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| Gateway Schools to Agribusiness |
| Career Pathways into the Cotton Industry |
| Classroom resources  Multiply by dividing  Year 8 Science  January 2013 |

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# Background

This sequence of lessons meets the requirements of the Australian Curriculum in Science Year 8. This is “*multi-cellular organisms contain systems of organs that carry out specialised functions that enable them to survive and reproduce*”.

Students explore how organisms reproduce, starting at a cellular level. They focus on cell structure, function and reproduction.

Students will:

* examine a variety of cells using a light microscope or digital technology
* identify structures within plant and animal cells and describe their function
* distinguish plant cells from animal cells and create representations of each cell type
* discuss examples of cell specialisation
* discuss how cells reproduce
* research and explore the history, use and ethics of reproductive technologies in mammals
* describe the structure of each organ in the human reproductive systems and relate their function to the overall function of the system
* compare and contrast reproductive systems of organisms
* distinguish between asexual and sexual reproduction
* communicate ideas and finding using scientific language

Lessons based on plant structure and physiology have full lesson plans. The symbol ✰ indicates these lessons. The lessons are based on cotton as a plant exemplar.

The lesson sequence is best delivered in Term 1 or 2 of a school year to utilise the life cycle of the cotton plant to best advantage.

A lesson sequence is supplied but this can be modified as required. The lessons have been planned for a 40 minute lesson – schools will need to modify the sequence dependent on the lesson length in each school.

## Further support

Cotton Australia will support teachers in organising visits to cotton farms. Contact Cotton Australia Telephone 02 9669 5222 <http://cottonaustralia.com.au>

Cotton Australia has available a cotton mini-gin to demonstrate processing of cotton fibre. To book, the mini-gin contact Cotton Australia.

If the school wishes to plants cotton as part of these lessons, there are compliance regulations for planting genetically modified cotton under Monsanto, the technology provider. Usually growers have to participate in compliance course and are then able to apply for a Technology User Agreement (TUA). This ensures that the technology is protected under various management strategies. Please contact Cotton Australia directly to organise the process for planting GM cotton.

# Lesson sequence

|  |  |  |
| --- | --- | --- |
| **PHASE** | **LESSON - Plant** | **CONTENT** |
| **ENGAGE** | **Lesson 1✰**  How do animals & plants reproduce? | To capture students’ interest and find out what they think they know about animal & plant reproduction (related to the life cycle of the cotton plant).  To elicit students’ questions about animal & plant reproduction. |
| Contrast sexual & asexual reproduction. |
| **EXPLORE** | **Lesson 2/3✰**  How are plant cells different to animal cells? | Examine a variety of animal and plant cells using a light or digital microscope  Identify specialised cell structures. |
| **Lesson 4/5**  Structure of animal & plant cell | Create a representation of each cell type |
| **Lesson 6**  Cell reproduction | Mitosis |
| **Lesson 7/8/9**  Structure & function of human reproductive system |  |
| **Lesson 10✰**  Flowers and pollination | To provide hands-on, shared experiences of the internal parts of a cotton flower and its role in pollination. |
|  | **Lesson 11✰**  Dissecting cotton fruit | To provide hands-on experiences of the structure of a cotton boll |
|  | **Lesson 12✰**  What’s inside a seed? | Seed dissection  To provide hands-on experiences of the outside and inside appearance of a cotton seed. |
| **EXPLAIN** | **Lesson 13/14/15✰**  Investigating conditions for seed germination.  How do scientists investigate?  How do seeds grow? | To support students to plan and conduct an investigation of the conditions that affect seed germination.  Designing an investigation in a scientific manner.  Conducting investigation |
| **ELABORATE** | **Lesson 16/17✰**  Understanding how science has changed plants. | To introduce current scientific practice on genetic manipulation of cotton. |
| **Lesson 18/19**  Understanding how science has changed animals including human reproduction. | Research the history, use & ethics of reproductive technologies in mammals |
| **EVALUATE** | **Lesson 20/21✰**  Animal & plant reproduction | To provide opportunities for students to represent what they know about the life cycle of cotton and to compare plant reproduction to animal reproduction. |

✰ These lessons have detailed lesson plans available.

# Lesson 1 How do animals & plants reproduce?

* To capture students’ interest and find out what they think they know about animal & plant reproduction (related to the life cycle of the cotton plant).
* To elicit students’ questions about animal & plant reproduction
* Contrast sexual & asexual reproduction.

### What to do

1. As part of a group discussion, ask students to think about what the word ‘reproduction’ means. Ask students questions such as:

* What do we mean by reproduction?
* What types of organisms reproduce?
* How do animals reproduce?
* How do plants reproduce?

1. Explain to students that there are different types of reproduction in animals and plants.
2. Discuss the ways in which asexual and sexual reproduction differ.
3. Complete the worksheet below with students using examples of different reproduction types. Try to include both animal and plant examples.

## Student worksheet: Comparing sexual and asexual reproduction

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Name** | **Asexual or sexual?** | **What happens?** | **Example of organism** | **Advantages** | **Disadvantages** |
| Binary Fission |  |  |  |  |  |
| Fragmentation |  |  |  |  |  |
| Budding |  |  |  |  |  |
| Pollination |  |  |  |  |  |
| Sexual Reproduction |  |  |  |  |  |

Use the diagram below to compare sexual and asexual reproduction.

1. List characteristics about sexual reproduction in the right circle.
2. List the characteriistics of asexual reprodcution in the left circle.
3. Where the two circles overlap, write the characteristics and the two types of reproduction have in common.

### Word wall

Use a word wall to record words about the topic. Ask students what words they would like to place on the word wall from today’s lesson.

A word wall might include a topic title or picture and words which we have seen or heard about the topic. It is an organized collection of words and images displayed in the classroom. It supports the development of vocabulary related to a particular topic and provides a reference for students.

#### Tips on using a Word Wall

Add words gradually, and include images where possible, such as drawings, diagrams or photographs. Build up the number of words on the word wall as students are introduced to the scientific vocabulary of the unit.

Position the word wall so that students have easy access to the words. They need to be able to see, remove and return word cards to the wall, A classroom could have one main word wall and two or three smaller ones, each with a different focus, for example, high- frequency words.

Choose robust material for the word cards. Write or type words on cardboard and perhaps laminate them. Consider covering the wall with felt- type material and backing each word card with a self- fastening dot to make it easy for students to remove and replace word cards.

Word walls do not need to be confined to a wall. Use a portable wall, display screen, shower curtain or window curtain. Consider a cardboard shape that fits with the unit, for example, an animal silhouette for an animal characteristics unit. If students use a different classroom each lesson, the word wall can be recorded on butcher’s paper that can be rolled and moved with each lesson.

Organise the words on the wall in a variety of ways. Place them alphabetically, or put them in word groups or groups suggested by the unit topic.

# Lesson 2 Identify specialised cell structures

* Understand how various cell parts function
* How cell parts are related to the genetic process by creating a model to depict the function of the cell parts.

## Cell City

### You will need

* Diagram of an animal cell with parts labelled.
* Construction paper, yarn, glue, old magazines that can be cut up
* Coloured markers, crayons, scissors
* Two pieces of white butcher paper 1 m3 with a large circle on each

### What to do

1. On one large paper circle, have students think of a city and how it operates. Draw and label figures within the circle that represent key buildings and people that are important for a city to run smoothly. Prompt students with questions like the following: Who protects the city? Where do we get electrical power? Where do we get food? How do you know when you are out of city limits?
2. Display a picture or diagram of an animal cell with its parts labelled.
3. Discuss the fact that each cell part has an important function, just like parts of a city. Explain that some parts of a cell are directly involved in the genetic process, while other parts take a supporting role but are still necessary to the whole cell.
4. Divide the class into small groups, and assign a cell part to each group. Instruct them to research the cell part to determine its function. Challenge them to think of a creative way to depict the function. Example: the cell membrane could be pictured as a gatekeeper, border guard, etc., because it determines what enters and leaves a cell.
5. Have each group cut out, draw, or construct a picture to represent the cell part's function. When each group is finished, have them attach their creation to another three-foot paper circle, which represents a cell, and explain the function and the symbol to the class. Pay special attention to the cell parts' genetic functions.
6. After each group has attached its part to the large cell diagram, have all the students enter the cell parts and their definitions in their science journal and add to the word Wall.

### Discussion Questions

1. What do you think would happen to a cell if (name the cell part) were missing or not functioning properly?
2. How is a cell like a city?
3. What do you think is the most important part of a cell? Why?
4. Why do you think we used analogies in this lesson to learn about the different parts of cells? Was it helpful?
5. A cell is microscopic, much smaller than what we can see with the naked eye. Are you surprised that so much happens in a cell, despite its size?

