with permeable membranes, allowing water and any nutrients mixed in with the water to be pulled into the roots. The water and nutrients are transferred from the roots to the leaves through the stem.

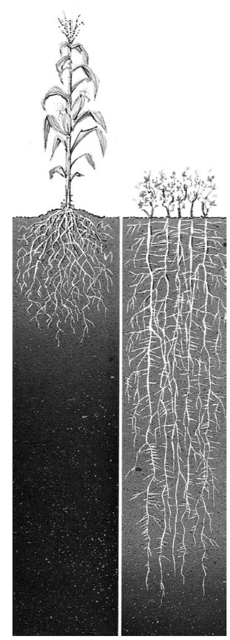
Grass Roots

Credit: USDA ARS

Vascular vs. Non-vascular Plants
Vascular plants, like wheat and corn, absorb water and nutrients through their roots.
Non-vascular plants, like moss, only absorb water through the plant's surfaces.

Plants may be classified according to their root systems. There are two types of root systems: fibrous (branching) and taproot.

A fibrous root system is characterized by many shallow, small, thin branching roots, although the size and number of branching roots vary according to the specific characteristics of the plant species, like its size. Crops like wheat, grain sorghum, and corn have very shallow fibrous root systems. The roots secure the plants in the soil, but because the roots are shallow, those plants may not tolerate extremely dry or cold conditions. In contrast, large trees may have very thick roots that grow deep into



Fibrous Corn Roots (left) vs. Alfalfa Taproots (right)

Source: University of Minnesota Extension Service

Fibrous Roots of Green Bean Plants
Credit: Jack Dykinga, USDA ARS

the soil. The root system of a large tree may branch out far enough that the spread of the root system nearly matches the circumference of the tree's canopy.

The other basic type of root system is a taproot. A taproot is a thick root that often grows directly from the stem. With only a few (if any) branches, a taproot does not hold the soil in place very well. However, because taproots grow deep into the soil, plants with taproots can withstand drier conditions by absorbing water from deeper levels in the soil. Soybeans and sunflowers are both examples of plants that have taproots. In fact, researchers have measured sunflower roots that were growing more than nine feet below the surface of the soil.[4] Some plants, such as carrots, store food in their taproots that can be used to produce new growth. That food is often harvested and consumed by people or by animals before the plant matures and begins the reproduction process.

Many plants produce enlarged roots that store food for the plant, such as the sweet potato, radish, and dandelion plants. These storage organs, known as root tubers, have one end attached to the main (parent) plant.

Taproots of Carrot Plants
Credit: Joe Larson, USDA NRCS

Root Tubers – Sweet Potatoes
Credit: Jo Ann Stoskopf

Sunflowers
Credit: Bruce Fritz, USDA ARS

Flowers

Flowers are a common characteristic of most plants. Many flowers are designed to attract pollinators. However, plant flowers vary greatly, and many do not resemble those found in floral bouquets or blooming in flower gardens. Even so, pollination takes place in the cells of the flowers, enabling plants to reproduce.

Pollination

Pollination, the transfer of pollen, is necessary for a plant or tree to produce seeds and reproduce. In many cases, those seeds provide food for people, such as wheat or rice. Seeds also provide food for animals and other living things, such as corn and grain sorghum used for livestock feed or sunflower seeds eaten by birds. Pollination also affects the quality of that food. For example, lopsided apples are a result of inadequately pollinated blossoms. Cucumbers that are curled and slim, rather than straight and plump, are also a result of poor pollination.

During pollination, the male cells of a flowering plant gain access to the female cells. Once fertilization takes place (the male and female cells unite), the plant can reproduce.

Although some plants and trees do produce flowers of only one sex, most flowers contain both male and female organs designed to encourage cross-pollination. Cross-pollination is the transfer of pollen between flowers on two different plants. It results in stronger and healthier offspring than if the pollen was only transferred from the male and female cells of a single flower or between flowers on the same plant, a process known as self-pollination.