# Lesson 3 How are plant cells different to animal cells?

* Examine a variety of animal and plant cells using a light or digital microscope

### Background

Hold up an egg and a picture of abacterium. Ask students what they have in common. They should guess that both are cells.

Discuss the differences and similarities between the cells. Focus on the differences found in eukaryotic cells, especially the major differences between plant and animal cells.

### You will need

* Access to the internet or microscopes

Use a website such as Cells Alive <http://www.cellsalive.com/cells/cell_model.htm> with animated models of animal and plant cells

OR

Use microscopes with prepared slides of basic animal and plant cells in conjunction with labelled diagrams of animal and plant cells.

* Cards and string (approx 3-4 m)

### What to do

1. Students identify the organelles in each cell type through the internet or microscope.
2. Students write organelle names on cards for both the animal and plant cell.
3. Using string and name cards, each group creates a Venn diagram with Animal Cell on one side and Plant Cell on the other. Common organelles are placed in the common area of the Venn diagram.
4. Students draw the Venn diagram into their Science Journal.

# Lesson 10 Flowers and pollination

* To provide hands-on, shared experiences of the internal parts of a cotton flower and its role in pollination.
* To provide hands-on experiences of cotton fruit.

## Student Worksheet: Flower dissection

Today you will examine the intricate structures that make up a flower.

### Background

Flowering is important to cotton production because pollinated flowers form cotton bolls. A cotton plant typically blooms or flowers for about 6 weeks.

The bloom process takes several days. On the day the flower opens, it is white in colour. On the second day, the flower will have a pink-like colour and a red colour on the third day. Approximately 5 to 7 days after a flower appears, it usually dries and falls from the plant exposing the developing boll.

Pollination of that flower usually occurs within a few hours after the white flower opens.

There are several developmental stages of the cotton flower bud that takes 21 days from square to bloom. A “pinhead” square is the first stage at which the square can be identified. The next stage of square growth is “match-head” or “one-third grown” square. Just prior to the time the flower opens, a candle shape can be seen (Figure 15d). This period of square development prior to bloom is called “squaring.”

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-15.jpg |
| Figure 1 Development of the bud from match head square (a) to flower (e) involves both a size increase and petal development. |

Many single flowers have both the male and the female sex organs surrounded by **petals**. The egg and the pollen (sperm) are contained in the same flower.

Flowers may **self-fertilize** if pollen from a flower is transferred to egg cells in the same flower, or they may **cross-fertilize**. Carried on the wind or by other means, pollen grains from other flowers may land on the sexual organs of a flower and fertilize it.

Can you think of other ways that cross-fertilization of flowers might happen (besides by the wind)?

The various parts of the flower help with the transfer of the pollen to the egg. There are typically four rings of structures in flowers, from outside to inside they are:

* sepals
* petals
* stamens
* carpels

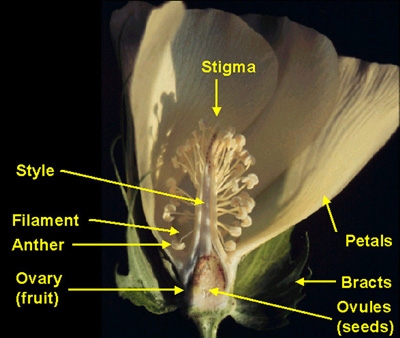


Figure 2: Cross-section of a cotton flower

### You will need

* 1-2 cotton flowers
* Hand lens
* Scalpel
* Cutting board
* Forceps
* Probe

### What to do

1. Examine the cotton flower, using the diagram in Figure 2 as a reference.
2. Look for the **sepals** of your flower. The sepals are typically on the outside of the flower, often green. The sepals protect the bud before it opens.
3. The **petals** compose the next "ring" of flower structures. You can think of petals as modified leaves. Examine the texture and colour of the petals using the hand lens.

Why do you suppose the petals of flowers are so colourful, fragrant, uniquely shaped?

1. The structures inside of a flower produce the eggs and pollen. The male reproductive structures of the flower, called **stamens**, may be T-shaped, collared, straight or gently curved. They consist of an **anther** supported by a **filament**.
2. Carefully pull back the petals of the flower to expose the stamens. If necessary, use the scalpel to help expose the internal structures.

How many stamens do you see in your flower?

1. The stamens each have an anther at the top of the filament shaft. Pollen grains are released from the anther. Each stamen will produce hundreds of pollen grains. Contained inside of each pollen grain there are two sperm.
2. Examine the anther using the lens and touch the tip of your finger to the anther.

Did any pollen rub off on your finger?

1. Making up the innermost ring of structures is the carpel. A **carpel** (see Figure 3) is a floral structure enclosing an egg and is divided into ovary, style, and stigma. A flower may have one or more carpels, either single or fused. (A single carpel or a group of fused carpels is also known as a pistil).

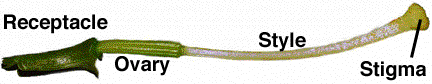


Figure 3: A carpel

1. To see the carpel clearly, gently separate the flower from the green sepals and base. The stamens will usually stay with the flower petals and the carpel remains attached to the base.
2. Cut open the carpel to see the **ovary**. The ovary contains the **eggs**.

Why do you think the stigma is sticky?

1. Once a pollen grain has become stuck onto a stigma, it begins to grow a tube through which the sperm nuclei travel down to the ovary. There, the sperm nuclei from the pollen unite with the egg cells to produce a **zygote**.

List three ways that the male organs of the flower are different from the female organs of the flower.

What part of the flower becomes the seed? What part of the flower becomes the fruit?

# Lesson 11 What’s inside a fruit?

* To provide hands-on experiences of the structure of a cotton boll.

### Background

When the plant sheds its flower, the fertilized egg develops into a seed. The **ovary wall** surrounding the seed often develops into a **fruit**.

After a cotton flower is pollinated, the **boll** begins to develop. Under optimum conditions it requires approximately 50 days for a boll to “open” after pollination occurs. Boll development can be characterized by three phases: enlargement, filling, and maturation.

The enlargement phase of boll development lasts approximately 3 weeks. During this time the fibres produced on the seed are elongating. Also during this time, the fibre is basically a thin walled tubular structure, similar to a straw. During the boll enlargement and fibre elongation phase, the development of the fibre is very sensitive to adverse environmental conditions. Low water availability, extremes in temperature and nutrient deficiencies can reduce the final fibre length.

The filling phase of boll development begins during the fourth week after flowering (Figure 1). At this time, fibre elongation ceases and secondary wall formation of the fibre begins. This process is also known as *fibre filling*.

The deposition of cellulose into the fibre cell is also sensitive to environmental conditions. The filling phase of boll development continues into the sixth week after pollination.

The boll maturation phase begins as the boll reaches its full size and maximum weight. The walls of the boll dry and the carpel walls split, and the boll opens.

|  |
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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-21.jpg |
| **Figure 1. Development of the cotton boll** |

### What you need

* Cotton bolls at different stages
* Whole cotton plant
* Digital scales
* Hand lens
* Scalpel
* Cutting board
* Forceps
* Probe

### What to do

1. Look at the cotton bolls to see the remnants of a flower. At the base of the fruit, notice any tiny withered sepals. If you pull back the edges of the sepal, you may be able to make out the remains of the stigmas and the styles. (You may need to use your hand lens to see this.)
2. Using the scalpel, cut open the fruit crosswise. Look at the "core." Inside, you will see the seeds. The ovary walls are the tough structures which separate the core from the receptacle.

What is the primary function of fruits?

Why do you think some plants put so much energy into synthesizing sugars and carbohydrates to put into fruits?

The contribution of a single boll to the yield of the cotton plant depends largely upon its position on the plant. First position bolls are heavier and produced in higher quantities than bolls at any other position.

1. Look at the whole cotton plant. Draw a line diagram line the one below.
2. Mark the main branches and the position of the bolls.

Where are most of the bolls on the plant?