Pollination Words
Pollen – microscopic, powder-like grains produced by the male reproductive organs of a flower.
Pollination – the act of transferring grains of pollen from the male reproductive organ of a flower to the female reproductive organ of a flower.
Pollinator – the transfer agent for pollen.
Cross-pollination – the transfer of pollen between flowers on two different plants.
Self-pollination – the transfer of pollen between the male and female reproductive structures of a single flower or between flowers on the same plant.

Honeybee Collecting Pollen
Credit: Peggy Greb, USDA ARS

Western Meadowlark
Credit: Gary Kramer, USDA NRCS

Alfalfa Leaf Cutting Bee
Credit: Peggy Greb, USDA ARS

Pollinators carry grains of pollen from the male cells of one flower to the female cells of another flower. Some species are pollinated by the wind and some aquatic plants produce pollen that can float along the top of the water, using the water to transfer pollen from one flower to another. However, almost 90 percent of all flowering plants rely on animal pollinators for fertilization. About 200,000 species of animals serve as pollinators, including insects, birds, bats, and small mammals such as mice. [5]

By far, the most important pollinators are insects. The U.S. Department of Agriculture (USDA) estimates that about one-third of the food eaten by people in the United States comes from plants and trees pollinated by insects. Specifically, the USDA estimates that honeybees alone are responsible for 80 percent of that pollination. [6]

Deep-throated Fire Lily
Credit: Scott Bauer, USDA ARS

Many flowers can be pollinated by any insect, but other flowers are designed to attract a specific pollinator. Plants may use color to attract insects, including those that can only see certain colors. Other plants have deep-throated flowers that only certain insects or birds can reach into.

In contrast to flowers, all grasses, including some agricultural crops in the grass family of plants, are pollinated by the wind. The wind also pollinates many trees. These plants produce lightweight pollen in high quantities, because much of the pollen carried by the wind never reaches its intended destination and does not result in pollination.

Developing New Plants

Cereal grains, such as wheat, rice, corn, grain sorghum, and oats, belong to the grass family of plants. Before the 1930s, seeds for these and other agricultural crops were selected from the tallest or most productive stalks with the expectation that the seeds would grow plants producing similar or improved results. However, since plants belonging to the grass family of plants are pollinated by the wind, the seeds selected to grow the next crop carried a wide variety of genetic traits from many different parent plants growing in that crop field. Those seeds never produced plants identical to the plants they were harvested from, making it difficult to improve plant yields or qualities.

Hybrid Seed

In 1930, Roswell Garst formed a partnership with Henry Wallace, a plant geneticist who provided the seed to grow a small crop of hybrid seed corn. By 1945, almost all of the corn grown in the United States was from hybrid seed. Following the successful hybridization of sweet corn, the global hybrid vegetable seed industry expanded after the end of World War II.

Hybrid seed is produced by controlling pollination and allowing only specific genes to be transferred to seed-producing plants. The result is a plant with specific characteristics, which is unable to produce seed for future plants with the same exact characteristics. Therefore, each planting requires the purchase of new seed, chosen for the specific needs of the field in which it is to be planted, the weather, and other natural conditions of that specific growing season.

Hybrid seed produces a crop that grows and matures at a uniform rate. Researchers continue to develop hybrids that are resistant to pests and diseases, tolerate dry conditions, use nutrients more efficiently, and produce higher yields. For example, vegetables like asparagus, carrots, pumpkins, and zucchini are grown from hybrid seed both in home gardens and as commercial agricultural crops. Improved uniformity, superior flavor, and earlier maturity make hybrid vegetable seed desirable. The bedding plant and cut flower industries also need seeds that produce a high percentage of uniform seedlings in order to supply large quantities of plants or flowers that are ready for sale at the same time.

Corn Before Hybrid Seed: County Fair Corn Display, 1916
Source: Library of Congress; Samuel L. Rank, photographer

Corn from Hybrid Seed, 1939
Source: Library of Congress; Arthur Rothstein, photographer

Biotechnology

Traditional plant breeding methods involve painstakingly transferring pollen from selected flowers to other selected flowers, all the while preventing any unwanted transfers of pollen between the flowers or within a single flower. Thousands of genes may be transferred at the same time, and it may take years to isolate the genes responsible for specific traits.

Collecting Potato Pollen
Credit: Stephen Ausmus, USDA ARS

Using Vacuum to Collect Pollen
Credit: Peggy Greb, USDA ARS

Modern technology, however, allows plant breeders to make precise genetic changes and address disease, insect, or environmental challenges more rapidly. Agricultural biotechnology is an advanced technology that allows plant breeders to identify the specific genes responsible for individual traits and transfer only the desired traits between plants. Agricultural biotechnology efforts focused first on increasing pest resistance, disease resistance, and herbicide tolerance (reducing competition for nutrients between crops and weeds). These efforts have allowed significant increases in food production without expanding the acreage devoted to crop production. Researchers are also developing crops that contain enhanced nutrients, are resistant to drought or other environmental conditions, and are allergen-free.

Today, it is estimated that at least 70 percent of the processed foods available in U.S. grocery stores contain at least one ingredient derived from plants enhanced through biotechnology.[7]

K-State Wheat Genomics Lab
Credit: Julia Debes

Gene Mapping
Credit: Scott Bauer, USDA ARS

Foods and plants developed using biotechnology are thoroughly tested and scrutinized before receiving regulatory approval for use. Agricultural biotechnology, the technology used by plant breeders to add beneficial traits to plants, is regulated by three agencies in the United States: the U.S. Department of Agriculture's Animal and Plant Health Inspection Service (APHIS), the Environmental Protection Agency (EPA), and the Food and Drug Administration's Center for Food Safety and Nutrition.

Globally, the adoption of agricultural biotechnology is increasing food production, particularly in areas with less than ideal growing conditions. In 2009, 14 million farmers in 25 countries used agricultural biotechnology. Ninety percent (13 million) of those were resource-poor farmers in developing countries. [8] By increasing resistance to disease, pests, and imperfect growing conditions, biotechnology is protecting plant health around the world.

Healthy Plants

Healthy plants absorb more sunlight, which leads to more photosynthesis and increased productivity. Water is essential to this growth, which is why some plants contain more water than solid matter. According to K-State Research and Extension, water makes up more than 90 percent of the weight of most crops. [9] Much of that water is released into the atmosphere as water vapor through transpiration, a form of evaporation that plays a significant role in the water cycle.

Corn Plant
Credit: Tim McCabe, USDA NRCS

The Water Cycle

Water covers nearly 70 percent of Earth's surface. Although specific locations may experience dramatic fluctuations in water availability, the amount of water in Earth's hydrosphere does not change. In fact, the overall volume of the Earth's water changes very little as water circulates through the hydrosphere in a process known as the "water cycle."

The movement of water around, over, and through Earth is called the water cycle. The water cycle – technically known as the hydrologic cycle – is the continuous circulation of water within Earth's hydrosphere (all the water found on, under, and over the surface of the planet, including water in the atmosphere). As water moves through the water cycle, it changes between liquid, solid, and gas phases.