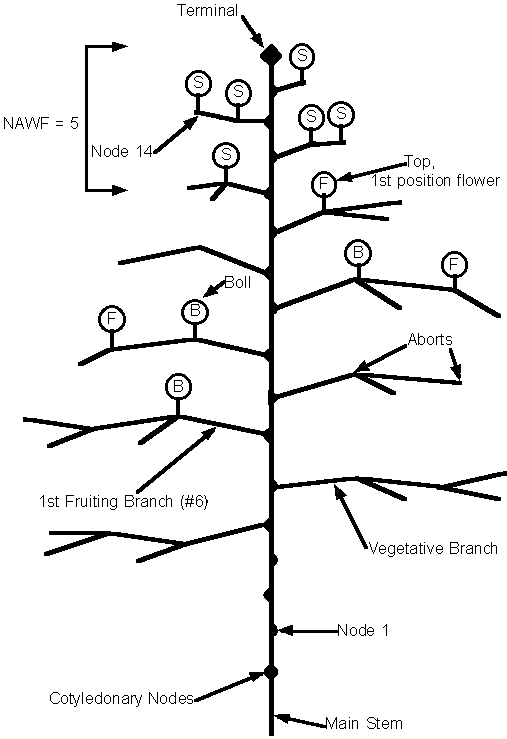
1. Remove the bolls and weigh them individually. Record the position and weight of each boll in a table.

Where are the largest bolls located on the plant?

Why do you think this is?

1. Graph the boll weight against position on the plant.

### Line diagram of cotton plant



# Lesson 12 What’s inside a seed?

### Background

* To provide hands-on experiences of the structure of a cotton seed.

A mature cotton seed contains all of the organs necessary to produce a small seedling. The seed is pointed on one end (the *micropyle*) and rounded on the other (the *chalaza*). The tip of the primary root, or *radicle,* faces the micropyle, and the precursors of the stem and cotyledons are plainly visible within the seed (Figure 1).

|  |
| --- |
| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-1.jpg |
| **Figure 1. A small, dormant seedling rests inside a mature seed. When the seedling emerges, the radicle will be the primary root, the hypocotyl will be the stem under the cotyledons, and the epicotyl will be the stem above the cotyledons from which shoot growth occurs.** |

The chalaza is the primary site of water and oxygen absorption during germination. The tip of the primary root, or radicle, is the first part of the plant to emerge through the micropyle. The cotyledons that will nourish the new seedling are folded inside the seed, with the hypocotyl below them ready to elongate and push the seedling through the soil. The *gossypol glands* visible throughout the inside of the seed are also visible in the tissues of the growing plant.

### What to do

Show students a container of cotton seeds that have been soaked in water overnight.

Students take two seeds and place them on paper towels in their work space. Instruct them to investigate one of the seeds. They may use their hands or tweezers, toothpicks, hand lens etc.).

Encourage the use of process skills by asking students to observe size, shape, number of parts, textures, etc. Ask students to record observations in appropriate ways and to draw a diagram of the parts of a seed and label it. (See picture of the seed.)

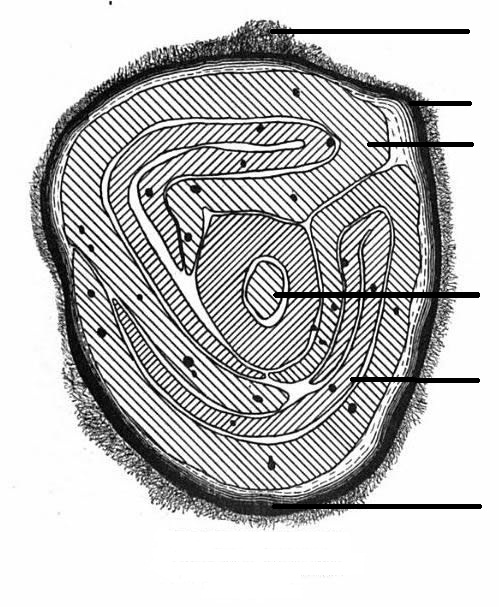
Ask students to:

* Describe and draw what you see.
* What clues does this seed give you about its growth?
* Instruct students to look for different parts when dissecting the seed and hypothesize their purpose.
* Students should complete the worksheet below.
* Instruct students to hypothesize as to the needs of the seed in order to germinate. (water, soil or other medium to hold moisture, warm temperature)
* Ask students how they might test their hypotheses.

Would the same be true for all seeds?

## Student worksheet: Cross-section of a cotton seed

Label the parts of the cotton seed with the terms form the table below.



|  |  |
| --- | --- |
| **Seed part** | **Function** |
| Seed coat |  |
| Embryo |  |
| Oil glands |  |
| Micropyle |  |
| Lint |  |
| Gossypol gland |  |

# Lesson 13/14/15 Investigating conditions for seed germination

* To increase student understanding of how scientists investigate through the Scientific Method
* Plan and conduct an investigation of the conditions that affect seed germination in a scientific manner.

Students are to design an experimental to test their hypotheses about the requirements for seed germination.

Start with a discussion about the different variables that affect seed germination. The topics might include the amount of water, sunlight, planting depth, type of soil, temperature of the environment and temperature of the water used on the seeds.

The students work in small groups to develop and carry out an experiment based on one of the seed germination variables.

At the end of the project, each group shares its results with the class to compile a collection of general seed germination knowledge.

## The Scientific Method

Students need to understand the scientific method to plan and conduct their experiment with a six step process.

1. Problem – What are you trying to figure out? Write this in the form of a question.
2. Hypothesis – What do you think you are going to find out?
3. Materials – List the materials you will use in the experiment.
4. Procedures – Make a detailed list of the steps in your experiment.
5. Results – What did you observe when you performed the experiment?
6. Conclusion – From what you observed, how would you answer your original question?

Scientific investigations involve ensuring that each experiment is a Fair Test. It involves variables that can be changes, measured, observed and controlled (kept the same).

* Change one thing – the independent variable
* Measure and observe one variable – the dependent variable
* Keep the other variables the same – the controlled variables

Allow students to set up and conduct experiments to test hypotheses formed during the first activity. Students should research their hypotheses through research in texts or web.

Have them gather needed resources (materials to test needs of seeds) and follow through with experimental activities.

Require students to journal findings of all experiments stating whether hypotheses were proven or disproved.

### What you need

Have a range of materials available to students. These should include:

* Potting mix
* Gelatine (See note)
* Clear plastic cups
* Distilled water
* Liquid plant food eg Aquasol
* Dilute hydrogen peroxide
* Potassium nitrate fertiliser
* Fish emulsion
* Sticky tape
* Marking pens

Note:

You may like to have students plant their seeds into gelatin, rather than soil. Clear gelatin makes an ideal growing medium for seed germination activities. The students can view the entire process, unlike planting seeds in soil which is only visible after the plant pushes up above the surface.

Make up the gelatin as normal and pour into a clear container. Allow to set. Press the plant seed about one-half inch below the gelatin's surface. The students observe and document the seed's changes each day.

### What to do

Use the following questions to stimulate student thinking about their experimental design:

* What happens if you plant the seeds deeper or shallower?
* What happens if you add more or less water?
* What will this environment cause the seeds to do?
* What factors are present that will enable the seeds to germinate and grow?
* Which seed do you predict will germinate first, second, last? Why?
* Does the amount of sunlight affect germination?
* Does stratification (breaking the seed coat) affect germination rate?
* Which soaking solution would germinate seeds most effectively?
* Does freezing for various intervals affect germination rate?
* What temperature is ideal for germination of cotton seeds?
* Do nutrients affect seed germination?
* What is the relationship between the size of a seed and its ideal planting depth?

# Lesson 16/17 Insect resistant cotton

* To research and explore the history, use and ethics of technologies
* Communicate ideas and finding using scientific language

### Background

A major insect pest of the cotton plant is the cotton boll weevil. The US company Monsanto has developed a variety of cotton with built-in resistance to the boll weevil, and other scientists are researching the use of viruses and venoms to kill cotton pests.

Australia's worst cotton pest is *Helicoverpa armigera*, a type of cotton bollworm. Cotton is eaten by this grub or caterpillar, which is an insect larva. The adult is a moth that lays its eggs on cotton plants. When the larva hatches it starts eating the food that its mother has provided for it. The grub then burrows into the cotton seed pod (boll) to find more food, thus damaging the cotton. Because of this it is called the cotton bollworm or cotton boll weevil.

When the larvae have grown, they crawl down the stem of the plant into the soil. Here they turn into pupae, inside a hard case. The pupae metamorphose (change) into the adult moth stage in the soil. Four or five generations of these moths can be produced each year.

### Activities

1. How to engineer cotton
2. People do not agree about genetic engineering of crops
3. Looking at media views - GM crops

These activities are available from the *Biotechnology Online* Secondary School Resource. <http://www.biotechnologyonline.gov.au/biotechnologyonline/migration.html>

## Student Worksheet: How to engineer cotton

The process of modifying the genes of an organism nearly always involves a common set of steps:

* a feature to be introduced into an organism is identified;
* a gene that controls the identified feature is located;
* the gene that controls the new feature is isolated and made ready for insertion into a new cell;
* the new gene is put into the DNA of cells of the organism to be changed; and
* the genetically modified cells are cultured

A gene that produces an insecticide exists in *Bacillus thuringiensis*, a soil bacterium. The gene is usually referred to as the Bt gene.