Planet Earth
Source: NOAA/GFDL

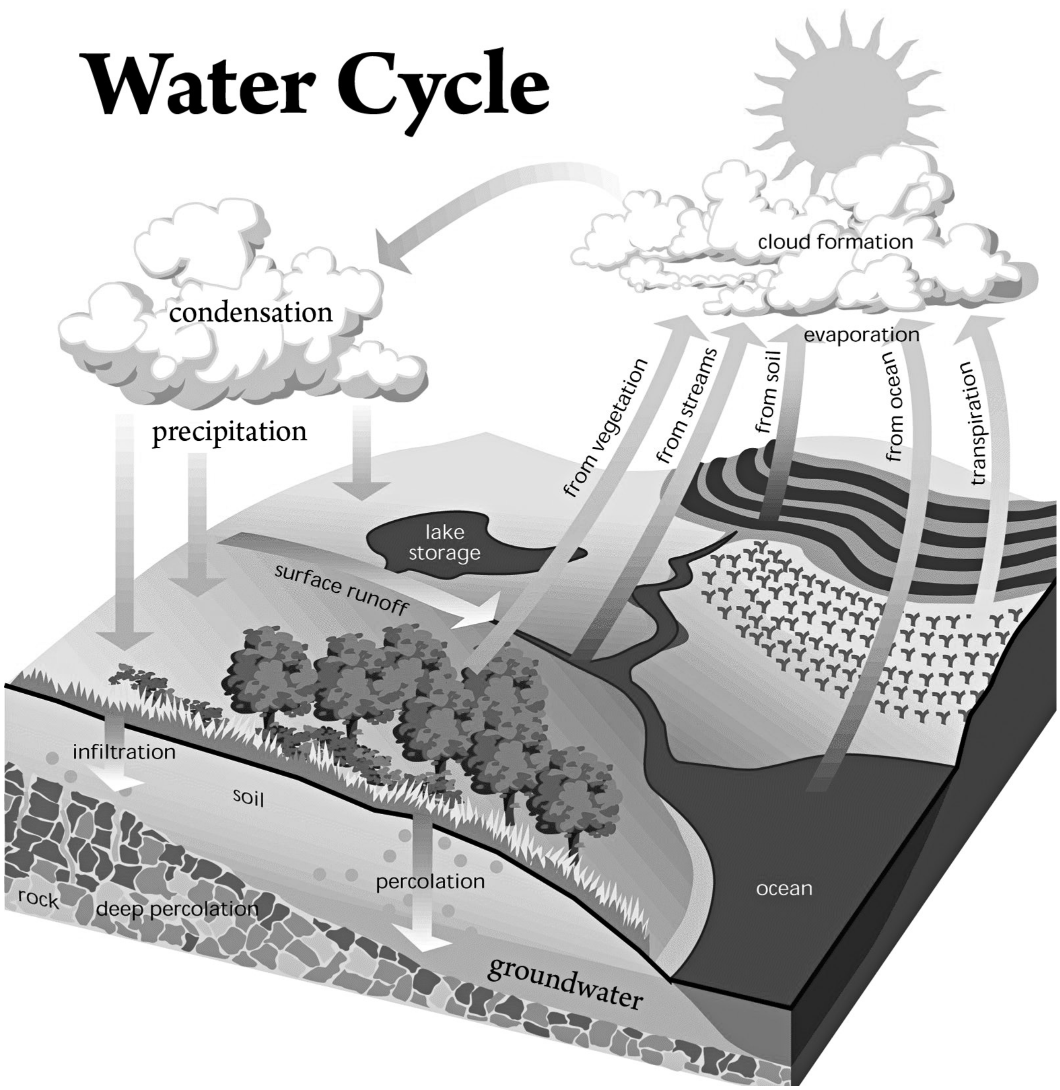
Water moves from one area to another through the physical processes of precipitation, infiltration, evaporation, and condensation. Precipitation is the falling of water in any form (i.e. rain, hail, or snow) to the Earth's surface. Infiltration is the process in which water is absorbed into the soil to become groundwater

Water Words
Hydro – from the ancient Greek prefix meaning "water."
Hydrologic cycle – the continuous circulation of water around, over, and through the earth; also known as the water cycle.
Hydrosphere – portion of the earth's surface that is water; includes atmosphere and underground aquifers.

or flows off the surface of the land, in which case it is called runoff. Evaporation occurs when water is heated and turns into water vapor. Condensation takes place when the water vapor cools and forms clouds, which carry the water and move it to different locations before releasing it in the form of precipitation.

The water cycle is a continuous process without a definable start or finish. Water evaporates from the oceans, forms clouds that precipitate back to Earth, and begins to evaporate again. Water that evaporates from the ocean and falls over land may evaporate, precipitate, become runoff, and condense multiple times before it returns to the ocean.

Water Processes
Percolation – process that occurs when gravity pulls excess water down through the soil and rock layers.
Precipitation – any form of water that falls to the Earth's surface; for example, hail, rain, and snow.
Infiltration – process by which water is absorbed into the soil or runs across the land's surface until it reaches a body of water.
Evaporation – process that occurs when water is heated and turns into water vapor; i.e. changes from liquid to gas state.
Transpiration – the evaporation of water from plants, mainly through leaves.
Condensation – the cooling of water vapor.



Source: FISRWG

Transpiration, a form of evaporation, occurs when plants lose water vapor through the stomata.

Transpiration

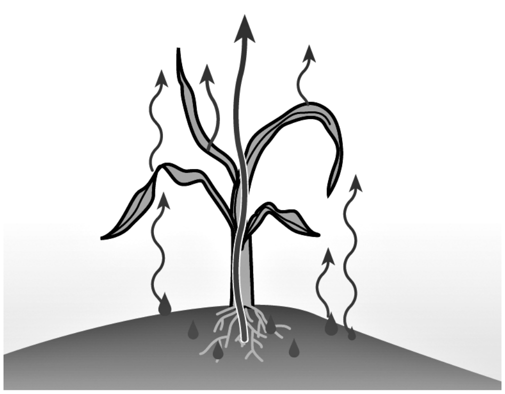
The timing and amounts of water provided to a plant during critical growth and development stages helps determine whether the plant reproduces or produces a crop. Since plants absorb water through their root systems, the water must be available at the same soil depth as the roots are growing, also known as the root zone. Water either soaks down to that level from the soil surface or the roots of a plant pull the water up through the soil layers from below.

Through a chain reaction-type process called transpiration, water is pulled from the soil into the roots of a plant, up through the cells of the plant, and eventually out into the atmosphere through the plant's leaves. Plants transpire more than 99 percent of the water they absorb over their lives. [10] During hot periods, transpiration helps cools the plant, much as a person sweats and the water evaporates and cools the skin.

Heat, sunlight, humidity, and wind affect the rate of transpiration, which is generally highest during the middle of the day and lowest at night. Additionally, transpiration continues only as long as there is an adequate supply of moisture in the soil. Once the water runs out, the plant will begin to wilt. Even if the plant does not die, it may be damaged to the point where it can no longer produce a seed or edible plant materials.

Drought-stunted Soybean Plant
Source: Ron Nichols, USDA NRCS

Evapotranspiration



- **Evapotranspiration is the combination of evaporation and transpiration.**
- **Evaporation is water movement from wet soil and leaf surfaces.**
- **Transpiration is water movement through the plant.**

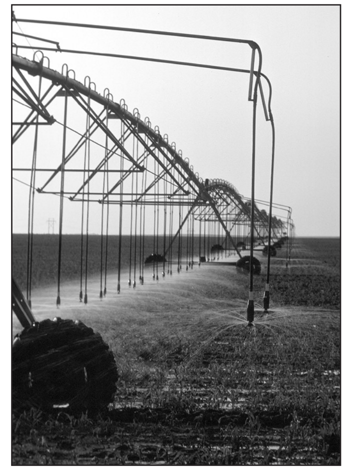
Source: K-State Research and Extension

Evapotranspiration

Evaporation occurs when water is heated and turns into water vapor. Soil acts as a reservoir – gathering, storing, and holding water until it is needed by plants. It is difficult to differentiate between water lost from the soil due to evaporation and water released to the atmosphere through the process of transpiration. The term "evapotranspiration" is often used to describe the combination of these two water processes.

Irrigation

The amount of precipitation, or water that falls in the form of snow or rain, varies greatly across the state of Kansas. For example, the western sections of Greeley, Hamilton, Stanton, and Grant counties receive less than 16 inches of annual precipitation. At the other extreme, the southeastern Kansas counties of Crawford, Labette, and Cherokee receive up to 44 inches of precipitation each year. The level of precipitation determines whether land needs additional water in order to support plant growth.