At the end of this activity you will:

* know that cotton has been genetically modified to produce an insecticide;
* understand the steps that scientists usually follow to produce genetically engineered cotton

### You will need

* access to the internet
* access to the information on cotton from *Biotechnology online*

<http://www.biotechnologyonline.gov.au/biotechnologyonline/migration.html>

### What to do:

1. Work with a partner.
2. Research the use of Bacillus thuringiensis as a source of an insecticide gene. Summarise the process that is used to:

* cut the Bt gene from the bacterial cell;
* implant the gene into cotton cells; and
* grow the cotton cells into mature plants

1. Display your information as a flow chart. These charts consist of:

* a box for each stage of the process where an action take place;
* arrows that connect each box indicating the direction of the process; and
* input and output boxes, connected with the arrows between the process steps, that show anything that is added to or removed from the process

1. Preparing a flow chart

* You might find it useful to write each step, input and output onto small rectangles of paper and to position these until the steps are in the correct order.
* Draw up the flow chart using a word processing package using text boxes and arrows.

Here is an example:



Useful resources

CSIRO - Gene Technology: How is it done? http://genetech.csiro.au/how2.htm

CSIRO - Current research <http://genetech.csiro.au/research/index.htm>

## Student Worksheet: People do not agree about genetic engineering of crops

People are concerned about some issues related to genetically modified crops. These range from whether or not genetic modification of living things should take place at all, to whether the promise of genetic modification to feed the increasing population of the world is achievable.

At the end of this activity you will:

* understand some of the issues about genetically modified crops that concern Australians;
* clarify your own values on some or all of the issues involved

### You will need:

* access to the internet
* information on canola from Biochemistry online

### What to do:

1. Work in a small group of 6 people.
2. Each person selects one of the resource articles listed below in 'Resources' and reads it.
3. Each person then takes 2 minutes or less to explain to the other members of the group what the article says. No questions should be asked at this time.
4. When all articles have been explained, each person has an opportunity to ask up to two questions about any of the articles.
5. Think about what your group has read and ask yourself whether you are not concerned, mildly concerned or very concerned about genetic engineering of crops.
6. The information you have read could be used as source material for a debate.

Possible topics for the debate include statements that:

* genetic engineering techniques have revolutionised Australian agriculture for the good;
* genetically engineered crops are dangerous to the Australian environment;
* genetically engineered food is safe to eat;
* genetically engineered crops will produce food more cheaply; and
* butterflies win over boll weevils any day

Resources:

Monsanto Statement on Bt Corn: Environmental Safety and a Recent Report on the Monarch Butterfly http://www.biotech-info.net/monsanto\_on\_btcorn.html

Managing Bt resistance http://genetech.csiro.au/research/cotton/fitt\_bt\_final\_short.htm

Risk Research: Transgenic Insect-Resistant Crops Harm Beneficial Insects http://www.biotech-info.net/beneficials2.html

Cotton with built-in pest protection http://genetech.csiro.au/research/cotton/cotton\_with\_build\_short.htm

Natural pesticides http://genetech.csiro.au/research/cotton/akhurst\_bt\_final\_short.htm

The science of gene technology: benefits and risks http://genetech.csiro.au/debate.htm

Gene Technology: community views for and against http://genetech.csiro.au/debate2.htm

## Student Worksheet: Looking at media views - GM crops

Many stories and many points of view are presented to us in media stories. Is the information presented scientifically accurate and complete? Is the point of view being expressed biased or designed to persuade the reader to a particular point of view? What should we look for in order to answer these questions?

In this activity you will work in groups and individually to analyse three newspaper stories about impacts of genetically modified organisms on the environment. The articles and your discussions will allow you to come to some personal conclusion about the answer to the question ‘Are genetically modified organisms good or bad for the environment?’

### You will need

* the three newspaper articles provided with this activity sheet; and
* access to newspaper or magazine articles or the TV news for a few days

(Your teacher may provide some newspaper or magazine clippings or video clips.)

### What to do

Work in a group.

1. Read each of the articles and summarise in one or two sentences the main arguments. Is the person being quoted for or against gene technology?
2. Under a heading of FOR or AGAINST or NEUTRAL put your group's summary for each article on a display board with those of the other groups in the class.
3. With each group taking a different article:

* Make a list of which of the points in the article is fact and which is an opinion. Is it hard to tell the difference?
* Decide who would benefit most if the point of view presented in the article was accepted by the public. Does this mean that the person quoted would benefit?
* Decide whether you feel the people being quoted are telling the full story, part of the story or just giving their points of view.

1. Select a member of your group to present your conclusions to the class.
2. Having listened to all the group reports, decide on your answer to the question ‘Are genetically modified organisms safe?’ and write an answer in the form of a press release that quotes you as a member of the public. You may combine points from two or more of the articles you have read so as to give a more balanced view or you may write a completely new article.
3. Investigate newspapers, magazines, TV news or the internet for a story about GM organisms and the environment. Analyse the story to decide whether it is balanced or if there is a possible vested interest behind opinions being put forward. Look for facts, opinions, who will benefit if the point of view presented is accepted, and whether the complete story is being presented. Write a report on the story.

### The media stories

Story 1

**We need to know more about biotechnology**

While we have made rapid advances in gene technology we need to be cautious about how quickly we adopt it, in case we accidentally cause irreparable damage to the environment.

This is the opinion of Dr David Dempster of the Cooperative Research Centre for environmental management of biotechnology, located at the University of the Tablelands.

Dr Dempster said, ‘While we see many benefits from genetically modified crops and animals, there is so much more we don't know. We need to slow down our adoption of this technology while we undertake thorough studies of the possible impacts on the environment.’

He also said, ‘These studies have to be large scale and very thorough. For instance there are studies that show that genetically modified corn in the USA was killing monarch butterflies, and other studies that showed that it wasn't harming them at all.’

‘The Australian environment is very sensitive and we might discover that some genetically modified organisms have a bigger adverse impact here than they might in Europe or North America.’

Dr Dempster said he did not support a moratorium on the introduction of GMOs, but advocated using the 'precautionary principle' in making risk-benefit analysis of their introduction.

‘The technology is very new and we have no real long-term data on possible impacts upon the environment,’ he said.

Story 2

**Call for ten-year moratorium on GM organisms**

Genetically modified organisms are a threat to Australia's fragile ecosystem and we should have a ten-year moratorium on all GMOs, according to Mr Simon Simpkins of the Green Zone Alliance.

Speaking at a public rally in Brisbane today, Mr Simpkins said that Australia should become a GM - free nation, and should only grow organic foods.

‘Scientists tell us the technology is safe, but they also told us that nuclear power was safe,’ he said.

‘GMOs can easily breed into superweeds which will take over the country, and we might also see superbugs, which have the potential to devastate life on our planet,’ he said.

He also said that as the technology was controlled by multinational companies, they were forcing Australian farmers to become reliant on growing GM crops and buying pesticides from the same companies to spray onto those crops.

‘We need to stand up to these forces and demand a ten-year moratorium to protect ourselves and our environment,’ he said.

Story 3

**GM organisms - good for the environment**

Genetically modified organisms will be good for the environment, according to Dr Dianne Millward, the Executive Director of the US-based Biotechnology Alliance.

Speaking in Melbourne yesterday, Dr Millward said that use of genetically engineered crops was already leading to decreases in pesticides and herbicides world-wide, which was good for the environment.

‘Surveys show that consumers are more concerned about pesticides than they are about GM foods,’ she said.

She also said that biotechnology could also be used to eliminate pests, develop plants that could grow in drought conditions and even clean up oil spills.

‘This is a good and natural technology for our planet,’ she said, ‘and it is important that anti-biotechnology groups don't scare people away from its benefits.’

‘Without the introduction of biotechnology solutions we are going to see increased damage done to our waterways, more land clearance to feed the growing population and more species becoming extinct,’ she said.

The Biotechnology Alliance, which is co-funded by industry groups and university research institutes, seeks to provide more information on biotechnology to the public.

# Lesson 20/21 Similarities and differences

* To provide opportunities for students to represent what they know about the life cycle of cotton
* Compare plant reproduction to animal reproduction
* Assist students to consolidate the learning of the unit.

### Background

The most important thing an animal can do in its lifetime, at least in terms of evolution, is reproduce. An individual, regardless of how long it lives, contributes nothing to the evolution of its species unless it passes its genes on to the next generation.