Center Pivot Irrigation
Credit: Tim McCabe, USDA NRCS

Irrigated Field near Elkhart, Kansas
Credit: USGS

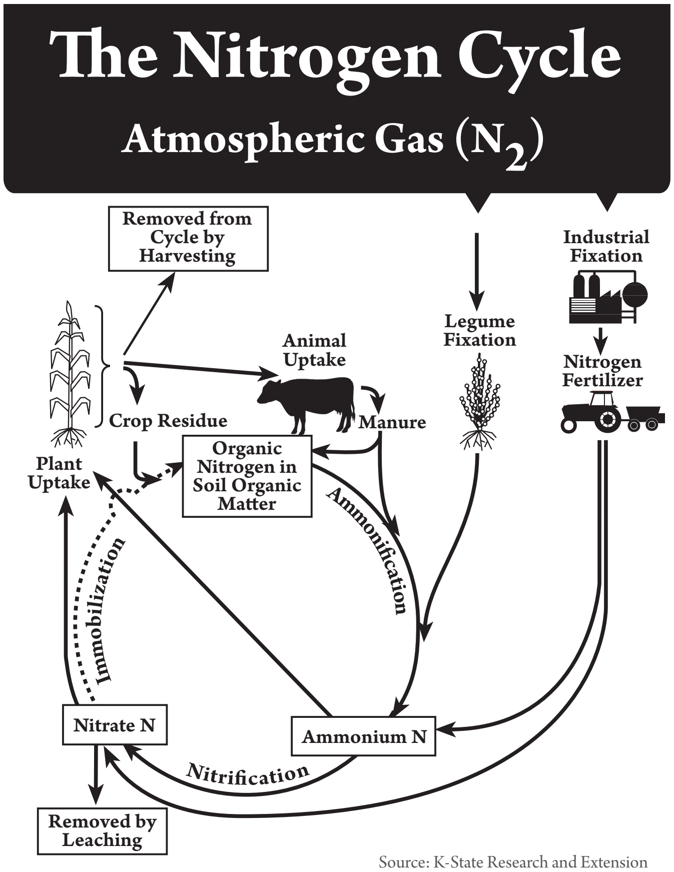
Cropland is classified as irrigated when the precipitation falling on the land is supplemented with other sources of water. The need for irrigation water increases or decreases depending on the amount of rainfall during the crop's growing season and whether the rainfall occurs at the critical stages of growth and development.

Plant Nutrients

In addition to water, there are at least 16 specific nutrients essential for a plant to complete its life cycle. These include nutrients that can be obtained from water and air, such as hydrogen, oxygen, and carbon, as well as nutrients obtained from the soil. Soil tests are used to determine when it is necessary to add nutrients to the soil to sustain or increase crop production. These soil samples are collected and sent to laboratories for chemical analysis to test for nitrogen, phosphorus, potassium, soil pH, and organic matter.

In order, nitrogen, phosphorus, and potassium are the three most critical nutrients for plant growth and development. Plants use nitrogen to manufacture proteins, which are used by plants to grow, develop, and produce seeds.
Additionally, phosphorus or phosphate helps plants utilize the sun's energy for photosynthesis,

Collecting a Soil Sample
Credit: Tim McCabe, USDA NRCS



Source: K-State Research and Extension

grow healthy roots, and fight diseases. Finally, all plants require potassium, commonly referred to as potash, to resist disease and to tolerate drought and extreme temperatures. Potassium also assists some plants in very specific ways. For example, potassium strengthens the stalks in some plants , enhances the size and color of some fruits and vegetables, and increases the oil content of oilseeds.

During transpiration, water carries essential nutrients to the cells of each plant. Over time, however, those nutrients may be removed from the soil through high humidity and rainfall, plant growth, and soil uses. Crop producers use soil test results to determine which nutrients need to be added to the soil to meet the needs of specific crops while minimizing the loss of unused soil nutrients through erosion and evaporation. These nutrients, known as fertilizers, support plant growth and development, just as vitamins support the healthy growth and development of children. Fertilizer is customized according to the needs of specific crops, just as vitamins are designed to meet the needs of specific age groups in people.


Fertilizer Application
Credit: Lynn Betts, USDA NRCS

Soil pH
Soil pH is a measure of soil acidity or alkalinity, which affects a plant's root growth and can limit water absorption.

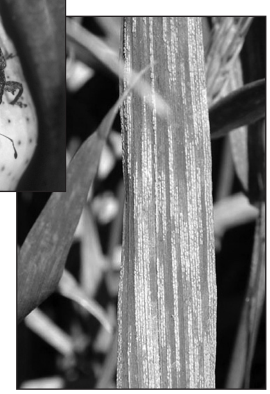

Field Testing for Soil pH
Credit: Tim McCabe, USDA NRCS

Plant Protection

Just like people, plants are vulnerable to attacks from diseases and pests. Writing about his garden, Oliver Wendell Holmes said, "... on every stem, on every leaf, and both sides of it, and at the root of everything that grew, was a professional specialist in the shape of a grub, caterpillar, aphis, or other expert, whose business it was to devour that particular part." [11] Plant products must also be protected after harvest to maintain quality and prevent deterioration during storage, while being transported or processed, and where food products are prepared or sold.

Plant protection products protect human health by contributing to an adequate safe food supply. In crop fields, protection takes many forms, including farming techniques like crop rotation and variety selection. Crop rotation, or growing a planned sequence of different crops, breaks pest life cycles by removing the plants preferred by insects or those susceptible to diseases present in the soil. Variety selection includes choosing crop varieties that are resistant to common pests or diseases. Destroying sources of pest infestation – weeds and plants that grow from seeds dropped during harvesting – eliminates sources that harbor insects and diseases.

Cotton Boll Weevil
Credit: Rob Flynn, USDA ARS



Colorado Potato Beetle
Credit: Scott Bauer, USDA ARS

Stripe Rust Disease on Wheat Leaves
Credit: Yue Jin, USDA ARS

Crop producers closely monitor diseases and insect populations, including those of beneficial insects, carefully weighing the control costs against the benefits before taking actions to protect crops. In addition to protecting healthy plants, crop protection practices and products reduce potential health risks that might arise as a result of insect damage or disease.

Integrated Pest Management – Crops

A pest is any organism that interferes with the production of a crop. Integrated Pest Management (IPM) is a process that determines which actions will be taken to control pests specific to the particular crop, pest, and situation.

The first steps of the process are monitoring for pests and identifying them accurately. The level at which the pests will either become an economic or health threat guides pest management. When pest control measures are deemed necessary, the most economical and effective actions are taken, while minimizing any potential adverse effects.

IPM takes advantage of all appropriate pest management options. Examples of pest control measures in agricultural crops include:

- Cultural - rotating crops
- Mechanical - cultivating weeds
- Biological - releasing beneficial insects
- Genetic - planting pest or disease-resistant varieties
- Chemical - applying herbicides, insecticides, or fungicides

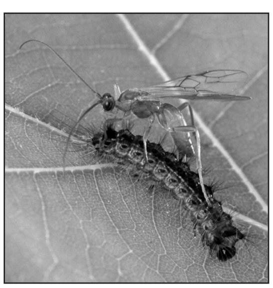
Beneficial Insects

Beneficial insects are insects that feed on or destroy pest species. Agricultural producers and home gardeners carefully monitor insect populations for these natural enemies of pest insects.

Beneficial insects can be categorized broadly as either predators or parasites. Insect predators actively search out and consume several prey insects, both during development and as adults. For example, the lady beetle, commonly called a ladybug, is a beneficial insect that is a predator. In contrast, insect parasites seek out and lay eggs on host insect eggs, larvae, or adult insects. When the eggs of the beneficial insect hatch, the larvae feed on the host insects. As a result, the host insects die. For example, many kinds of wasp are beneficial insects that are parasites.

A commercial insectary produces beneficial insects and offers them for sale. The production, transportation, and importation of beneficial insects is regulated by the Animal and Plant Health Inspection Service of the U. S. Department of Agriculture, as well as state agencies regulating agriculture, natural resources, and environmental protection.

Source: Oklahoma Cooperative Extension Service



Beneficial Wasp
Credit: Scott Bauer, USDA ARS

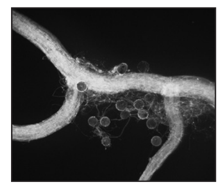
Ladybug Devouring Pea Aphid
Credit: Scott Bauer, USDA ARS

Pesticides

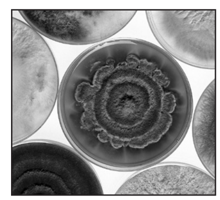
Many crop protection products are regulated as pesticides. According to the U.S. Environmental Protection Agency (EPA), a pesticide is any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest. The EPA regulates the production and use of pesticides in the United States, including common consumer products like insect repellents, flea and tick pet collars, kitchen and bath disinfectants and sanitizers, and cockroach and ant baits.