Organisms reproduce in a wide variety of ways. Some reproduce asexually, producing offspring that are genetically identical to themselves. Many plants, including strawberry plants reproduce this way at least some of the time. Many single-celled organisms also reproduce identical copies of themselves by replicating their DNA and then dividing in half -- a process called binary fission. Only when a mutation occurs in the replication process does an offspring differ genetically from its parent.

Other organisms, including humans and the cotton plant produce offspring by sexual reproduction. During sexual reproduction, organisms divide their genetic material in half and then combine their half-set of genes with the half-set of another individual of the same species. This method, however, requires some effort on the part of the individual. After all, finding a suitable mate can be a time-consuming process.

Furthermore, where the objective is to pass the maximum number of genes on to the next generation, it seems that sexual organisms get a smaller return from their investment than do asexual organisms. So if sexual reproduction is such an arduous and inefficient process, why do organisms bother?

Scientists often refer to sex as a biological tradeoff. On one hand, the genes of a sexually reproducing organism are, in a sense, diluted: Each parent passes on only half of its genes to its offspring. On the other hand, the genetic mixing that results from sex ensures that each generation will be different from the previous generation and that individuals of the same generation will be sufficiently different from one another.

This genetic variation provides an important evolutionary advantage: It gives species (not individuals) the ability to evolve more quickly in response to challenging and constantly changing environmental conditions. This is because natural selection, the process that drives evolution, acts on genetic variation within a population. Stated simply, in a highly varied population under a given set of conditions, some individuals will have an advantage relative to others in the population. They will pass more of their genes on to the next generation and will have a greater effect on shaping the genome of the species than will others in the population. In populations with little genetic variation, no individual has much survival or reproductive advantage over any other individual. Thus, evolution moves much more slowly.

Animals follow a life cycle similar to plants. Reproduction followed by a new organism's growth and maturation and eventual reproduction create the life cycle of animals. Animals are born from eggs or carried in a womb and born vaginally. Once born, animals must survive infancy and mature to an adult form before being to create another generation of animals. Animals, such as flies and insects, live for brief periods while others, such as mammals, live much longer. Some species of turtle can live for hundreds of years.

Animal reproduction is often very different from plants. While plants are fertilized by external forces like wind and animals, animals must copulate in order to reproduce. If a viable fetus is created, the female animal gives birth to the infant and the animals care for the offspring until it reaches maturity. Once animals are able to fend for themselves, they seek out their own sources of food and find mates to continue the life cycle.

The life cycles of plants and animals are often related. Plants and animals reproduce most commonly in the springtime, when food is abundant. Although there are many variations on the basic life cycle of plants and animals, the similarities create relationships between both types of organism. Plants are often heavily dependent on animals for their own reproduction, and animals could not live to maturity without feeding on plants or other organisms.

### What to do

Form students into groups of 4 to 5. Each group will consider the same series of questions that reflect on plant and animal reproduction.

Ask:

* What is the result of reproduction?
* Why do organisms bother to reproduce? Why don't they just live forever?
* What would eventually happen to a species if every member suddenly lost its ability to reproduce?

Students discuss these questions in their group in a series of stages:

* Ask students to have an open discussion or brainstorm of their thoughts.
* Each person writes one thought on a sticky note that they place on a blank wall (or other space).
* This process continues until the group feels that they have exhausted their individual ideas.
* Now, the group needs to group its ideas around the three questions above.

At this stage, stop the discussion and remind students that, although they may have a lot of ideas, they need to consider the evidence for the idea.

* This means they have:
* A claim or idea
* Evidence for each claim
* A reason for how the evidence supports the claim

The group returns to its consideration of their ideas with encouragement to move from claims only to develop a series of claims, evidence and the reasons.

After choosing their main ideas, the evidence and reasons is written on sticky notes next to the ideas.

Remind students that there can be more than one piece of evidence for an idea and the reasons can vary.

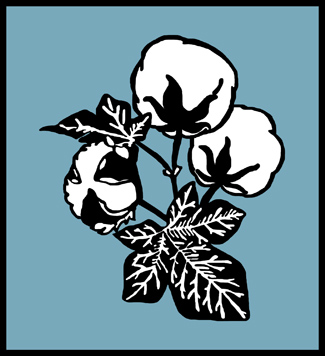
The final position for each group can be presented in many ways – some of these are:

* Oral presentation
* Ideas wall
* Posters
* Videos
* Powerpoint

# Appendix 1 Cotton Growth and Development

Cooperative Extension Service  
The University of Georgia College of Agricultural and Environmental Sciences

Bulletin 1253/September, 2004



[Introduction](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Introduction)  
[Inside the Seed](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Inside)  
[Germination and Seedling Development](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Germination)  
[The Cotyledons and First True Leaves](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Cotyledons)  
[Soil Effects on Germination and Early Root Growth](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Soil)  
[Root Development](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Root)  
[The Meristems](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Meristems)  
[Vegetative Growth](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Vegetative)  
[Leaf and Canopy Development](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Leaf)  
[The Source to Sink Relationship](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Source)  
[Development of Fruiting and Vegetative Branches](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Fruiting)  
[Formation of the Cotton Bud from Square to Bloom](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Bud)  
[The Cotton Flower](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Flower)  
[Stages of Flowering](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Stages)  
[Nodes above White Flower and Cutout](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Nodes)  
[Defoliation and Harvest Timing](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Defoliation)  
[Fruit Shedding](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Shedding)  
[Boll Development](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Boll)  
[Yield Distribution](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Yield)  
[Heat Units or DD60s](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Heat)  
[Summary](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#Summary)  
[References](http://www.soilcropandmore.info/crops/CottonInformation/B1252/b1252.htm#References)

#### Introduction

Domestic cotton has a unique origin and history among cultivated crops. The wild ancestors of modern cotton species were perennial vines that inhabited several distinct geographic areas, including Africa, Arabia, Australia and Mesoamerica. During the past several centuries, people native to these regions developed four distinct species of cultivated cotton, including upland cotton (*Gossypium hirsutum* L.), the primary species grown in the United States. Despite the selective breeding efforts of humans, many of the wild characteristics of cotton have not been removed, making cotton management difficult and unique.

Wild cotton is a tropical perennial plant with an indeterminate fruiting habit, meaning that it continues to produce new foliage even after it begins to create seed. Despite its inherent perennial growth habit, however, cotton is managed as an annual crop plant, and growers try to produce as much lint and seed as possible. Continued vegetative growth after flowering diverts the plant’s energy away from lint and seed production, so the perennial nature of even modern cultivars opposes our current production system.

The cotton plant also produces fruit on two different types of branches, each unique in growth habit, further complicating crop management. In addition, cotton growth is very sensitive to temperature and soil conditions. As in other crops, producers use chemicals in cotton to control weeds and insects, but cotton is unique in that crop growth must also be regulated and eventually terminated by chemical means. Understanding the growth and development of the cotton plant helps producers grow a high-yielding, high quality crop.

The following discussion is intended to provide applicable information on the growth and development of the cotton plant.

#### Inside the Seed

A mature cotton seed contains all of the organs necessary to produce a small seedling. The seed is pointed on one end (the *micropyle*) and rounded on the other (the *chalaza*). The tip of the primary root, or *radicle,* faces the micropyle, and the precursors of the stem and cotyledons are plainly visible within the seed (Figure 1).

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-1.jpg |
| **Figure 1. A small, dormant seedling rests inside a mature seed. When the seedling emerges, the radicle will be the primary root, the hypocotyl will be the stem under the cotyledons, and the epicotyl will be the stem above the cotyledons from which shoot growth occurs.** |

The chalaza is the primary site of water and oxygen absorption during germination. The tip of the primary root, or radicle, is the first part of the plant to emerge through the micropyle. The cotyledons that will nourish the new seedling are folded inside the seed, with the hypocotyl below them ready to elongate and push the seedling through the soil. The *gossypol glands* visible throughout the inside of the seed are also visible in the tissues of the growing plant.

#### Germination and Seedling Development

Germination begins as the seed absorbs water and oxygen through its chalaza after planting. The water swells the dormant tissues, and cell growth and division begin to take place. The radicle emerges through the micropyle, turns downward, and grows deeper into the soil, providing a taproot that will supply water and nutrients throughout the life of the plant (Figure 2a and b). The hypocotyl elongates from the radicle and forms an arch or crook that begins to push up through the soil, a brief period often referred to as the “crook stage” (Figure 2c).

Seedling emergence normally takes place 4 to 14 days after planting. At the soil surface, the hypocotyl straightens and pulls the folded cotyledons out of the soil (Figure 2d), a process known as *epigeal germination.* After the cotyledons are pulled through the soil surface, they unfold and expose the epicotyl and the apical meristem, or growing point, which will be the source of subsequent growth (Figure 2e-f). At this point, germination and seedling emergence are complete and the plant begins its active vegetative growth.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-2.jpg |
| **Figure 2. Germination and early seedling development. Root growth dominates the early growth of the plant.** |

#### The Cotyledons and First True Leaves

The cotyledons (Figure 3) serve a dual role in germination. Before they unfold, they supply stored food to the germinating seedling. After the cotyledons unfold, they produce chlorophyll, become green, and produce energy through photosynthesis. The apical meristem emerges at the base of the cotyledons, and all further vegetative and reproductive growth of the plant occurs through the meristems.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-3.jpg |
| **Figure 3. The cotyledons are storage organs that are formed in the seed and emerge from the soil as leaf-like structures oriented opposite each other on the seedling stem. The cotyledons provide nutrients for the seedling. The apical meristem emerges through the cotyledons and will be the source of new growth as the plant matures.** |

A week or so after seedling establishment, the first true leaf appears above the cotyledons (Figure 4). The first leaf shifts the plant’s primary energy source from storage to photosynthesis and signals the move from emergence to vegetative growth.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-4.jpg |
| **Figure 4. The first true leaf emerges about 7 days after seedling establishment. From this point on, the meristems will produce all vegetative and reproductive structures on the plant.** |

#### Soil Effects on Germination and Early Root Growth

Root growth dominates the growth of the cotton plant during germination and seedling establishment. In fact, the taproot may be as deep as 10 inches by the time the cotyledons emerge. This is a critical time for the development of the root system. Cold soils, seedling disease, low soil pH, water stress, hard pans and herbicide injury all inhibit root growth and development, but careful crop management can minimize most of these stresses. The roots absorb water and nutrients that are vital to the development of the plant and any hindrance of root development in these early stages of cotton growth may cause a disappointing production season.

Cotton emerges the quickest from warm, moist soil. Low temperatures (below 60 degrees F) or less than adequate soil moisture may hinder germination by slowing metabolic processes (see the discussion on heat units). Physical impedance, such as crusting, does not slow germination, but it can prevent the hypocotyl from emerging. This often causes thickening of the hypocotyl and a condition referred to as “big shank” or “thick-legged” cotton, resulting in reduced seedling vigour (Figure 5). Generally, the longer it takes for emergence to occur, the greater the risk of plant death and yield loss. A rule of thumb for planting cotton in most regions of the U.S. Cotton Belt is that the soil temperature at 4 inches deep should be at least 65 degrees F for 3 consecutive days, with warm temperatures in the forecast.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-5.jpg |
| **Figure 5. Thick shank in a cotton seedling. Soil crusting, compaction or other mechanical factors can cause thick shank.** |

#### Root Development

As the cotton plant grows, the radicle that originally emerged from the seed becomes a taproot, from which lateral roots begin to form and grow. Lateral roots and the taproot collectively make up the basal root system. Other “higher order” roots then develop from this basal root system. These higher order roots have a functional life of about 3 weeks. They form when environmental conditions are good, and then die when nutrients and water are depleted in the area in which they developed.

As the plant matures, the roots continue to spread and probe deeper in the soil profile for water and nutrients. Therefore, the distribution of roots tends to match the most fertile soil zones. Figure 6a shows an example of the root distribution of an unstressed cotton community. Most of the roots in this case can be found between 1 and 3 feet deep in the soil, but large quantities of roots can still be found more than 4 feet deep in the soil. The amount of roots generally peaks during the cotton flowering phase then declines as the plant partitions more carbohydrates to the developing bolls (Figure 6b).

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-6.jpg |
| **Figure 6. (a) Comparison of root quantity with soil depth for a mature cotton plant. New roots are constantly produced in areas of the soil profile that have water and nutrients.  (b) Comparison of root quantity with cotton growth stage. Roots begin to decline after flowering as the cotton plant shifts its energy from root to boll development.** |

#### The Meristems

The cotton plant has meristems, or growing points, at the top of the main stem and on its fruiting branches. These meristems allow the plant to simultaneously grow upward and outward. Figure 7a is a micrograph of the apical meristem and first two fruiting branches, which are too small to be seen without magnification.

Thrips feed on these young meristems, and plant injury occurs when the thrips insert their mouth parts into the cells to feed. The cells near the insertion point die, but the cells around them continue to expand and divide, resulting in crinkling and distortion of expanding leaves. Thrip damage slows plant growth, and thrip-damaged leaves have a puckered appearance and may have holes in them because of this damage (Figure 7b).

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-7.jpg |
| **Figure 7. (a) Light micrograph of a cotton plant apical meristem magnified 40x. The two fruiting branches in this micrograph are too small to be seen with the naked eye. (b) The cells where thrips feed on the meristems die, and the resulting leaves appear crinkled and have holes in them.** |

#### Vegetative Growth

Cotton has an indeterminate growth habit and can grow very tall under conditions of unrestrained growth. Growth regulators, such as mepiquat chloride, are generally applied to cotton to slow internode elongation, especially for well-fertilized irrigated cotton. Otherwise, vigorous cotton varieties with plenty of water and nutrients can develop very tall, heavy vegetative growth (Figure 8). This type of rank growth promotes boll rot and fruit abscission, and makes a cotton crop difficult to harvest.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-8.jpg |
| **Figure 8. Cotton can grow very tall if its growth is not held in check by environmental factors or management practices.** |

The first vegetative structures that appear on the main stem are main stem leaves (Figure 9). Main stem leaves and branches form at points of attachment on the main stem called nodes. As a general rule, a new node is produced from the apical meristem an average of every 3 days, although nodes develop more quickly early in the growing season than later in the season.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-9.jpg |
| **Figure 9. Growth of a fruiting branch from the main stem. The branch forms in the axil above a main stem leaf. The leaves and stems on nodes above and below the one illustrated have been removed.** |

The stem-like structure that connects the leaf with the stem is called a petiole. Leaves that arise directly from the main stem are referred to as *main stem leaves,* while leaves that arise from the fruiting branch are referred to as *subtending leaves*. The fruit produced by a branch will primarily receive carbohydrates produced by the leaf subtending that fruit. However, the main stem leaf also supplies carbohydrate for fruit development. Fruit produced closer to the main stem will receive more carbohydrates from the main stem leaf than fruit produced at more distal positions.

A fruiting bud, called a square, begins to form at the initiation of the fruiting branch. The first square produced on a fruiting branch is referred to as a first-position square. As this square develops, the portion of the fruiting branch between the main stem and the square also elongates. This portion of the fruiting branch is also called the *internode,* similar to the portion of the main stem between main-stem nodes. An axillary meristem also develops adjacent to this square. The axillary meristem produces a second position square and subtending leaf. As many as four squares may be produced in this fashion on a fruiting branch.

#### Leaf and Canopy Development

Plant growth and development are both functions of sunlight interception and temperature. As a cotton plant develops, new leaves appear and expand, increasing sunlight interception. Initially the carbohydrates produced by the leaves are used to produce roots and more leaves. This production of new leaves causes the leaf area of the cotton plant to increase rapidly. Once reproductive structures begin to develop, carbohydrate supplies are slowly shifted to the developing fruit. As the fruit load on the plant increases and ages, the carbohydrate demand increases, and the development of new leaves steadily declines. Therefore, fruit development occurs with a leaf population that is steadily aging.

Leaf photosynthesis does not remain constant as the leaf grows and develops (Figure 10). A cotton leaf reaches its maximum photosynthetic capacity at about 20 days of age, after which it declines. Collectively, as the reproductive growth of the cotton plant is increasing, it is doing so with the support of a leaf canopy that is aging. Premature aging of the cotton leaf canopy due to water stress, low fertility and other stresses further reduces the photosynthetic capacity of the crop.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-10.jpg |
| **Figure 10. Photosynthetic capacity of a cotton leaf relative to leaf age. Leaves reach peak photosynthetic capability about 20 days after they unfold, after which their efficiency decreases over time.** |

#### The Source to Sink Relationship

Most of the cotton plant’s carbohydrate energy is directed to root growth prior to the time reproductive growth begins. This is a function of carbohydrate source to sink relationships (Figure 11). Carbohydrates are transported from supply areas, called sources, to areas of growth or storage, called sinks. The leaves are the primary source of carbohydrate production during the early vegetative growth of cotton. Carbohydrates are produced through photosynthesis in the leaves and channelled through the phloem to the roots, which act as the main carbohydrate sinks during this phase. The source-to-sink phenomenon also applies to the transport of inorganic nutrients and water. The roots are the source for all inorganic nutrients and water, which are transported through the xylem to sinks throughout the plant. Thus, the root and shoot systems are very interdependent, and damage to either system slows growth and decreases yield.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-11.jpg |
| **Figure 11. Source to sink relationships at two stages of cotton growth. During early vegetative growth, most of the carbohydrates produced by the leaves are sent to the root system. Later in the season, how-ever, most of the carbohydrates are sent to the developing bolls, and the root system and shoot growth rate decline.** |

As bolls begin to develop, they become much stronger carbohydrate sinks than roots and shoots. At this stage, root and shoot growth slow, and boll development dominates plant growth, and the widely established roots continue to supply large quantities of water and nutrients to the shoot.

#### Development of Fruiting and Vegetative Branches

The branches on a cotton plant can be classified as either vegetative branches *(monopodia)* or fruiting branches *(sympodia).* Vegetative branches, like the main stem, are referred to as monopodia (meaning “single foot”) since they have only one meristem. Because vegetative branches have only one meristem, they grow straight and erect much like the main stem (Figure 12). Vegetative branches can also produce fruiting branches.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-12.jpg | **-** | http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-13.jpg |
| **Figure 12. A cotton plant with leaves removed shows the straight growth habit of the main stem and the vegetative branch.** |  | **Figure 13. A fruiting branch with leaves removed shows its zigzag growth habit.** |

The branches from which fruiting buds arise are called fruiting branches, or sympodia (meaning “multiple feet”), because each fruiting branch contains multiple meristems. Fruiting branches have a “zigzag” growth habit, as opposed to the straight growth habit of the vegetative branches (Figure 13). The initial growth of a fruiting branch is terminated once a fruiting bud forms. The fruiting branch, however, initiates a new growing point, called an *axillary meristem*. The axillary meristem is located at the base of a leaf that subtends the newly formed fruiting bud. The “zigzag” growth habit is a consequence of the stop-and-go growth of the fruiting branch.

The first fruiting branch will generally arise at main-stem node 5 or 6. A cotton plant will mainly produce fruiting branches, but several common environmental factors such as low population density, insect and disease pressure and over-fertilization can cause vegetative branches to form. Vegetative branches are produced after fruiting branches, and develop at nodes directly below the node at which the first fruiting branch was developed. For instance, if the first fruiting branch is initiated at main-stem node 5, a vegetative branch may develop at main-stem node 4.

The cotyledons are oriented opposite each other on the stem, but the true leaves and branches of the cotton plant occur in a 3/8th alternate phyllotaxy, meaning the distance from one leaf to the next is 3/8th of a complete turnaround the stem (Figure 14a). Branches on the main stem also show this 3/8th alternate arrangement, since they grow adjacent to the leaves. Nodes are numbered in the same order the leaves are numbered, where the cotyledonary node is considered node 0 (Figure 14b).

New fruiting branches are generally believed to develop approximately every 3 days, although recent studies show that this developmental rate varies. Squares are produced at new positions on a fruiting branch approximately every 6 days. The age of fruiting structures on a cotton plant can be mapped according to this time sequence (Figure 14b).

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-14.jpg |
| **Figure 14. (a) A defoliated cotton plant shows the 3/4 alternate phyllotaxy of branches. Each branch is 3/8 of a turn around the stem from the branch below it. The branches form from the axils of main stem leaves. (b) A diagram of the general timing of flower emergence from buds on the fruiting branches by fruiting position.** |

#### Formation of the Cotton Bud from Square to Bloom

During the 21-day period from square to bloom, there are several recognized developmental stages of the cotton flower bud. A “pinhead” square is the first stage at which the square can be identified. The next stage of square growth is “match-head” or “one-third grown” square. Just prior to the time the flower opens, a candle shape can be seen (Figure 15d). This period of square development prior to bloom is called “squaring.”

Once the cotton begins to bloom, it is said to be “flowering.” A cotton plant typically blooms or flowers for about 6 weeks. Thus, until the cotton begins to produce fruit, the stage of development is discussed in terms of leaves or nodes. Once fruiting begins, the stage of cotton development is discussed in terms of square development and the number of nodes. Once blooms are present, the stage of cotton development is discussed in terms of weeks of bloom.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-15.jpg |
| **Figure 15. Development of the bud from match head square (a) to flower (e) involves both a size increase and petal development. Two bracts have been removed from each square, candle and bloom to show this development.** |

#### The Cotton Flower

As discussed previously, the cotton square is actually a flower bud. The first visible structures of the square are the leaf-like bracts, or *epicalyx*. Three bracts surround the flower bud in a pyramid-like shape. The cotton plant produces perfect flowers, meaning the flower contains both male and female organs (Figure 16). The first square is typically visible on node 5 to 7 about 35 days after planting. *Anthesis*, or a flower bloom, occurs approximately 21 days after the first square appears.

When a pollen grain reaches the stigma, it germinates into a pollen tube. The pollen tube grows through the style, the micropyle, and into the ovule chamber, where fertilization takes place. Anything that reduces egg or pollen viability or tube growth in a flower adversely affects the final yield for that boll.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-16.jpg |
| **Figure 16. Parts of a mature cotton flower. The cotton flower contains both male and female parts.** |

#### Stages of Flowering

Flowering is important to cotton production because pollinated flowers form cotton bolls. The bloom process takes several days, and bloom age can be estimated by the bloom characteristics (Figure 17). On the day a flower opens it is white in colour. Pollination of that flower usually occurs within a few hours after the white flower opens.

On the second day the flower will have a pink-like colour and a red colour on the third day. Approximately 5 to 7 days after a flower appears it usually dries and falls from the plant exposing the developing boll. Occasionally a flower will stay attached to the developing boll for a longer period of time. This is referred to as a *bloom tag* (Figure 17d).

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-17.jpg |
| **Figure 17. Development of a cotton bloom. A white flower emerges on day 1 (a), then gradually darkens and takes on a red colour during days 2, 3 and 4 after emergence (b and c). The bloom eventually dries up and either falls off or becomes a bloom tag (d).** |

#### Nodes Above White Flower and Cutout

The development of the cotton plant in terms of leaf number, node number and fruiting stage is discussed in previous sections. During the flowering period, the stage of cotton development can also be discussed in terms of *Nodes Above White Flower* (NAWF). This is a measurement documenting the number of nodes separating the uppermost first position bloom and the terminal of the plant.

When the cotton plant first begins to bloom there will be approximately 9 to 10 NAWF (Figure 18). As the season progresses, the number of NAWF decreases. This reduction in NAWF can be related to the source to sink relationship of carbohydrate supply. NAWF generally decreases more quickly after bloom in early-maturing varieties than in mid or full season varieties. As the flowers develop into bolls, they become stronger sinks for carbohydrates and their combined demand for carbohydrates increases. Eventually the carbohydrate supply produced by the leaves will be used primarily by developing bolls, leaving less and less available for the production of new vegetative growth. As flowering progresses up the plant, less top growth is produced, allowing the NAWF to decrease.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-18.jpg |
| **Figure 18. Comparison of canopy photosynthesis with boll development. Cutout occurs as photosynthesis declines and more energy is partitioned to forming bolls.** |

As the flowering approaches the top of the plant, the plant eventually puts all of its energy into boll development and ceases flower development. This event is termed *cutout*. Cutout generally occurs at 4 or 5 NAWF. Cutout occurs when carbohydrate supply equals demand and vegetative growth ceases. At cutout, no more harvestable fruit is set.

#### Defoliation and Harvest Timing

Defoliants, or harvest aids, are used to defoliate cotton, enhance boll opening, and control regrowth prior to harvest. Defoliants effectively terminate the cotton crop and prepare it for machine harvest at the end of the growing season. These chemicals also give the producer some control over harvest timing and increase harvest efficiency. Defoliant performance is affected by temperature, plant condition, spray coverage and product rate. Temperature is the primary force in determining harvest-aid rate. Under optimal conditions, a cotton crop might be harvestable in as little as 7 days after defoliation, but cool temperatures will prolong the defoliation process.

Cotton harvest aids can be classified into two modes of action, herbicidal and hormonal. Herbicidal harvest aids injure the leaf, stimulating the production of ethylene. Hormonal harvest-aids increase the ethylene concentration in the leaves without causing any injury. A list of the active ingredients in most defoliants is found in Table 1.

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| **Table 1. Active ingredients of chemicals used for defoliation and harvest preparation of cotton.** | | |
| **Class of Defoliant** | **Active Ingredient** | **Comments** |
| Hormonal | Thidiazuron | Enhances ethylene production and inhibits auxin transport. |
|  | Dimethipin | Causes rapid water loss through the stomata of the leaves, which leads to ethylene production as leaves become water-stressed. |
|  | Ethephon | Increases ethylene production; used primarily for boll opening. |
| Herbicidal | Tribufos | Injures leaf cells to trigger ethylene production. |
|  | Carfentrazone | Inhibits a step in chlorophyll synthesis, causing destruction of cellular membranes and ethylene production. |
|  | Pyraflufen Ethyl | Inhibits a step in chlorophyll synthesis, causing destruction of cellular membranes and ethylene production. |
|  | Paraquat | Non-selective desiccant. |
|  | Chlorates | Non-selective desiccant. |
|  | Glyphosate | Used for regrowth control and weed management. |

A detailed discussion of defoliation and harvest timing can be found in the University of Georgia extension publication *Cotton Defoliation, Harvest-Aids, and Crop Maturity,* by Philip Jost and Steve M. Brown, and yearly updated specific harvest-aid suggestions can be found on the University of Georgia Cotton Web Page at [**http://www.griffin.uga.edu/caes/cotton**](http://www.griffin.uga.edu/caes/cotton)

#### Fruit Shedding

A phenomenon often seen in a cotton field is square shedding (Figure 19). The shedding of squares may be the result of several factors, including water stress, shading (from prolonged cloudy weather), nutrient deficiencies (especially N), high temperatures, high plant populations, high percent fruit set and insect damage. In addition, the reproductive cells formed during square development are very sensitive to environmental conditions. High temperatures and humidity, and nutrient deficiencies (especially boron) can inhibit gamete production and result in flower sterility and ultimately square loss. Sterility may also decrease seeds per boll and locks per boll. One cause of pollen sterilization and subsequent yield loss is misapplication of glyphosate in Roundup Ready® cotton.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-19.jpg |
| **Figure 19. Square shedding is a common occurrence in cotton.** |

Flowers and young bolls may also be shed from the plant due to the same factors that lead to square shedding (Figure 20). Generally, though, the sensitivity of squares, flowers and bolls to shedding can be related to their age. Young fruiting forms are more likely to be shed than are more developed squares and bolls.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-20.jpg |
| **Figure 20. Examples of square and boll shedding. Shedding can be related to several environmental factors such as population density, water, nitrogen, insect pressure and disease. Newly formed bolls and young squares tend to be the most susceptible to shedding.** |

#### Boll Development

After pollination occurs the boll begins to develop. Under optimum conditions it requires approximately 50 days for a boll to “open” after pollination occurs. Boll development can be characterized by three phases: enlargement, filling, and maturation.

The enlargement phase of boll development lasts approximately 3 weeks. During this time the fibres produced on the seed are elongating and the maximum volume of the boll and seeds contained therein are attained. Also during this time, the fibre is basically a thin walled tubular structure, similar to a straw. Each fibre develops from a single epidermal cell on the seed coat. During the boll enlargement and fibre elongation phase, the development of the fibre is very sensitive to adverse environmental conditions. Low water availability, extremes in temperature and nutrient deficiencies (especially potassium) can reduce the final fibre length.

The filling phase of boll development begins during the fourth week after flowering (Figure 21). At this time, fibre elongation ceases and secondary wall formation of the fibre begins. This process is also known as *fibre filling*, or *deposition*. Cellulose is deposited inside the elongated fibre every 24 hours, filling the void space of the elongated fibre. The deposition of cellulose into the fibre cell is also sensitive to environmental conditions. Water, temperature and nutrients (especially potassium) are the primary environmental factors that influence this stage of boll development. The filling phase of boll development continues into the sixth week after pollination.

The boll maturation phase begins as the boll reaches its full size and maximum weight. During this phase, fibre and seed maturation take place and boll dehiscence occurs. The capsule walls of the boll dry, causing the cells adjacent to the dorsal suture to shrink unevenly. This shrinking causes the suture between the carpel walls to split, and the boll opens.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-21.jpg |
| **Figure 21. Development of the cotton boll. Undeveloped cotyledons have a jelly-like consistency. As the cotyledons develop, they become firm and leaf-like, and a black layer that will become the seed coat begins to form around the seed. As the black layer matures and the outside of the boll dries, the dorsal suture splits, allowing the cotton boll to open.** |

#### Yield Distribution

The contribution of a single fruiting structure to the overall yield of the cotton plant depends largely upon its position on the plant. First position bolls are heavier and produced in higher quantities than bolls at any other position. In cotton populations of three plants per foot of row, first position bolls contribute from 66 to 75 percent of the total yield of the plant, and second position bolls contribute 18 to 21 percent.

Yield distribution research is an intensive, detailed process that involves counting and weighing bolls from each fruiting position on many plants. First position bolls tend to fill out more and be heavier than bolls from other positions, so the majority of boll weight on plants generally comes from the first position fruit between nodes 7 and 20 (Figure 22).

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-22.jpg |
| **Figure 22. Comparison of cotton yield by fruiting position and main-stem node. First position bolls are heavier and more abundant than bolls at the other positions, making them the primary source of yield.** |

#### Heat Units or DD60s

Cotton growth milestones are often given in terms of days after planting or between growth stages, but the development rate of cotton is strongly influenced by temperature. A cotton crop grows more slowly on cool days than on warm days, so temperature measurements during the cropping season help estimate when a crop reaches a specific developmental stage. Heat units, or DD60s, are an estimation of this accumulated temperature effect during a day, based on the average of the maximum and minimum daily temperatures in degrees Fahrenheit (ºFmax and ºFmin, respectively). The number 60 is subtracted from this average, because 60 degrees F is generally accepted as the lowest temperature at which cotton growth occurs. The formula for calculating heat units per day is as follows:

http://www.soilcropandmore.info/crops/CottonInformation/B1252/equation.jpg

Calculating the accumulated heat units of a crop over time can then be used to estimate the growth of the cotton during the season. Table 2 demonstrates how to calculate accumulated heat units over a 5-day period.

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| **Table 2. Calculation of daily and accumulated heat units based on daily high and low temperatures.** | | | | | |
| **Day** | **Daily High Temperature (ºFmax)** | **Daily Low Temperature (ºFmin)** | **Average Daily Temperature (ºFmax+ºFmin)/2** | **Daily Heat Units (ºFmax+ºFmin)/2 – 60** | **Accumulated Heat Units** |
| 1 | 81 | 61 | 71 | 11 | 11 |
| 2 | 83 | 63 | 73 | 13 | 24 |
| 3 | 82 | 62 | 72 | 12 | 36 |
| 4 | 85 | 66 | 75.5 | 15.5 | 51.5 |
| 5 | 80 | 62 | 71 | 11 | 62.5 |

Scientists at the University of Georgia Tifton Campus have measured daily temperature data since 1928, and the average heat unit accumulation pattern for a cotton crop planted on May 1 at this location is illustrated in Figure 23.

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| http://www.soilcropandmore.info/crops/CottonInformation/B1252/B1252-23.jpg |
| **Figure 23. Accumulated heat units during the growing season based on historical data at Tifton, Ga., from 1928 to 2003, assuming a May 1 planting date. The heavy bar represents the average accumulated heat units, and the light bars are ± 1 standard deviation.** |

Table 3 shows typical heat unit accumulations at which a cotton crop reaches various growth milestones, as well as the average number of days after planting that these heat units are accumulated in South Georgia. These numbers will vary according to location, year and cotton variety.

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| **Table 3. Accumulated heat units required for a normal cotton crop to reach a specific growth stage. These values will differ by variety. The third column shows the average number of days after planting at which these heat units are accumulated, based on historical data from Tifton, Ga.** | | |
| **Growth Stag** | **Heat Units** | **Days** |
| Emergence | 50 | 5 |
| First Square | 550 | 38 |
| First Flower | 950 | 59 |
| Open Boll | 2150 | 116 |
| Harvest | 2600 | 140 |

#### Summary

Cotton is a unique crop plant, and its innate growth pattern makes it challenging to grow. However, the plant develops in a somewhat predictable pattern. Initially, leaf area and vegetative structures are developed that will then support future reproductive growth. If this initial vegetative growth is compromised, subsequent reproductive growth also suffers. Unlike many other crops, the cotton plant continues vegetative growth after flowering begins. The development of fruiting structures ultimately reduces vegetative growth as the plant matures. The environment regulates every developmental process of the cotton plant, both vegetative and reproductive. Heat unit accumulation dictates development as much as time.

Due to increasing production costs and decreasing or stagnate commodity prices, cotton producers must be able to critically evaluate every input. An understanding of the development of the cotton plant is crucial for making management decisions and maintaining profitable production.

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