Specific types of pesticides used to protect agricultural crops include herbicides, insecticides, fungicides, and rodenticides. Herbicides control weeds, or plants growing where they are not wanted. Insecticides control insects, using specific products developed for different life stages like egg, larvae, or adult. Fungi are controlled with fungicides and rodenticides control rodents. In the United States, agricultural uses of pesticides are tightly regulated to protect the safety and quality of the food supply. This includes protecting agricultural products during transportation, storage, processing, and packaging in addition to where food products are sold or consumed. Pesticide management uses a pest-by-pest approach to fit pesticide uses to individual situations, using the least hazardous approach that will provide the necessary protection.

Bacteria on Brussels Sprouts Root Hairs–Microscopic View
Credit: Lisa Gorski, USDA ARS



Fungus on Corn Root–Microscopic View
Credit: Sara Wright, USDA ARS



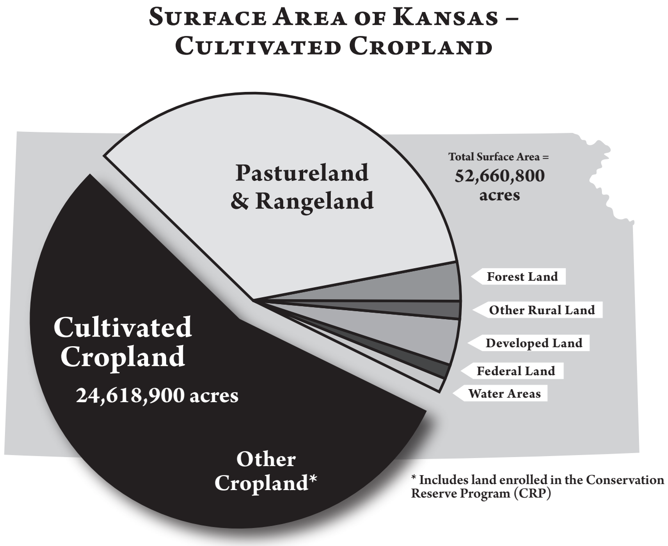
Destructive Mold Cultures
Credit: Scott Bauer, USDA ARS

The use of agricultural biotechnology can speed up the response time to specific threats. By improving genetic resistance to a common insect pest or disease in a plant, agricultural producers who plant the genetically enhanced varieties of that crop reduce or eliminate pesticide controls for those insects or diseases. Scientists have developed several agricultural crop varieties that are resistant to specific herbicide products, allowing crop producers to use those products to effectively kill weeds competing for nutrients while the crop is growing in the field. Herbicide use also allows crop producers to reduce tillage, which in turn conserves water and nutrients in the soil, reduces fuel consumption, and decreases the potential for soil erosion.

Agricultural producers use a combination of pest control tactics that weigh the costs and benefits of economic, human health, environmental, and safety concerns. The proper use of pesticides decreases the associated risks of pesticide use to the level deemed acceptable by the EPA and other regulatory agencies.

Insecticide Application for Alfalfa Weevils
Credit: Anthony Luerman

Herbicide Application
Credit: Bob Nichols, USDA NRCS



Source: 2003 Natural Resources Inventory, USDA NRCS

Growing Kansas Crops

All together, crop production represents the largest land use in the Kansas. About 50 percent of the land in Kansas, around 23 million acres according to Kansas Agricultural Statistics Service, is planted to agricultural crops each year. [12] Today, agricultural producers face many of the same challenges that early settlers faced – erratic rainfall, unpredictable climatic conditions, destructive insects, weeds, and crop diseases. However, advancements in technology, plant breeding, and scientific knowledge give today's crop producers additional tools to compete against these challenges and protect the future of crop production in Kansas.

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Teacher's Resources

The Kansas Foundation for Agriculture in the Classroom (KFAC) offers lesson plans and other educational resources on the KFAC website: **www.ksagclassroom.org**.

Notes: