Cover Crop Science Project Book

Section 1:
How are Cover Crops Grown & Developed?

- Module A: A Plant Primer
  What do flower parts tell us about plants?
- Module B: Cover Crops in the Rotation
  How do cover crops fit between cash crops?
- Module C: Planting & Harvesting
  Why do we build different farm machines?
- Module D: Natural & Artificial Selection
  What do we do to improve crops over time?
- Module E: Gene Editing
  How can we accelerate artificial selection?

Section 2:
What are the Benefits of Cover Crops?

- Module A: Reducing Soil Erosion
  How do we keep land healthy?
- Module B: Pollinator Services
  Which pollinators might we see in our field?
- Module C: Cover Crop Products
  What can we make from cover crops?
- Module D: Crop Product Supply Chains
  What happens to a crop after harvest?

Center for Mathematics, Science, and Technology
Illinois State University

USDA National Institute of Food and Agriculture
U.S. DEPARTMENT OF AGRICULTURE

This project was developed as part of the IPREFER project (Integrated Pennycress Research Enabling Farm and Energy Resilience) at Illinois State University.

IPREFER is supported by Agriculture and Food Research Initiative Competitive Grant No. 2019-69012-29851 from the National Institute of Food and Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the USDA.

Introduction

This book is designed for youth in grades 6-8 to learn about cover crops. It can be used with 4-H projects and clubs, in schools, or in after-school or other out-of-school programs.

It was designed as a standalone project, but it does not need to be used in that way. It may be combined with other project areas or used as a part of a larger agriculture curriculum.

There are educator/facilitator implementation guides at https://covercrops.cemastprojects.org/ to help you if you would like to use the materials here in a setting with multiple youths.

If you plan to use this book as a guide for a 4-H project, be sure to check with your county for additional record keeping guidelines and exhibit requirements.

Background Information

What is a cover crop? A cover crop is planted off-season, or when the main cash crop is not being grown. As you will learn, cover crops have many benefits. They protect soil and provide food and shelter to many organisms.

Throughout this experience, we will investigate a variety of cover crops, but we will focus on one more than the others. Pennycress (*Thlaspi arvense L.*) is an oilseed cover crop which can offer all the benefits above. For more about current research, visit https://iprefercap.org/.

Pennycress can be harvested to make biofuels, cooking oils, and more. It is an appealing cover crop option for farmers.

Pennycress has not traditionally been used as a cover crop, but because it is being researched as we speak, it is the perfect place to start learning about cover crops. You will be learning about this specific cover crop alongside scientists throughout the Midwestern United States.

Scientists are exploring the potential of pennycress by working in a variety of teams.

The agronomy and crop management team is working to discover how to best plant and harvest pennycress, as well as how to minimize weeds and pests. We will explore this group's work in Modules 1A through 1C.

The breeding and genetics team is looking at how to help pennycress produce the most seeds with the most seed oil. We will look at this group's work in Modules 1D and 1E.

The ecosystems services team is working to identify the benefits pennycress has for soil, water, and pollinators. We will explore this group's work in Modules 2A and 2B.

The supply chain team is looking at how to take seeds and turn them into products like crayons, cooking oil, and biofuels. We will explore this group's work in Modules 2C and 2D.

How to Use This Book

This book contains 9 modules. Each module includes several hands-on or minds-on activities. Though each module can be completed on its own, you will develop a better knowledge base and have a richer experience if the modules are used in order. In this way, you will build on your previous learning and form connections to prior explorations.

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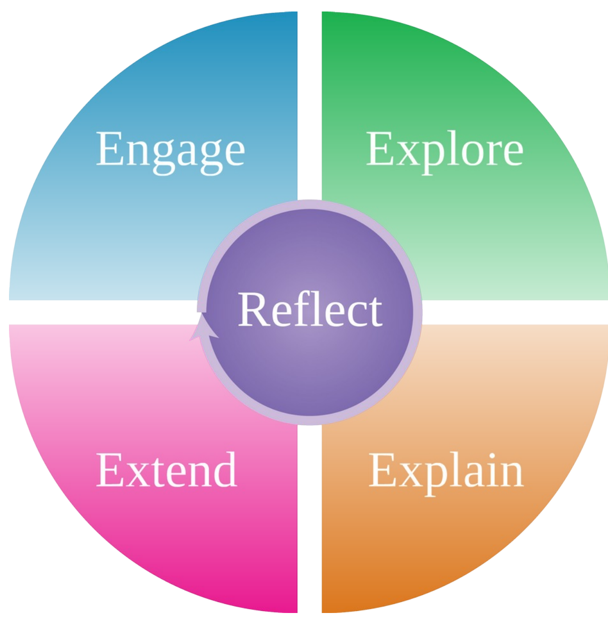
A Note to the Project Helper

The help and support of an adult project helper can make a huge difference in the life of a young person! This might be an adult relative, a teacher, a 4-H leader, or a family friend. Knowledge of education or agriculture may be helpful, but any caring adult can fill this role.

As the young person works through the modules, the project helper can make sure activities are done safely. They can also provide support as the young person gathers materials and information. They might encourage reflection by asking additional questions as well as provide positive guidance and feedback. They should challenge the young person to continue their growth through new opportunities and constructive appreciation.

The modules in this book are arranged in an inquiry-based format that follows these stages:



- Introduce/Engage – Youth are introduced to the topic through pictures, web searches, readings, and other activities. This activity develops a driving question that will guide the rest of the module.

- Explore – Youth do an activity, monitor results, observe phenomena, and/or collect data related to the driving question.
- Explain – Youth analyze their results, observations, and data to develop an answer to the driving question.
- Extend – Youth apply their new knowledge to a different context. They make connections to the driving question.
- Reflect – Youth think through what they knew before and what they know now. Reflection can take place at every stage of the module, but specific reflection questions are given at the end.

These stages work together in a cycle, and some modules walk through the stages more than once.

Each module also highlights a career connection. These show how today's cover crop science learning can be the first step on a path to the future.

This project book centers around cover crop science, and it strives to help young people gain knowledge and skills in this topic. However, it is important to note that this project is also a vehicle for more holistic positive youth development (PYD). This matches the goal of all 4-H programming.

PYD strives to foster behaviors and attitudes in young people that will allow them to thrive throughout their life.

National 4-H Council has summarized essential elements of PYD with the acronym BIG-M. BIG-M stands for Belonging, Independence, Generosity, and Mastery. As a project helper, you can look for ways to build upon these elements within the project work.

Belonging

- Develop a healthy and caring relationship with your young people.
- Ensure a physically and emotionally safe environment during project work.
- Remind young people that they are part of something bigger. This project brings youth into current, ongoing cover crop research taking place throughout the Midwestern U.S.

Independence

- Allow young people to ask their own questions. They should follow their own unique areas of interest as you explore cover crops together.
- Serve in a supporting role as youth make their own decisions about their path through the project.
- Use the Career Connections to help young people see how their current and future decisions can impact their future.

Generosity

- Ask young people how they can use their new skills and knowledge to give back to their larger community.
- Discuss the ways cover crops and other sustainable agriculture practices benefit everyone. Planet and climate health are important to all of us!
- Help young people brainstorm and carry out a service project or educational campaign focused on cover crops.

Mastery

- Encourage young people to share or exhibit their new skills and knowledge.
- Challenge young people to deepen their skills and knowledge with further project work or further opportunities.
- Recognize effort, attitude, perseverance, and a willingness to try new things.

About the Authors

Matthew Hagaman, M.S., M.A.
Matthew has been engaged in middle-level and higher education for over a decade, with a focus in science and technology education. When he is not exploring nature or writing curriculum, you may find Matthew making web sites or furniture.

Rebekka Darner, Ph.D.
Rebekka is director of the Center for Mathematics, Science, and Technology at Illinois State University and a science education researcher. When she is not studying how non-scientists use STEM to make decisions, Rebekka enjoys gardening, yoga, and bouldering.

Rachel Sparks, Ph.D.
Rachel is a biology education researcher who focuses on how students think about evolution. Evolution is an area which unites all of biology, but is especially visible in developing new plant and crop species. When Rachel is not working with scientists and non-scientists of all ages, you may find her exploring local parks, thrift shopping, or watching Star Trek.

Emily Schoenfelder, M.S.
Emily has been engaged in youth development for nearly a decade, with a focus in STEM engagement and social-emotional development. When she is not leading a training, writing curriculum, or developing new partnerships, you may find Emily sitting on the floor of her office, building marshmallow catapults out of craft sticks or designing mazes for robots for her next STEM program.

Willy Hunter, Ph.D.
Willy Hunter is a professor of chemistry at Illinois State University. He works with teachers and faculty across the United States and internationally to improve science and math education in K-12 schools. When he is not investigating chemistry in the natural world, he can usually be found hiking, cycling, gardening, or engaged in another outdoor pursuit.

Expert Reviewers

The authors are indebted to each of the experts who reviewed one or more modules for content and language accuracy and clarity.

- Jim Anderson, Ph.D.
- Chris Aulbach, CoverCress, Inc.
- Mark Bernards, Ph.D.
- Constance Carlson, B.A.
- Kate Edler, M.S.
- Frank Forcella, Ph.D.
- Nicholas Heller, Ph.D.
- Taylor Irvin
- Layla Jones
- Alexander Lindsey, Ph.D.
- Michaela McGinn, Ph.D.
- Primin Nietlisbach, Ph.D.
- William Perry, Ph.D.
- Karyn Rader
- Lucas M. Roberts, M.S.
- Rob Rhykerd, Ph.D.
- John C. Sedbrook, Ph.D.
- Pamela Tas, Ph.D.
- Winthrop B. Phippen, Ph.D.
- Samantha S. Wells, Ph.D.
- Tad Wesley, M.S., CPAg
- Julia Zhang, Ph.D.

A Plant Primer

What do flower parts tell us about plants?

Introduction (~5 minutes)

Parts of our bodies have different jobs, and the same is true of plants.

For each of the survival tasks listed in the table below, identify which plant part you think does that job.

There may be several answers for each task. It is okay if you are unsure of some items.

The word bank on the right shows some structures you might want to choose from.

Word Bank

Stems	Roots	Leaves
Fruits	Flowers	Seeds

Task Needed for Plant Survival	What Plant Structure(s) Do This Task?
Absorb water and nutrients from the soil	
Absorb carbon dioxide gas from the atmosphere	
Gather light energy	
Reproduce	
Attract pollinators	
Distribute seeds	
Support other plant parts	

Explore 1 Materials List

- A fresh flower from a florist or grocery store, preferably an *Alstroemeria* flower (Peruvian lily), lily, or tulip. Avoid mums, daisies, roses, asters, and irises.
- Tweezers or forceps
- Toothpick or wooden skewer
- Hand lens (magnifying glass or jeweler's loupe)
- Sharp blade and a responsible adult's help

Explore 1 (~20 minutes)

We might think first of flowers as gifts. Humans give flowers to show concern or affection. To plants, flowers are reproductive parts.

Most flowers produce gametes which will mature into sperm and egg. Each gamete has a mixed half of the parent's genes. When the two gametes are combined, a new plant with a unique mixture of the parents' genes is made. This is called two-gamete or sexual reproduction.

Many plants can also reproduce asexually. If you take a cutting from one plant and place it in water, it can sprout roots. This new plant's will be an unchanged match to its parents' genes.

All plants reproduce with two gametes, but not all plants do so with flowers. Only plants called angiosperms produce flowers. We refer to this group as "flowering plants." To explore how plants use flowers to reproduce, let's take a flower apart!

Read through the following passages. As you read, gently pull your flower apart. Start from the outside and work toward the center, using your tweezers, hand lens, and toothpick as tools. Use the images on the next two pages to guide you.

Angiosperms use flowers to reproduce sexually. Most flowers sit inside a green basin made of thick, modified leaves called sepals. Flower petals are found just inside the sepals. If you cannot tell the difference between flower petals and sepals, they are called tepals.

Petal traits like bright colors and exotic scents attract pollinators. Some flowers also have nectaries to attract pollinators. These pockets at the base of the petals produce sweet nectar. Flowers with nectaries often have tube-shaped flowers.

Do you think your flower has a nectary? How do you know?

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As you move inward from the petals, you will find the flower's reproductive organs. Perfect flowers have both male and female reproductive organs. Imperfect flowers have one or the other.

In flowers, the male organs are the filament and anther. Together these form the stamen.

The anther is responsible for making pollen, and it is held high by the filament.

How many anthers does your flower have?

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Pollination is the transfer of pollen from the anther to the stigma. The stigma is the top of the female part of the flower. You can find it as a sticky platform in the center of the flower.

How did you find the stigma in your flower?

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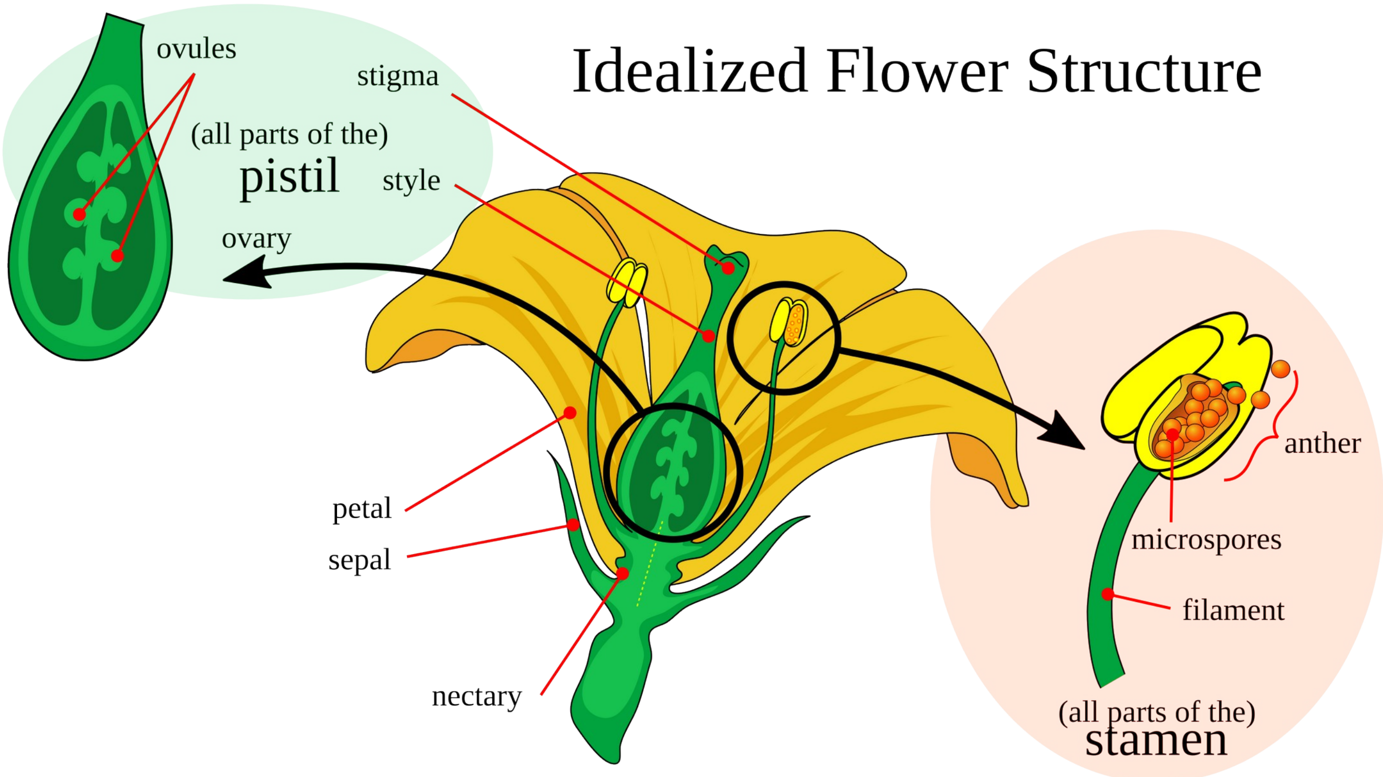

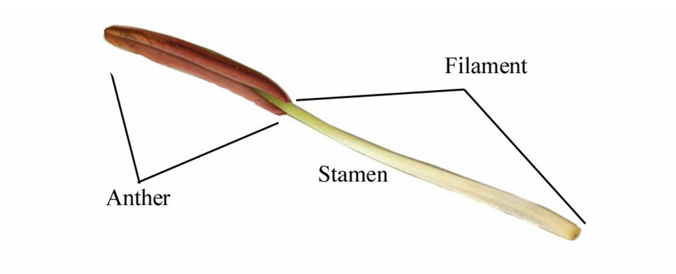

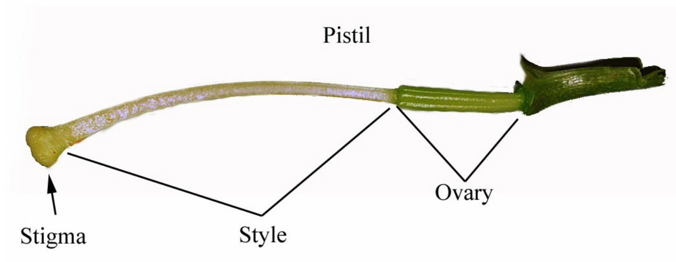

The stigma is held up high in the flower's basin. This is where pollination is most likely. The stigma is supported by a thin stalk called the style. At the bottom of the style, in the bottom of the flower, is the ovary. Together, the stigma, style, and ovary are called the pistil.

How does the pistil in your flower compare to the diagram?

With an adult's help, use a blade to gently cut open the ovary. Inside, you can see ovules.

When a pollen grain lands on the stigma, it forms a microscopic pollen tube and moves through the style and to the ovary. Near the bottom of the ovary, the pollen grain divides into two sperm cells. The sperm cells move into the ovary's entrance. Fertilization occurs the moment a sperm cell unites with an ovule's egg cell.

What do you see inside the ovary?

A fertilized ovule will mature into a seed, or a baby plant. The surrounding ovary will mature into a fruit. Fruits have many adaptations to help better disperse seeds.

Some have air-catching tufts for wind-dispersal (think of a dandelion). Others taste delicious, encouraging animals to eat the fruit. Later they will poop out the seeds in a new location, complete with a dose of fertilizer!

What plants can you think of that produce delicious fruit?

In nearly every species, offspring survive better if the two parents are not genetically similar.

Perfect flowers can self-pollinate, but many species with perfect flowers have ways to discourage it. Filament or style length are two of many factors which make self-pollination less likely.

How easy or difficult was it to find these structures in your flower? Why do you think that was?

Explain 1 (~10 minutes)

For each flower part that you just looked at, match its function below.

Plant Structure	Function
1. __ Petals	A. Sticky platform that catches pollen
2. __ Sepals	B. Holds the stigma up at a height likely to catch pollen from different flowers
3. __ Filament	C. Attracts pollinators
4. __ Anther	D. Matures into a seed that can begin the next generation
5. __ Stigma	E. Produces pollen
6. __ Style	F. Protects the flower before it opens
7. __ Ovary	G. Holds the anther up at a height most likely to effectively transfer pollen
8. __ Ovule	H. Produces ovules, matures into the fruit
9. __ Pollen	I. Produces sperm after successful travel through the stigma and style

Pollination occurs when pollen is transferred to a flower’s stigma, but fertilization cannot happen until pollen matures into sperm.

Compare the event of fertilization in plants with what you know about the same event in animals.
What do they have in common?
What is different?

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Explore 2 (~40 minutes)

Flowers are not the only parts of plants that help them survive. Leaves are important too!

Carbon dioxide gas enters the plant through tiny pores called stomata. There are usually more of these on the bottom of a leaf.

Stomata can open and close with the help of hotdog-shaped "guard" cells on either side of the hole. The guard cells inflate and deflate with water. If water is scarce, stomata will close to prevent water loss through transpiration. They have to be open sometimes, though! The plant needs carbon dioxide to make food.

Photosynthesis takes place in leaves, where carbon dioxide and water combine to make sugar. The energy to make sugar comes from light captured by the leaves' green pigment chlorophyll.

Have you ever put a thin layer of school glue on your fingertip, let it dry, and then peeled it off to see your fingerprint? (If you haven't, try it! It's so cool!). In this activity, you are going to do the same thing to the underside of a leaf. When you peel the thin layer of glue off the leaf, it will show you stomata and their guard cells.

Gather a leaf from up to 6 different plants. Note what type of plant each leaf came from.

After you have gathered your leaves, think about the plants you collected them from. Do some research if you can.

What are the habitats to which they are adapted? (Many houseplants are tropical!)

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If you want to learn more about the natural habitats of common houseplants, check this out: https://www.bobvila.com/slideshow/50773.

What do you think their stomata and guard cells will look like? Do you think they will change based on their native habitats?

Sketch what you predict the stomata and guard cells will look like from each houseplant. These sketches will be a type of hypothesis. Label each leaf type in the space provided.

Leaf type:

Leaf type:

Explore 2 Materials List

- White school glue
- Small brush (like a watercolor paint brush)
- 40x jeweler's loupe
- Leaves of various types (ask a parent before you clip off leaves from houseplants)
- Water dropper
- White styrofoam plate
- Cell phone light

Leaf type:

Leaf type:

Leaf type:

Leaf type:

With the paint brush, paint a very thin layer of glue on the undersides of your leaves. If you have collected a pine needle, try to paint a thin spiral of glue going up the needle.

Let the glue dry.

Once dry, gently peel the layer of glue off each leaf. Keep your leaf peels organized so you do not get them mixed up. You need to know which peel came from which plant.

Place the cell phone, with the light on and pointing up, on a table. Put the styrofoam plate upside down over the light.

Drop 2-3 drops of water on the styrofoam plate, and then place one of your leaf peels in the water. Place another 2-3 drops of water on top of the leaf peel.

With your loupe held close to your eye, move your head close to your leaf peel until it is in focus. Then scan it, looking for those hotdog-shaped cells on either side of a hole.

Once you find a stoma, sketch it! Also make note of how many stomata there are per area. It's okay if this is a relative measurement like "not many," "some," or "a lot."

Leaf type:

Stoma density:

Leaf type:

Stoma density:

Leaf type:

Stoma density:

Leaf type:

Stoma density:

Leaf type:

Stoma density:

Leaf type:

Stoma density:

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Explain 2 (~5 minutes)

Evaluate your hypotheses by comparing your sketches with your predictions. Did the stomata you observed differ in any way? If so, how?

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Why do you think stomata are different in different plants?

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Extend (~35 minutes)

Scientists have studied plants and animals for a long time. They have recorded the diversity of plants and animals around the world.

Extend Materials List

- Device with iNaturalist app (inaturalist.org)
- Access to the Simple Key for Plant Identification at gobotany.nativeplanttrust.org

They have even preserved plants and animals in museum collections. The Chicago Field Museum holds one such archive of Earth's biodiversity through time and space.

Every specimen in the collection has notes. The notes show the exact date and place of collection, as well as who collected it. These collections are important. They allow scientists to compare modern plants and animals with those of the past. They allow us to see humans' impact on the Earth's biodiversity.

Are you ready to add to a great natural history collection? You can record the plant diversity you see around you on iNaturalist.

Choose a place to go for a nature walk with a responsible adult. It should be away from lawns and landscaping. This can be a community trail, the edge of a farm field, or in a nature park.

Before you start your walk, open the iNaturalist app and have the Go Botany key open on your phone's browser.

Keep an eye out for non-landscaping plants. We often call these plants "weeds," but these are the oness to record. They may be native plants and they show the biodiversity in your community!

Once you find a plant, use the Go Botany key to identify it. Start with the Simple Key for Plant Identification. You can use the advanced tool later if you need it. (As you identify plants, you will need to look at the plant parts you have just learned. This is a great way to apply what you know!)

Once you have identified your plant, open the iNaturalist app and record it. Continue to document plants along your walk or wherever you go. The more specimens you record, the more you are contributing to biodiversity research. If you find a plant you cannot identify, experts in iNaturalist can also help you.


Common Violet


Common Milkweed


Field Pennycress


Joe-Pye Weed


Trout Lily


Wild Ginger

Reflect (~10 minutes)

At the beginning of this exercise, you completed a table similar to the one below. Now, complete this table again, using all that you have learned.

It's possible for the same structure to match more than one task, but most structures will have one best match.

Task Needed for Plant Survival	What Plant Structure Does this Task?
Absorb water and nutrients from the soil	
Absorb carbon dioxide gas from the atmosphere	
Gather light energy	
Reproduce	
Attract pollinators	
Distribute seeds	
Support other plant parts	

What kinds of questions can scientists answer using databases like iNaturalist?

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What else do you think you learned by doing these activities?

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Career Connection: Plant Taxonomist

Plant taxonomists figure out how different plants are related to each other. They search for patterns between species and between regions. They often compare the DNA of present-day plants and plant specimens from natural history museums.

Most taxonomists earn a doctoral degree. This is usually after they complete a bachelor's degree in biology or biochemistry. Earning the bachelor's degree lets them gain lab experience.

Cover Crops in the Rotation

How do cover crops fit between cash crops?

Introduction (~5 minutes)

When you hear the term, "cover crops," what do you think of? What have you heard others say about cover crops in the past?

While this entire project book addresses these questions, we will begin to explore some of them in this chapter. Before you get started, jot down your thoughts in response to these questions.

What do you think of when you hear "cover crops"?

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What are some of the benefits of growing cover crops?

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What are some of the drawbacks to growing cover crops?

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Explore (~15 minutes)

Look at the page at the back of this module. At the top is a two-year calendar. The center of the page is a key, showing you when each of the crops can be grown in the Midwest.

Cut along the dotted lines so you will be able to place the crops on the calendar. You'll notice the cash crops do not have cut lines. You never want to shorten the season of your money-making crop! The cover crops can have shortened seasons, though there are consequences for *any* shortened season.

Place the corn and soybeans (only) where they fit on the calendar. How much brown/black soil do you see left on the calendar? The brown/black represents how much of the year the soil is left fallow (not growing anything).

Now try introducing a cover crop or two. Crops can continue from the end of year 1 into the beginning of year 2. They can also continue from the end of year 2 into the beginning of year 1. Most farmers alternate planting corn and soybeans because the two plants use different nutrients. (A crop rotation like this is a great way to save money on fertilizer!)

Try fitting each of the cover crops into the calendar until you find the best combination of cash and cover crops. Note that crops can sometimes overlap if they are interseeded, or one is planted before the other is harvested.

When two crops are harvested in one year, it is called double-cropping.

Which combination of crops do the best job of covering the soil across the whole year?

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Explain (~10 minutes)

Pennycress is an emerging cover crop. It can be grown as a winter cover crop. It fits into a normal crop rotation, and it keeps the ground covered most of the year.

Most seeds store their energy in starches. Pennycress seeds store energy as an oil (an energy-dense liquid fat). Pennycress can be a cash crop, or a crop that can be sold. Its oil can be made into biofuel, cooking oil, and more. After its seeds are crushed to extract oil, leftover materials can feed cows or other livestock.

Domesticated pennycress could give farmers $50-$250 of revenue per acre every winter, so it provides more income than fallow fields.

Take a look at the jumbled photos. Put them in order from seed to harvest by numbering them. Then, label each photo with the activity you see.

Word/Phrase Bank

Harvest | Flowering | Drying | Developing seed pods | Seed | Rosette

Image __ of 6

Label:

Image __ of 6

Label:

Image __ of 6

Label:

Image __ of 6

Label:

Image __ of 6

Label:

Image __ of 6

Label:

Explain to a friend or family member how domesticated pennycress could fit into a normal corn-soybean crop rotation. Use the photos and your two-year calendar to explain the process.

Extend (~10-30 minutes)

The Corn Belt is the region in the Midwest where soil and climate are ideal for corn and soybeans. This region includes Indiana, Illinois, Iowa, Minnesota, Nebraska, and Kansas. The Corn Belt is vital to our food supply. Corn and soy also earn farmers most of their income.

Because these crops are so important, cover crops generally avoid breaking these cycles.

What are some questions to answer before using pennycress as a cover crop? One question is given, but you should come up with at least three more. If you know any farmers, you can ask them to help brainstorm questions.

1. Domesticated pennycress is planted in the fall after the corn/soy harvest. By what date does pennycress need to be planted to start growing before winter?

2. ______________________________

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3. ______________________________

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4. ______________________________

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5. ______________________________

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After you have devised your list of questions to consider, do a web search to find answers to your questions.

Here are some websites to get you started.

- https://www.iprefercap.org/
- https://artsandsciences.osu.edu/news/pennycress
- https://www.forevergreen.umn.edu/crops-systems/winter-annual-grains-oilseeds/pennycress

Notes

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Reflect (~5 minutes)

Return to the questions you pondered at the beginning of this chapter. How have your ideas changed?

What do you think of when you hear "cover crops"?

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There are benefits from growing cover crops. Which can you think of?

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There are drawbacks to growing cover crops. Which can you think of?

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Career Connection: Agronomist

Agronomists work to apply knowledge of soil and plants to agriculture. They decide how to best manage crops. This requires a grasp of crop science, soil science, hydrology (the study of water), and other related fields.

Agronomists work in labs, offices, and in the field. They usually have a four-year degree in ag. or a related field. Many go on to earn advanced degrees.

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Year 1 January	Year 1 February	Year 1 March	Year 1 April	Year 1 May	Year 1 June	Year 1 July	Year 1 August	Year 1 September	Year 1 October	Year 1 November	Year 1 December
Year 2 January	Year 2 February	Year 2 March	Year 2 April	Year 2 May	Year 2 June	Year 2 July	Year 2 August	Year 2 September	Year 2 October	Year 2 November	Year 2 December

∨ Cash Crops

Corn is planted in **April**.
It is harvested in **Late September**.

Soybeans are planted in **Late May**.
They are harvested in **Early September**.

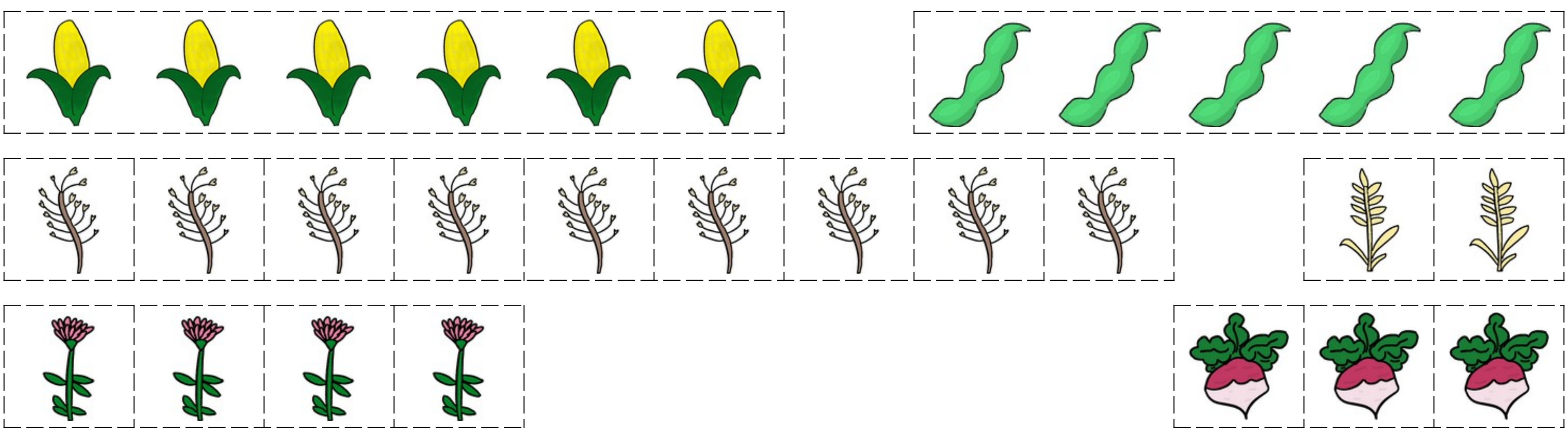
Cover Crops >

Pennycress is planted in **October**.
It is harvested in **Early June**.

Annual Ryegrass is planted in **Late September**.
It is terminated in **Late October**.

Crimson Clover is planted in **Late September**.
It is terminated in **Early December**.

Turnips are planted in **Late September**.
They are terminated in **November**.



Planting & Harvesting

Why do we build different farm machines?

Introduction (~10 minutes)

Which comes first—planting or harvesting? It's safe to say this is an age-old question like "which comes first – the chicken or the egg?"

During much of human history, humans gathered food from wild plants. Around 12,000 years ago, humans turned to agriculture. Instead of searching for fruit and nuts to harvest, humans collected seed, spread that seed, and cared for the plants as they grew. Planting and harvesting seed by hand is easier than hunting and gathering. It's still hard work, though. As time and technology progressed, humans built machines to spread and harvest those seeds more and more easily.

Let's see how harvesters work.

First, thoroughly mix the rice, beans, and oregano from the materials list. Rice represents our desired seed and beans represent seed from a different plant. Oregano represents the leaf litter which is sometimes mixed in with seed.

You will be using your fingers and/or your spoon to separate the desired seed (rice) from the other materials. How long do you think it would take for you to separate all the rice from the other materials? Write your prediction in the data table below.

Introduction/Explore Materials List

- Dry rice (30 mL or 2 Tbsp)
- Dry beans (15 mL or 1 Tbsp)
- Oregano, parsley flakes, or a similarly-sized plant fragment (5 mL or 1 tsp)
- Spoon
- Other tools for separation (e.g., fork, paper cup, sieve, fan)
- Timer

Tool	Predicted Time	Actual Time
Hands & Spoon		

See how close your prediction is! Set a timer for 5 minutes and see how much rice you can separate. Remember, you want to collect rice only—no beans or oregano.

When the timer goes off, estimate how long it would take you to separate all the rice. (For example, if you separated half of it in 5 minutes, the whole cup would take 10 minutes.)

Explore (~25 minutes)

Try a few more ideas. Can you find or make a reliable sieve? (A sieve is an object with holes to help separate materials based on size.)

Are there other methods or tools you could use to improve your process?

Before you try each idea, predict how long it would take to separate the rice using that tool and record your prediction on the previous page. Then, try it!

After you have tried each idea, estimate the actual time as you did before. Then make note of each tool's benefits and shortcomings in the table below. Don't forget that time could be an important benefit or drawback!

Tool or Method	Benefits	Shortcomings	Other Notes
Hands & spoon			

Explain (~15 minutes)

Which of the tools you tried worked best? What evidence do you have to support that claim?

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How might you combine two methods to do the work better or faster than either method alone?

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Engineers solve problems using science and math. What research or calculations could you do to make sure your method is the best one possible?

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Modern combine harvesters use a series of tools to harvest only seed. Leaves, stems, cobs, and any other materials are left on the field. These materials provide nutrients to future crops and can help prevent soil erosion.

Watch the video at https://vimeo.com/350413370.

The video shows the series of tools used in harvesting most crops:

1. The header gathers and cuts the plants.
2. A belt under the cab carries the plant materials into the combine.
3. A variety of rotors and shaking screens break and separate the materials.
4. The heavier seed falls into a collection pan.
5. Fans blow the other materials behind the combine.

Extend (~20 minutes)

The harvester is only one machine which helps farmers. Mechanical planters use some of the same processes as a harvester.

Look back at the harvester steps at the top of this page. Which of these processes do you think are used in mechanical planting machines?

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Watch a video of some planter processes at https://vimeo.com/433441222.

Extend Materials List

- 16 colored paper punches or dried peas (to represent soybean seeds)
- 16 pennycress seeds, mustard seeds, or another small, untreated seed
- Yardstick or meter stick with inch marks

Starting with the row cleaner, what are some steps the mechanical planter takes?

1. Row cleaners brush away debris.
2. ____________________________________
3. ____________________________________
4. ____________________________________
5. ____________________________________

The video explains that corn is often planted 6 inches apart within its row. Soybeans are often planted 2 inches apart within their rows. Seed spacing reflects the size of the seed and the size of the plant.

What about a small-seeded plant like pennycress? Let's see what a field of pennycress would look like compared to soybeans.

Find an open area on the floor to plan a planting of soybeans. Bean rows are often planted 15 inches apart. Within each row, beans are planted 2 inches from each other.

Use paper punches and your yardstick to map out this spacing.

Domesticated pennycress plants are seeded by weight, not distance. Six pounds of seed are recommended for every acre.

- Each pound contains ~525,000 seeds.
- An acre measures about 6,000,000 inches in each dimension.

Let's calculate how far apart the pennycress seeds should be.

6 lbs./acre * ______,______ seeds/lb. ÷

__,______,______ square inches per acre =

__.____ seeds per square inch.

If about half a seed will be planted every square inch, a full seed will be planted every 2 square inches. A seed could be placed at the corner of each rectangle measuring 2 in. x 1 in. Use small seeds to map this on a separate area of the floor.

How many pennycress plants would it take to fill the area used by the 16 soybean plants?

____

Reflect (~25 minutes)

Think back to the tool systems used in a corn or soybean planter. These tools are built for 15- or 30-inch rows. What would a machine look like which could drop a seeds to make a 2-inch grid? Draw your idea for a pennycress planter below.

Air seeders are an option which allow for rows as close as 6 inches.

Watch a video to learn how an air seeder works: https://youtu.be/XvxMv6NTOFc.

Compare your idea to the air seeder. What processes are found in both tools?

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Again, compare your idea to the air seeder. Which of your ideas might be better? Which of the air seeder processes might be better?

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List as many jobs as you can related to building, maintaining, and using planters or harvesters.

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Why do you think there are a lot of different jobs related to the same tools?

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Seed spacing is important. It gives plants room to germinate and grow without leaving too much bare soil. This helps prevent soil erosion.

Seed-soil contact is also important. It ensures seeds will have easy access to water and other nutrients in the soil.

Finally, seed depth is important. Each seed has limited energy for the plant to begin growing. The plant will need to grow out of the ground far enough to capture energy from the sun.

Look back at your answers to the planter steps on page 3. What would the effects be for the young plant if you removed one or more of these steps?

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This project was developed as part of the IPREFER project (Integrated Pennycress Research Enabling Farm and Energy Resilience) at Illinois State University.

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Career Connection: Agricultural Engineer

Engineers solve problems related to structures, machines, and the environment. An agricultural engineer can solve these problems and more! In agriculture, there will always be a need for a greater yield, better crop quality, and a safer environment.

Ag. engineers must complete a four-year bachelor's degree. Usually this is in agricultural or biological engineering. Some ag. engineers get a master's degree to gain more specific knowledge.

Natural & Artificial Selection

What do we do to improve crops over time?

Introduction (~5 minutes)

There are plants all around us! There are trees, flowers, grasses, bushes, crops, succulents, ferns, and many more! In this module, we will explore how plants change over generations. We will also learn how we ended up with so many types of plants in the world.

First, look around you and make a list of all the plants you can identify. You may need to walk outside and a little bit away from your building.

Nearby, we have the following plants:

____

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Explore (~10 minutes)

How often do you think about the variety of plants around you? Think about a grocery store flower aisle alone. (There are roses, tulips, carnations, lilies, and many more!) There is an enormous variety of colors, shapes, and sizes! You can find similar variation in leaves, stems, and all the other plant parts we've explored.

Variation exists in all species. The way we get variation is by mixing gene variants during reproduction. In *A Plant Primer*, you learned:

- The anther produces sperm-containing pollen
- The ovary contains ovules that mature into seeds
- When sperm reaches the ovules, seeds grow to produce the next generation of plants.

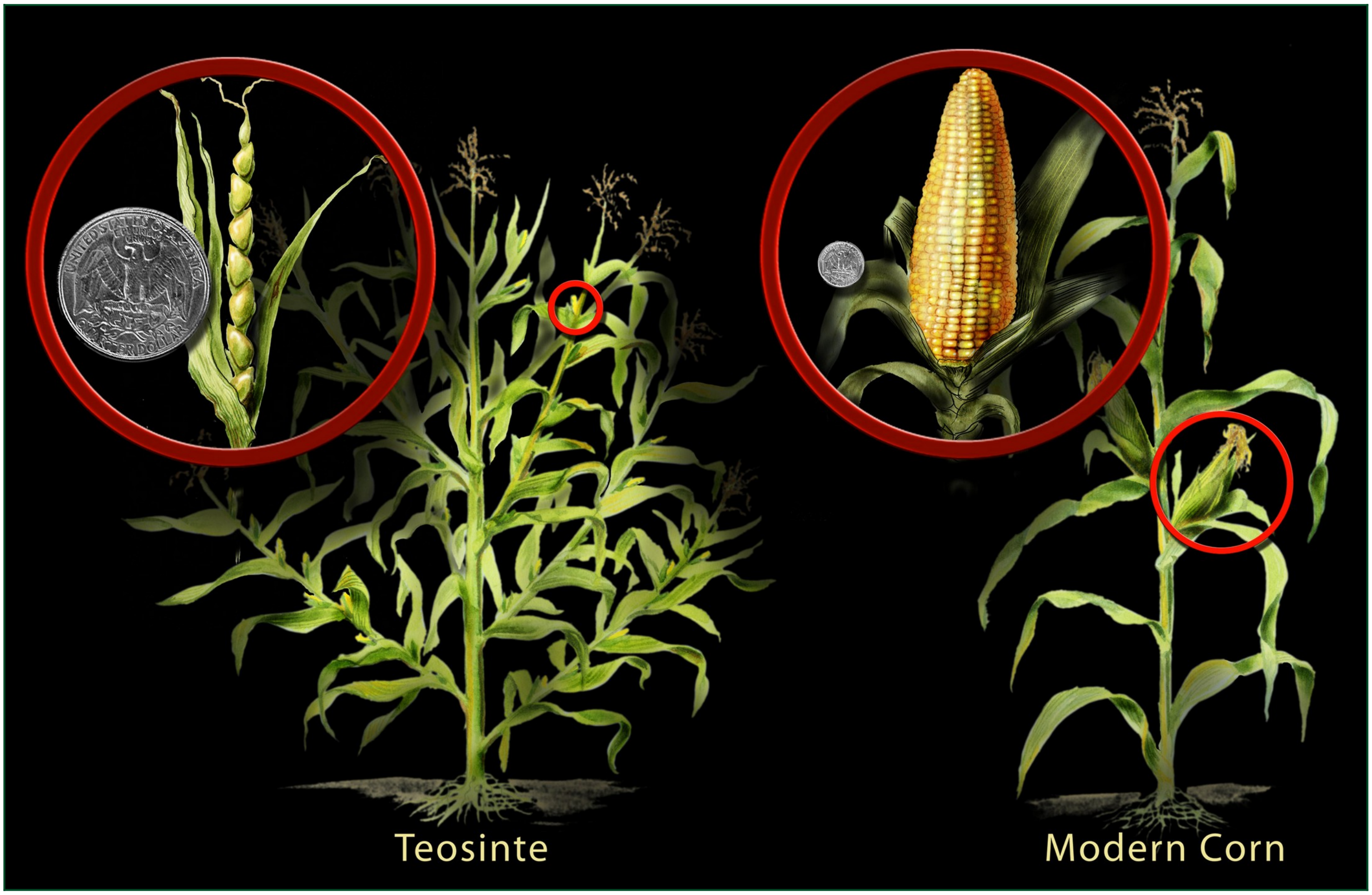
Through this process of sexual reproduction, offspring are different from both parents. Each offspring is a unique organism! It will have new combinations of its parents' gene variants.

The same gene can come in different forms called alleles. Different alleles lead to different phenotypes. (Phenotypes are the traits we can see resulting from alleles.) Your hair color shows a phenotype of the hair color alleles you got from your parents. Phenotypes are also shaped by the environment. Without enough water, peas bred for large size will still be small.

Some individuals reproduce more successfully than others, so not all alleles will be passed on at the same rate. To know how common alleles are in a population, we look at allele frequency.

A high allele frequency means that allele is very common. A low allele frequency means that allele is rare. Scientists often wonder how allele frequencies occur. Fortunately, plants are very helpful in exploring these questions.

To see how plants have changed over generations, let's look at two related plants. Corn and teosinte share a common ancestor. They both evolved from the same plant species 9,000 years ago.



Although corn and teosinte have a common ancestor, they look very different. Use the image above to compare these two plants. Record your observations in the table below. If you have an ear of corn, look at it to see these traits in real life!

Plant Structure	What does it look like in teosinte?	What does it look like in corn?
Seed / kernel		
Size of ear		
Overall plant width		

Corn and teosinte are very different. There are many differences we can't even see in this picture!

It is useful to compare corn and teosinte. Their traits have changed for different reasons. Teosinte has gone through natural selection for 9,000 years. In the same time, corn has gone through artificial selection.

Selection refers to how often we see different alleles over time. As organisms with different phenotypes reproduce, some alleles will be found more often. Natural selection is when allele frequencies change naturally over time. Natural selection occurs when one phenotype leads to better breeding in the wild.

Artificial selection occurs when humans shape which alleles are passed on. Humans look for desired phenotypes (larger fruit, for example). They select for these alleles by helping those plants reproduce. This makes the desired phenotype more common in later generations.

Explain (~20 minutes)

Consider the phenotypes below. For each phenotype we can observe, identify the matching function.

Phenotype	Function
1. ___ Soft kernels without an outer case	A. Protects seed from digestion, letting it survive and grow wherever it is excreted by animals
2. ___ Kernels have hard outer case	B. Makes kernels easier for humans to digest

3. ___ Many branches that produce many ears per plant, with a small number of kernels per ear	A. As different branches dry at different rates, seeds drop at different times
4. ___ One stalk with no branches, producing fewer ears per plant but many kernels per ear	B. Keeps kernels in one or two locations for easier harvesting and processing

5. ___ Ear shattering to spread seeds/kernels	A. Spreads seeds nearby even if they are not consumed and excreted elsewhere
6. ___ Ear not shattering; seeds/kernels all stay on ear	B. Prevents loss of kernels to ensure plentiful harvest

7. ___ Few leaves	A. Gives greater surface area to capture light energy
8. ___ Many leaves	B. Enables multiple plants to be planted close to each other

What are the benefits of each phenotype?

Describe why it would be desirable or beneficial.

The traits that help the plant survive in the wild are the ones that were naturally selected. These are present in modern teosinte. The traits that humans would want the plant to have were artificially selected. These are present in corn.

Phenotype	Beneficial For:	Why Beneficial?
1. Soft kernels without an outer case	Wild plants / Humans (circle one)	
2. Kernels have hard outer case	Wild plants / Humans (circle one)	
3. Many branches that produce many ears per plant, with a small number of kernels per ear	Wild plants / Humans (circle one)	
4. One stalk with no branches, producing fewer ears per plant but many kernels per ear	Wild plants / Humans (circle one)	
5. Ear shattering to release seeds/kernels	Wild plants / Humans (circle one)	
6. Ear not shattering; seeds/kernels all stay on ear	Wild plants / Humans (circle one)	
7. Few leaves	Wild plants / Humans (circle one)	
8. Many leaves	Wild plants / Humans (circle one)	

If you planted corn and teosinte in the wild, which would you expect to be more successful? (Think about survival and reproduction.) Why?

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Extend (~20 minutes)

You now know how natural and artificial selection can cause two plants to diverge from their ancestor and evolve into new varieties. Corn became a staple in the human diet thanks to ancient farmers in Mexico. They selected plants with phenotypes they wanted, then bred these plants with each other. This is selective breeding, one of the ways artificial selection happens.

All the fruits and vegetables we eat come from selective breeding. Take a look at the image below. All these foods come from the same plant: wild cabbage (*Brassica oleracea*). You can see an undomesticated wild cabbage above.

broccoli
var. *italica*

brussels sprouts
var. *gemmifera*

cabbage
var. *capitata*

cauliflower
var. *botrytis*

Chinese kale
var. *alboglabra*

kale
var. *acephala*

kohlrabi
var. *gongylodes*

Each of these foods comes from different plant structures. Farmers selectively bred cabbage plants to enhance these plant structures and make these varieties.

There are now dozens of different varieties (or cultivars) of wild cabbage. Each grows a different food. Recall the different plant structures that you learned about in *A Plant Primer*. What plant structure(s) do you think humans focused their breeding efforts on to make each variety? Record your answers in the table on the next page.

Cultivar	Plant Structure(s)
1. __ Cabbage	A. leaves and stems
2. __ Kale	B. flower bud clusters
3. __ Broccoli	C. lateral buds (buds along the stem)
4. __ Cauliflower	D. stem and root
5. __ Chinese kale	E. flower buds and stem
6. __ Kohlrabi	F. leaves
7. __ Brussels sprouts	G. terminal buds (buds at the end of a leaf)

Remember, all of these foods come from the same ancient plant! Farmers had to carefully breed cabbage to make these different foods. To learn a bit more, check out a SciShow episode: https://youtu.be/JcVJDz1-8Lc.

Choose one of the foods listed above. Check your answer using the video. What actions might farmers have taken to selectively breed it?

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Uncultivated wild cabbage, or wild cabbage that hasn't been selectively bred, still exists. It is also different from ancient wild cabbage.

Why do you think modern wild cabbage has phenotypes different from ancient wild cabbage? How could that have happened?

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Reflect (~15 minutes)

Look back at the list of plants that you made in the Introduction. For each plant, do you think it is a product of artificial selection or natural selection?

Plant	Selection (circle one)
	Natural / Artificial
	Natural / Artificial

Plant	Selection (circle one)
	Natural / Artificial
	Natural / Artificial
	Natural / Artificial
	Natural / Artificial
	Natural / Artificial

When you thought about plants before completing this module, what did you picture? What do you picture now when you think about plants?

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This lesson focused on how plants that we eat have changed over time. These are the plants that have been selectively bred for the longest time. (Humans have always needed to eat!) However, there are plants that humans don't eat but still breed.

Some of these plants may include cover crops like pennycress or sorghum sudangrass, house plants like aloe or spider plants, and decorative flowers like roses and lilies.

Pick a few of these plants and look them up if you need to. Do you think these non-food plants have gone through natural selection, artificial selection, or both? Why?

Plant	Selection (circle one)	Why?
	Natural / Artificial	
	Natural / Artificial	
	Natural / Artificial	
	Natural / Artificial	
	Natural / Artificial	

Career Connection: Molecular Biologist

There are many processes which happen deep inside living things. Molecular biologists look at molecules and cells. They try to understand how organisms grow and develop, one cell at a time. They need skill with lab equipment and knowledge of biology, chemistry, and genetics.

Entry-level positions require a bachelor's degree in biology. Researchers often have master's or doctoral degrees. Higher education is rewarded with higher salary.

Gene Editing

How can we accelerate artificial selection?

Introduction (~10 minutes)

If you've ever eaten blueberries, you may have noticed that each one has a slightly different taste. (You may even have kept eating berries until you found that one with the perfect flavor!) In contrast, every banana with the same ripeness tastes exactly the same.

Every banana (*Musa acuminata*) at your grocery store is probably a Cavendish banana known as Grand Nain. Every Grand Nain banana is the same genetically, so they are basically clones! This is true of many seedless fruits, though some fruits have more varieties. For example, there are many types of seedless grapes.

You might think that's a good thing. You know exactly what to expect when you buy a banana! Sadly, the fact that they are all the same puts them in danger. Cavendish bananas are threatened by banana wilt. Banana wilt has already destroyed many banana plantations (farms) in Asia and Australia. In fact, it nearly completely destroyed the last cultivar of banana.

You may have also wondered why banana candies taste different than banana fruits. Banana flavoring tastes more like Gros Michel bananas. Between the 1950s and 1960s, these bananas were wiped out by the same disease.

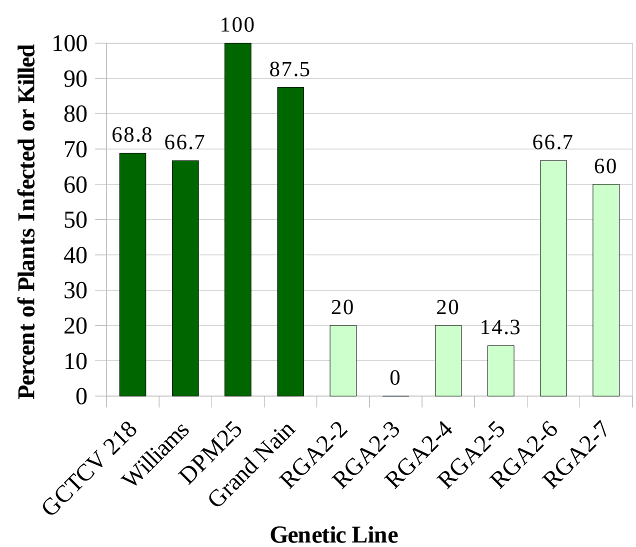
The fungus that causes banana wilt has spores which can survive in soil for decades. No known Cavendish bananas have resistance to this fungus.

What can we do? Scientists have found other bananas with resistance to the fungus, but those bananas are not edible. If we can add this resistance to the Grand Nain banana, perhaps our bananas can stay disease free.

Researchers modified the DNA of Grand Nain bananas to make 5 transgenic banana lines. They added genes from a wild Indonesian banana which was resistant to banana wilt. These new banana lines were planted alongside unmodified plants and the results are below.

The bars in dark green show the control group plants which were infected or killed. The control group are those plants whose genes were unmodified. The bars in light green show the plants with new genes which were infected or killed.

Panama Disease in Control Groups and Transgenic Bananas



Were bananas in the control group or the transgenic group most susceptible to banana wilt? (Remember, 100% means every plant was infected or killed.)

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Which specific line of bananas was least impacted by banana wilt? (Remember, the lower the percent, the less disease.)

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Why do you think some lines of bananas were more likely to be infected than others? (Make sure you think about genetic factors, the environment, and more.)

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Explore (~20 minutes)

In *Natural & Artificial Selection*, we learned how farmers improve crops to have desired features. This process has been used for a long time. It allows us to have more unique crops. For example, there are more than 7,500 types of apples around the world! Farmers' efforts have also led to seedless bananas and grapes.

The process of artificial selection is not an easy one. As farmers change features within a crop, undesired traits may appear. What if there was a way to choose favorable alleles without the undesired traits?

In 2012, Drs. Jennifer Doudna and Emmanuel Charpentier came up with just such a method. They knew that bacteria were able to pick up DNA from attacking viruses. The bacteria keep a copy of this DNA to fight later infections.

If the bacteria recognize an invading virus' DNA, they make an enzyme. This enzyme's job is to cut up the viral DNA. This saves the bacteria.

Drs. Doudna and Charpentier adapted this method to cut the DNA of interest in an organism. They received the 2020 Nobel Prize in Chemistry for their work. We can insert a CRISPR-Cas9 protein into an organism, and it will cut the DNA exactly where we need it to.

Let's model this. Get a bag of your favorite small, colored candy. You will need about 100 pieces of 4 colors of candy. (If there's a fifth or sixth color, you can eat them as you work!)

Explore Materials List

- About 100 pieces of colored candies, with around 25 each of 4 colors. Alternately, you could use 4 colors of paper clips, 4 colors of identical building blocks, etc.

Look at which colors you seem to have the most of. Write those four colors alongside the list below.

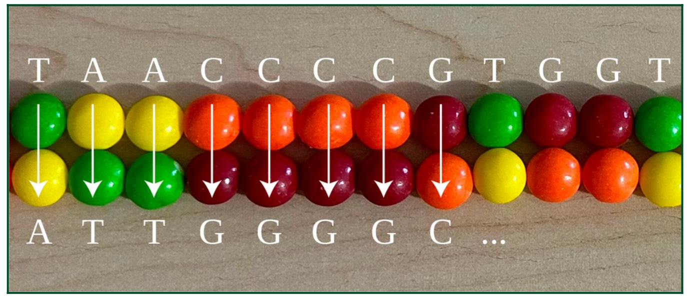
Color Key
____________________ will represent **A**.
____________________ will represent **T**.
____________________ will represent **C**.
____________________ will represent **G**.

These colors represent four different bases: adenine, thymine, cytosine, and guanine. These are often shortened as A, T, C, and G. These are the four nucleic acids found in the double-stranded DNA which stores all your genes (and the genes in bananas too!).

If you've ever heard that we share about 50% of our genes with bananas, that's true. Both humans and bananas have many of the same proteins, and we do some important things in the same way. For example, we both break down sugars for energy. However, our total DNA is only about 1% similar. (DNA doesn't just encode genes. It also has instructions for how to use those genes and some instructions we don't fully understand.)

Line up 40 candies side-by-side on a clean table. Don't place the candies down in any specific order or pattern. Make their order random. If you need help making the order random, you might press a small pile of candies into a long line using two clean rulers or both your hands.

Now use the key you made earlier to add another line of 40 candies. This time you will need to be careful about their placement.



Where you have an A, add a T (and vice versa).
Where you have a C, add a G (and vice versa).

Nice job making a paired, double-strand of DNA! Our candy model misses a lot of details, but it does a good job representing the nucleic acids inside DNA. In the real world we also need to worry about transcribing DNA to RNA. We will keep things simple and focus on what happens to DNA.

Pick out 2 more candies: two Gs. This is the first sequence we will be looking for. Look from one end of your DNA to the other. Do you see those colors in that sequence? How many times?

____

It's likely you found the sequence, and it may have occurred more than once. It was a short sequence!

In the CRISPR process, this short sequence is a first step in the search for a specific gene. It is easier to find two matching colors side-by-side than it is to find a more complex pattern.

Every time your 2-candy sequence is found, we are going to do another check. We will look for a 20-candy sequence coming right before it. This longer sequence will be all or part of the gene we want to modify. In a banana, we might be looking for the place to add a gene to help the banana plant resist banana wilt.

Look before each GG. Do you see the following exact sequence? If so, CRISPR would unzip the DNA strands and cut them within the 20-candy sequence.

ACGC TGAC ACGC CTAC GTAG

You likely did not find that exact 20-base sequence. Why not?

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Think about how long it took you to complete your search. How much longer would it take to search through 500 million candies instead of 40? (There are over 500 million bases in the banana genome!) The CRISPR system can do something that would be very difficult for us. It can very quickly search all the DNA in a cell!

Cutting the DNA is just the start of the process. What do you think your cell would do if it found two cut ends of a strand of DNA?

a. re-attach the two strands
b. add a few bases, then re-attach the two strands
c. remove a few bases, then re-attach the two strands
d. all of the above

Explain (~10 minutes)

When a cell finds a broken length of DNA, it will repair it. Most of the time, it will re-attach the two strands with no changes. Sometimes it will add or remove a few bases. If there are any changes at all, it is often enough to do what scientists need CRISPR to do. Adding nearby bases results in a mutation.

Often, this will break the gene. If scientists want to turn off a gene, breaking it might be enough. These kinds of mutations happen naturally, but by targeting all the cells in a seed, a mutation caused by CRISPR is more likely to take hold.

A scientist may want to add specific DNA instead. For example, they may want to add a protein which would make a banana resistant to banana wilt. They just need to include copies of the DNA to make that protein. Scientists insert "donor DNA" into the cell at the same time as the CRISPR enzyme. When the cell goes to repair the cuts in the DNA, the donor DNA will be handy and is likely to be included.

Imagine you are a molecular biologist. Which method would you want to use in each of the situations on the next page? Make your choice and explain why you think it is the better option.

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Situation	Choice (circle one)	Reasoning
You want to add a gene to make your crop more resistant to drought.	Mutation only / Include donor DNA	Adding a gene requires donor DNA. Anytime a new or specific gene is needed, it must be included.
You want to reduce the amount of erucic acid in a crop since it may affect human heart health.	Mutation only / Include donor DNA	Reducing the impact of a gene just requires mutation. A mutation will "break" the normal gene.
You want to reduce the odor of a crop to make it more palatable as food.	Mutation only / Include donor DNA	
You want to decrease the amount of fiber in a plant's seed to increase germination.	Mutation only / Include donor DNA	
You want to increase the amount of oil in a plant's seed to make it more valuable.	Mutation only / Include donor DNA	

Extend (~20 minutes)

Nearly every crop is being carefully gene edited. Scientists use CRISPR and other gene editing methods to explore the effects of small changes to DNA. These studies take place in greenhouses and labs.

Many studies look at mutations. Mutations are a natural part of a plant's growth, but gene editing allows humans to make changes in years instead of decades. Gene editing is much faster than artificial selection!

Extend Materials List

- Domesticated pennycress (yellow) seeds and undomesticated pennycress (black) seeds. Any set of seeds from related plants can work, including kale and cauliflower.
- A jeweler's loupe or microscope

One helpful mutation is one which changes black-seeded (wild) pennycress into yellow-seeded (domesticated) pennycress. Use your jeweler's loupe to examine your seeds. Draw and describe the differences you see between the seeds.

Name and Drawing	Description
Seed 1:	
Seed 2:	

If you looked at pennycress seeds, you likely noticed the yellow seed was smaller, smoother, and (of course!) a different color. All three of these changes were the result of one mutation. The mutation reduced the amount of fiber in the seed coat. With less fiber, the seed also has more oil in less space.

If you looked at kale and cauliflower, you likely noticed the cauliflower seeds were smaller, less spherical, and lighter in color. These are likely the result of many genetic changes as ancient wild cabbage was turned into kale and cauliflower by artificial selection.

All of these changes were the result of mutations. Domesticating pennycress was much faster than kale and cauliflower, though.

Why does domestication take less time now?

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Think back to the activities you completed in *Natural and Artificial Selection*. Which of the changes you noticed in your seeds were beneficial changes for humans?

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Which of the changes you noticed in your seeds would offer an advantage to the wild plant?

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Reflect (~10 minutes)

Gene editing can be beneficial because:

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Gene editing can be potentially risky because:

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Think about what you had for lunch. What one change would you like to make to a food you ate? Do you think that is a change that could be made with DNA? Why or why not?

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Molecular biologists work with things that are very small. What is an example of another career where humans work at a very small scale?

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Career Connection: Biochemist

Biochemists study the chemistry of life. They may look at the chemicals that plants produce, or they may monitor the effects of chemicals on plants. In either case, they seek to understand how chemistry helps organisms grow and develop.

Biochemists need 4-year degrees, even to work in a lab. Leading a lab usually requires a master’s or doctoral degree.

Reducing Soil Erosion

How do we keep land healthy?

Introduction (~15 minutes)

Take a close look at the pictures on the right. What do you see happening in each picture? Why do you think this is happening?

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What do the three pictures have in common? How are they different?

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Each of the above photos shows erosion. Do an Internet search to learn more about erosion.

Be prepared to write down your definition and where you found your information on the next page. (If you don't have Internet access, ask teachers or other adults to help you come up with a definition.)

It's always a good idea to use several sources. This lets you compare the information and ideas from each source. If multiple sources give similar information, there is a better chance the information is true. You can also merge the different views. This lets you create more well-rounded knowledge.

My definition of erosion:

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Source 1:

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Source 2:

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Source 3:

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Explore (~50 minutes)

For billions of years, natural forces such as wind, water, and ice have shaped the land on Earth. Now it's your turn to see erosion at work!

To begin your experiment, find a container with deep sides and fill it about halfway with sand. Add water and mix it into the sand until the sand is wet enough to shape.

Pile all the sand on the end of the container opposite the hole. Slope the sand down to the end of the container with the hole. You have just made your hill. It will be the starting shape each time you begin a new step in your experiment.

On the right, draw pictures showing what your container looks like with the sand in the starting position.

Let's look at the impact of water erosion. We are going to pour water into the sandbox at the top of the hill and collect the water and sand which flow out through the hole in the bottom. Will measuring the amount of *sand* or *water* which comes out tell us more about erosion?

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Prepare one cup to collect the water that will flow out of the hole at the end of your box. You may need to press the cup against the box to avoid losing sand and water, but be sure not to lift the box.

Use one cup filled with about 1 cup (8 fluid ounces) of water to pour water onto the top of your hill. Pay attention to how you pour—you will need to pour the same way every time.

Explore Materials List

- A shoebox-sized waterproof container with a ¼" hole drilled at the base (to allow outflow of water)
- Sand
- Water
- 2 See-through cups for pouring & collecting
- Other materials to simulate erosion prevention

Top View

Side View

Record your observations after this first trial in the space below. Draw a top and side view as before, but also note how much sand was collected. (Remember, the amount of sand tells us more about the movement of soil than the amount of water.)

Reshape your hill and repeat your experiment. This time you can use your collection cup as your pouring cup, and the pouring cup from the last experiment can be used to collect. You may add a little water to your cup to keep its level the same. Record your observations in the space below. Scientists use multiple trials to ensure the results will be the same every time. If the results are different, scientists will look for an explanation.

Were your results similar in your two trials? If not, you will want to repeat your experiment one more time to be sure you know what to expect as we test a method to reduce erosion.

Sand Only, Trial 1
Top View
Side View
Amount of Sand Collected

Sand Only, Trial 2
Top View
Side View
Amount of Sand Collected

When soil is erodes, it becomes more difficult to grow plants. It can take decades for soil to recover if too much is washed away.

There are many ways people try to reduce soil erosion. Sometimes people build walls to hold back soil. Short-rooted grasses and deeper-rooted trees and bushes can help hold soil in place. Piping and irrigation systems can also be used to redirect water so it doesn't erode soil.

Let's see if we can reduce the amount of erosion in our sandbox by trying one of these solutions. You can also try other solutions you think of.

Walls and other structures can be built using craft sticks. Grass can be simulated using green scouring pads. (Lawn grasses have a very shallow root system.) Deeper-rooted plants can be simulated with pads from a hair brush. Pipes can be simulated with straws.

Reshape your hill and set up your way to limit erosion. Remember that as scientists we must carefully control our experiment. Pay attention to where and how your wall, plants, or pipes are placed. To ensure accurate results, we also want to pour water from the same height and at the same speed into the same spot.

Conduct your experiment as you did before, then repeat it. Record your results below as before.

Modified Hill, Trial 1
Top View
Side View
Amount of Sand Collected

Modified Hill, Trial 2
Top View
Side View
Amount of Sand Collected

Explain (~10 minutes)

Why do you think it was important to conduct your experiment more than once?

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Did you notice any differences when you repeated the same experiments? What were they? What might have caused these changes?

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What new things did you learn about erosion from this experiment? What did you observe that helped you learn this? (What is your evidence for these new ideas?)

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Water isn't the only force of erosion—wind is impactful as well. If you've never explored the topic, look at some photos from the 1954 Dust Bowl: https://life.com/history/dust-bowl-photos-from-an-american-catastrophe/. Write a cause and effect statement based on what you see.

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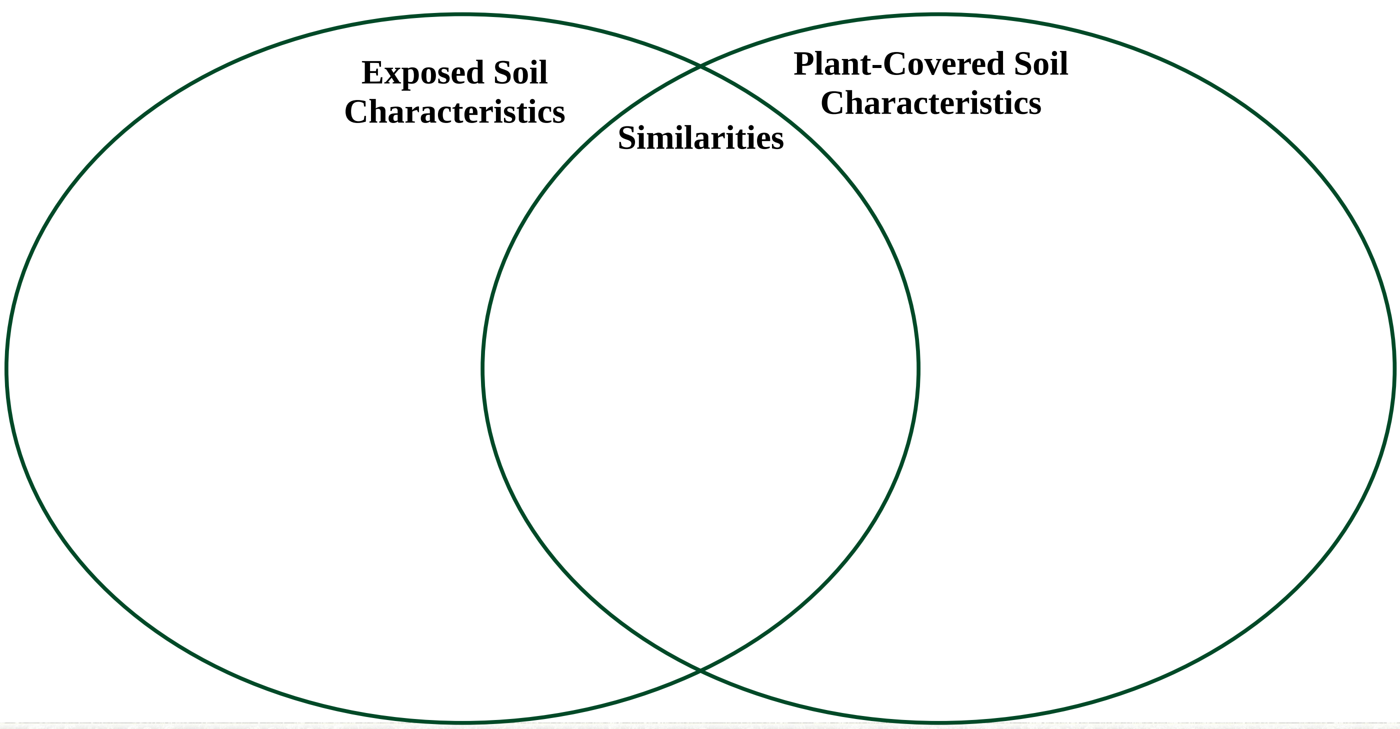
Extend (~35 minutes)

Ask an adult to join you on an outdoor walk. As you're walking, keep an eye out for parts of the ground that are covered with plants and parts of the ground with bare earth exposed. (A planted field, garden, or wooded area might be a great place to find these!)

If it is safe to do so, examine both of these areas more closely. Look at and feel the soil under the plants, then do the same for the exposed soil.

What are each of these like, or what traits do they have? How is the soil from each of these areas the same? How is it different?

You can use the Venn Diagram below to help you organize your thoughts and answer these questions.



If you have permission to do so, try pulling up one of the plants. Hold the plant at the base of the stem (near the ground), and pull with a steady motion. What happened? Was it easy or a difficult thing to do?

Did the roots come up with the plant? If so, what do you notice about them? If the roots didn't come up with the plant, why do you think that is?

What effects do you think plant roots have on erosion? What evidence do you have for this?

Why would cover crops reduce soil erosion?

This project was developed as part of the IPREFER project (Integrated Pennycress Research Enabling Farm and Energy Resilience) at Illinois State University.

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Reflect (~10 minutes)

What was your favorite part of this lesson? Why?

Do you think erosion is good, bad, or neutral? Why do you think that?

What are some things humans have done that has made erosion worse? What are some things humans have done to reduce erosion?

Pollinator Services

Introduction (~5 minutes)

Just like humans and all other living things, plants need to reproduce to survive. In *A Plant Primer*, you learned how plants reproduce through two-gamete reproduction. In case you forgot, here's a quick review.

Petals are often brightly colored and scented. Some flowers also have nectaries. These traits have changed over generations to help attract pollinators.

The plant's sex organs are inside the flower. Complete flowers have both male and female organs. Incomplete flowers have either male and female organs.

In flowers, the male organs are the filament and anther. The anther makes pollen, and it is held high by the filament. The filament length maximizes the chances of pollination. This is especially true of tube-shaped flowers.

The female part of the flower that receives the pollen is the stigma. It is a sticky platform in the center of the flower. The stigma is held up high by the style. When pollen lands on the stigma, it travels down the style to the ovary.

Which pollinators might we see in our field?

In *A Plant Primer*, you also learned that it is better for the next generation if pollen is moved between plants. Flowers can't move to mate with another flower, so they rely on pollinators.

Pollinators are usually animals (mostly insects, birds, and bats). They move pollen from the anther of one flower to the stigma of another. They are vital for plant reproduction, but pollinators don't help plants just to be kind. Plants and pollinators have a mutualistic relationship. They both benefit from pollination.

We know how the plants benefit. They get to reproduce with another plant. But how do the pollinators benefit? Pollinators are interested in the flower's nectar or sometimes the pollen itself.

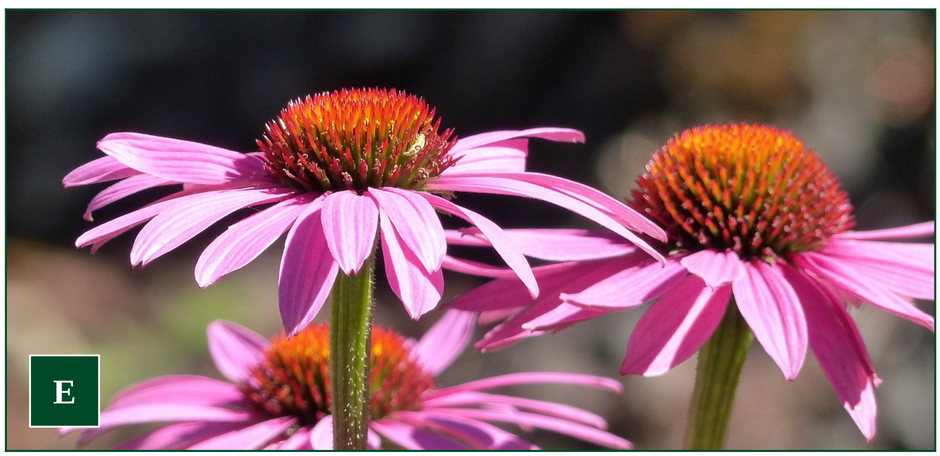
Nectar is a sugary liquid found at the very bottom of flowers. If you like candy, cake, or other sweets, you can understand that nectar is an appealing food source! When the pollinator goes to the bottom of the flower to get nectar, they are sure to touch pollen along the way. (See the cute bee covered in pollen to the left.) When they visit another flower, some of that pollen will brush against the new flower's stigma.

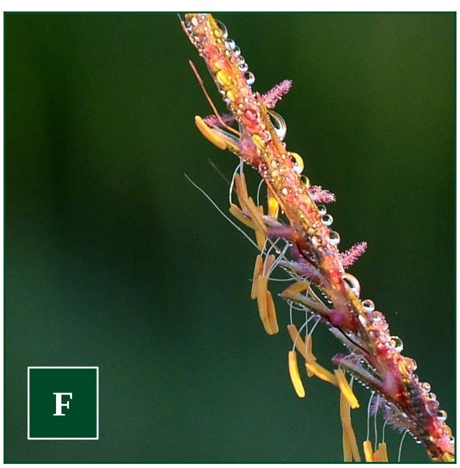
Pollen is also a food source: it contains sugars, starches, fats, proteins, vitamins, and minerals.

Explore (~40 minutes)

In this activity, you will work to find what pollinators like about flowers. Plant ecologists watched different flowers (see below). They counted how many pollinators visited each flower over the course of an hour.

Their results are in the table on the next page. Sadly, they left out some data about the flowers. Use the images to complete the "Traits" column in the data table. These traits could be a key way flowers attract pollinators.





		Number of visits by each pollinator					
	Traits	Bats	Bees	Birds	Butter-flies	Flies	Moths
A	**Color:** **Size:** **Shape:** **Smell:** foul or odorless **Other:** blooms during the day, must be pollinated within 24 hours	7	0	0	0	72	20
B	**Color:** **Size:** **Shape:** **Smell:** strongly sweet **Other:** delicate landing pad, flowers open around sunset	11	5	0	0	0	34
C	**Color:** **Size:** **Shape:** **Smell:** subtly sweet **Other:** blooms during the day throughout the summer	0	17	0	43	0	8
D	**Color:** **Size:** **Shape:** **Smell:** none **Other:** smaller flowers are complete and can self-pollinate, blooms in spring	0	0	0	3	5	8

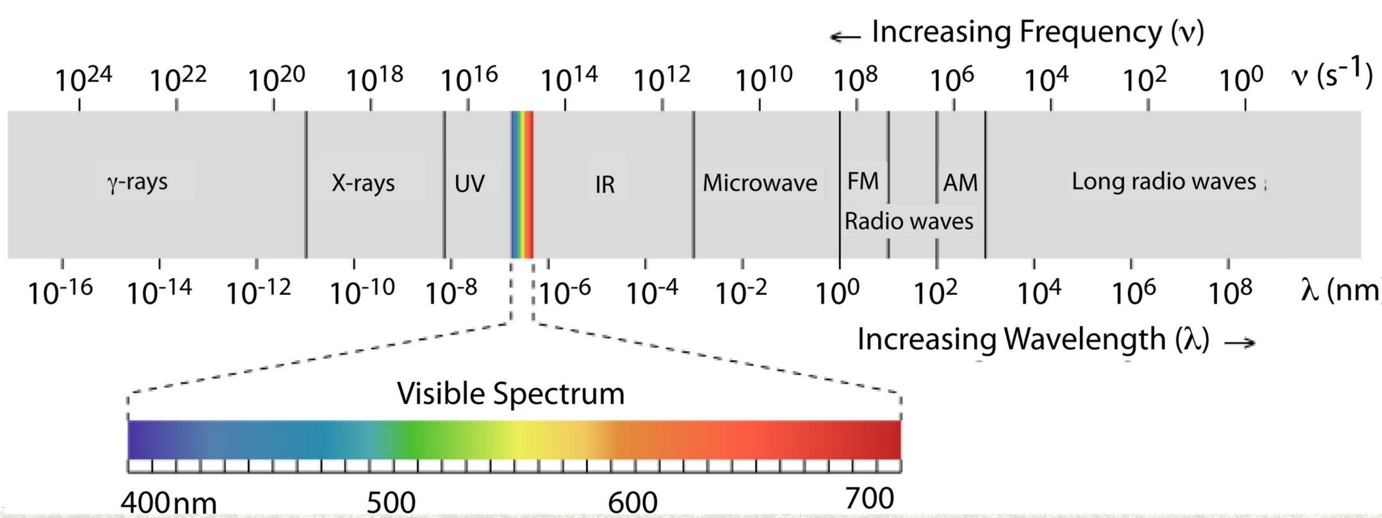
	Traits	Bats	Bees	Birds	Butter-flies	Flies	Moths
		Number of visits by each pollinator					
E	**Color:** **Size:** **Shape:** **Smell:** subtly honey-like **Other:** blooms during the day throughout the summer	0	63	0	15	9	0
F	**Color:** **Size:** **Shape:** **Smell:** none **Other:** blooms in late summer through early fall	0	3	2	4	0	0
G	**Color:** **Size:** **Shape:** **Smell:** none **Other:** no landing pad, flowers point down	0	0	38	9	0	4
H	**Color:** **Size:** **Shape:** **Smell:** sweet and musky **Other:** sturdy landing pad, flowers open at night, must be pollinated within 24 hours	23	0	4	0	0	13

After you complete the tables on the previous pages, figure out what flower traits each pollinator likes. Use the data to find the traits that you think each pollinator prefers!

Pollinator	Color	Size	Shape	Smell	Other
Bats					
Bees					
Birds					
Butterflies					
Flies					
Moths					

Explain (~30 minutes)

You may have learned about electromagnetic radiation (EMR) before. In the diagram below, you can see everything from gamma rays, x-rays, and ultraviolet light through radio waves.



Visible light is the part of EMR spectrum that humans see as color.

Of course, humans aren't the only species that can see color. Some species can see parts of the electromagnetic spectrum we cannot. Use the images on page 2 and the descriptions of pollinators below to check your table. While you do so, answer the questions.

Bats
Most bats in North America are insectivores. Many bats in subtropical and tropical regions consume fruit and nectar instead. Bats can hover, but will also land on flower petals that are sturdy enough to hold their weight. Contrary to popular myth, bats are not blind but can see quite well, even in low light. They also have good senses of smell. They visit and pollinate flowers at night.

Think about being outside at night. What colors (including black and white) are most visible outside at night?

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Bees
Bees can see light from about 300-650 nanometers, as well as UV light. They are attracted to sweet smells and land on flower petals to gather pollen.

Look at the electromagnetic spectrum. What colors do bees see? What flower colors do you think they're most attracted to?

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Birds
Birds can see very well. They can see UV light as well as the entire visible light spectrum. Birds are most attracted to bright reds and oranges. However, they have poor senses of smell.

Hummingbirds have long beaks that house an even longer tongue. Their tongue is used to reach deep into tube-shaped flowers and suck up sweet nectar. Birds do not rest on the flower petals or sepals to consume nectar. They typically hover by the flower.

Consider birds' senses of sight and smell. Which do you think they use to locate flowers and feed on nectar?

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Butterflies
Humans have three types of color receptors in their eyes. Butterflies can have up to 15 different color receptors. Generally, butterflies can see the entire visible light spectrum and UV light. Like birds, they have a poor sense of smell.

Butterflies have a long, hollow proboscis that unfurls to drink nectar from flowers, like using a straw. Many butterflies are able to hover, although some rest on the flower petals to eat.

Think about how big butterflies are. What size flowers do you think they are most likely to feed on and pollinate?

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Flies

Flies have a strong sense of smell and are often attracted to foul odors. Flies that pollinate flowers often lay their eggs on plants. When larvae hatch, they have a ready food source. Many fly larvae are insectivores, eating plant pests like aphids. Since aphids will eat the plants, even young flies are helping the plants.

Flies usually pollinate flowers that are pale in color with dark brown or dark purple patches. They land on flower petals to gather pollen and typically visit flowers that are on trees or close to the ground.

Flies are smaller insects. Fruit flies, for example, are only about ⅛ of an inch long. What size flowers do you expect them to pollinate?

Moths

Moths are nocturnal relatives of butterflies, so they are active at night. They also have a long proboscis to drink flower nectar and tree sap. Moths can see UV light and white light but not colors. Moths have a strong sense of smell and are attracted to sweet smells. Like butterflies, many moth species can hover.

Moths and butterflies are physically similar; for instance, they both have a long proboscis. What type of flower shape does this proboscis allow them to feed on and pollinate?

Moths and butterflies look similar, but they differ in the types of flowers they prefer to pollinate. Think about moths' and butterflies' senses of sight and smell. How do these senses affect the type of flowers they prefer to pollinate?

Look back at the images on page 2. Are there any plants that don't seem to have a dominant pollinator? How else can pollen be spread?

Extend (~30 minutes)

You now know some pollinator preferences! Let's look at some cover crops.

Can you figure out what types of pollinators visit these crops? In the table on the next page, fill out the predicted pollinators column.

Cover Crop	Predicted Pollinators	Actual Pollinators
Rapeseed (*Brassica napus*) 		
Common Buckwheat 		
Red Clover (*T. pratense*) 		
Lady Phacelia or Purple Tansy 		
Pennycress (*Thlaspi arvense*) 		

Go to your favorite search engine, then find each plant's pollinators. University, park service, or USDA web sites are usually reliable.

Fill in the actual pollinator(s) column.

You probably found that bees pollinate many cover crops. You may have seen a lot about native bees. You already know cover crops help prevent soil erosion and help soil retain nutrients. Now you know that they are also important for pollinators!

We can thank native bees for nearly one third of the mouthfuls of food we eat. Wild bees have three basic habitat needs. They need access to food, protection from pesticides, and areas to nest in. (As we know, food comes in the form of pollen or nectar. Pesticides come in many forms, but they are all chemicals used to kill unwanted insects, fungi, or other pests.)

Cover crops can meet all three habitat needs! Research suggests that having diverse pollen and nectar sources improves bees' health. This increases their chances of surviving exposure to pesticides. Cover crops also have nesting sites in their stems and in larger flowers. Cover crops are a great way to make a habitat for bees when cash crops like corn are not in season. This increases the chances that they'll be there to pollinate cash crops when they grow later in the summer.

Pennycress can be a very useful cover crop. Many bees hibernate in the winter. When they wake up in the spring, most flowers have not bloomed, so food is hard for them to find. Pennycress flowers early in the spring. It can provide both pollen and nectar to bees before other crops begin to flower. Pennycress is visited by over a dozen species of flies and small bees, with up to 68 insect visits per minute!

If there is an area near you that has cover crops or wildflowers, take a walk there with a trusted adult. This may be in a park, near a planted field, or even in your own backyard! Open the iNaturalist app that you used for *A Plant Primer*. Enter the flowers that you see on your walk. Remember, the more you enter, the more you are helping research the Earth's biodiversity!

Reflect (~20 minutes)

Pennycress produces both pollen and nectar for bees. However, it doesn't make as much as some other cover crops. How could scientists help pennycress make more pollen and nectar? (Hint: Think about how plants change over time.)

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If you took a walk to find flowers in this module or when completing the *Plant Primer* module, look at the pictures you took.

a. What do you think pollinates these plants? (If you look close, you may see pollinators in your picture!)

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b. Does it seem like the same type of insect pollinates most plants, or is there a variety?

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c. Are there any pollinators that you see fewer of in your community? Look up that pollinator. What does it like to pollinate?

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What pollinators didn't you know about before? What did you learn that surprised you?

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Why are cover crops important for pollinators?

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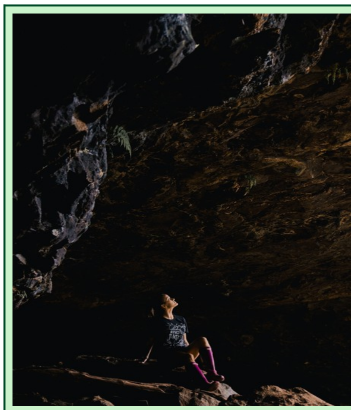

Career Connection: Chiropterologist

Chiropterologists (or bat biologists) are scientists who study bats. As you've learned, many bats are pollinators! Bats are studied for lots of reasons. They are unique creatures. They are also model organisms for studies on hearing, echolocation, and even fighting disease!

Most bat biologists begin with a 4-year degree in a field of biology. They will then earn a master's degree in an area like wildlife biology. They will learn common biology methods and how to use technology. Tools make up for humans' poor sight and hearing in bat habitats.

Cover Crop Products

What can we make from cover crops?

Introduction (~10 minutes)

Inks are made by mixing pigments (color-rich chemicals) with a solution which will not spread or blur on paper. Most inks use petroleum bases, but did you know that you can also make ink using plant oils?

Inks from seed oils, including soy or pennycress, stick better than their petroleum counterparts. (They do not rub off.) They also make paper easier to recycle, are more biodegradable, and are made from a renewable resource!

Gather the materials from the list on the right. (Note that the oils do not need high levels of processing. This means any pennycress oil you have extracted yourself is perfect for this activity!)

Begin by mixing your water and pigment in your plastic cup until it is well-mixed. Add the oil and stir it well.

When your liquid is well-mixed, stop stirring and watch it for one minute or more. Do you see oil, water, or solids beginning to separate? Describe what you see.

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Add the lecithin, then continue mixing your ink until the appearance is as uniform as possible.

Stop stirring and watch the liquid for another minute.

Do you see oil, water, or solids beginning to separate? Describe what you see.

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Use your ink to draw, write, stamp, or otherwise create a work of art.

Introduction Materials List

- Pennycress or vegetable oil (1 mL or 1/8 tsp)
- Granular lecithin (1 mL or 1/8 tsp, found in health food stores)
- Dry pigment (5 mL or 1 tsp; you can use dry tempera paints, crushed charcoal, ground spices like paprika, or even a sugarless, colored drink mix)
- Water (5 mL or 1 tsp)
- Stir stick
- Small cup (~100 mL or 3 fl. oz.)
- Rubber stamp, traditional dip pen, or a toothpick to use as a stylus
- Paper for printing or writing
- Tools for measuring wet and dry volume

Explore Materials List

- Pennycress or vegetable oil (3 mL or ½ tsp)
- A second oil (3 mL or ½ tsp)
- Water (8 mL or 1½ tsp)
- 4 small cups (~100 mL or 3 fl. oz.)
- Isopropyl (Rubbing) Alcohol (1 mL or 1/8 tsp)
- Granular lecithin (2 mL or ½ tsp)
- Stir stick
- Tools for measuring wet and dry volume

Explore (~25 minutes)

You should have seen a distinct difference in how the solution separated with or without lecithin. Why is that? Let's mix some materials to discover what lecithin does.

For each row on the next page, mix the materials as described. For each row, observe the mixture for one minute or more. Complete the column for observations without lecithin.

Then, stir and add 0.5 mL of lecithin. Observe for another two minutes, and record your observations in the remaining column.

When you are finished, ask a trusted adult how to dispose of the mixtures. (You may be able to turn one or more into ink if you have extra materials!)

Mixture	Observations when mixed WITHOUT lecithin	Observations when mixed WITH lecithin
1 mL Oil #1 and 2mL Water		
1 mL Oil #2 and 2mL Water		
1 mL Rubbing Alcohol and 2mL Water		
1 mL Oil #1 and 1 mL Oil #2		

Explain (~10 minutes)

Which solutions mixed well without lecithin?

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Which solutions mixed better with lecithin?

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Let's take a look at the properties of each.

- Oil is non-polar (charges on opposite sides cancel each other out). It is also hydrophobic (it does not mix well with water).
- Alcohols are somewhat polar. Unlike oil, alcohols are not very hydrophobic. They will mix with water, but not immediately.
- Water is polar (it has positively-charged and negatively-charged sides). It is also hydrophilic (it mixes well with water).

If lecithin helps both polar and non-polar molecules to mix, what is it? Lecithin is a more complex molecule which is an "amphiphilic surfactant." Amphiphilic means it has both polar and non-polar ends, so it can keep water and oils mixed. A surfactant is a chemical which reduces surface tension. With a surfactant, a liquid will lie flat (not "bead up.")

Why would surfactants be an important ingredient in an ink?

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What do you think is the most important ingredient in ink? Why?

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Extend (~25 minutes)

As we've already learned, polarity is an important part of why inks work. In most inks, water is the delivery system for the pigment and oil helps hold the pigment to the paper. Without a chemical like lecithin, you would have to shake your ink bottle (and maybe even your pen!) before every dip.

There are many other products which had to overcome a similar problem. Have you ever had non-homogenized milk? In non-homogenized milk, cream floats to the top, and the milk must be shaken to spread the milk fat throughout the liquid milk.

Most of the milk we buy has been homogenized. In homogenized milk, milk fat is cut into very small particles so the cream can remain suspended in water. Homogenized milk is a colloid, where the fat isn't dissolved, but the particles are so small it doesn't easily separate.

For milk to be homogenized, the milk fat particles must be about 1 micron (1 micrometer) in size. A human hair is about 70 microns wide, so the globules of milk fat are far smaller than you can see with your eyes alone.

While we cannot see how particles of milkfat are distributed in milk, we can see how particle size affects our ink.

Follow the steps from the Introduction of this module to make two new batches of ink. This time, try using pigments of different sizes than you did last time. Our goal is to compare how the pigment spreads when we compare relatively large, medium, and small particle sizes. Sugarless drink mixes often have very small particle sizes, and ground spices are often larger than most.

Remember that some of your observations can come from your original batch of ink if it is still available.

Extend Materials List

- Pennycress or vegetable oil (2 mL or ¼ tsp)
- Granular lecithin (2 mL or 1/4 tsp, found in health food stores)
- Dry pigment (10 mL or 2 tsp; you can use dry tempera paints, crushed charcoal, ground spices like paprika, or even a sugarless, colored drink mix)
- Water (10 mL or 2 tsp)
- Stir sticks
- 2 Small cups (~100 mL or 3 fl. oz.)
- Traditional dip pen or a toothpick to use as a stylus
- Paper for printing or writing
- Tools for measuring wet and dry volume

Observations

Smallest Particle Size:

I used: ____________________________________

I observed: ________________________________

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Medium Particle Size:

I used: ____________________________________

I observed: ________________________________

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Largest Particle Size:

I used: ____________________________________

I observed: ________________________________

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How did the ink flow differ when pigment size changed? Did one write more smoothly? Did one have a more consistent color?

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Reflect (~10–25 minutes)

Have you tried to make ink or paints before today? (Many flowers, even dandelions, can be used to make watercolors.) If so, was the ink-making process you used today any different?

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Flavor mixes for milk (eg. Nesquik® or Ovaltine®) include soy lecithin. Why do you think lecithin is a key ingredient?

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Materials scientists look closely at traits like color, spread, and permanence. How could your ink could be improved?

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What experiment(s) could you conduct to find a better recipe? Conduct your experiment and report your results!

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Career Connection: Materials Scientist

Many of the materials we use in our everyday lives do not come directly from living things. Many materials are modified by humankind to be better: stronger, more flexible, or more resistant to wear. Materials scientists work to understand and modify the properties of these materials in order to meet human needs.

Materials scientists start with a bachelor's degree in chemistry, though most jobs require a master's degree or higher.

Crop Product Supply Chains

What happens to a crop after harvest?

Introduction (~10 minutes)

When you're hungry for a peanut butter and jelly sandwich, you may head to your cupboard or you may have to go to the store. Fortunately, you won't need to find a peanut plant and start the process from the beginning!

On the right half of this page, write steps you can think of in the process of making a jar of peanut butter. A first and last step have been included. As you can see, you can write your ideas in any order.

Don't forget about the steps described in earlier modules of this project book, like planting and harvesting. Think as well about those steps which may take place more than once, like shipping. There are many possible answers!

When you are finished, re-order the steps from start to finish. There are blank spaces on the next page. You can cut out the steps on this page if it would help you rearrange them.

Farmer buys peanut seeds
Customer buys jar of peanut butter

(This panel is left blank to allow cutting and re-arranging the steps on the front page.)

Steps to make & buy a jar of peanut butter
1. Farmer buys peanut seeds
2.
3.
4.
5.
6.
7.
8.
9.
10.
11.
12.
Customer buys jar of peanut butter

Explore (~15-25 minutes)

You have listed the most important steps of making peanut butter, but it is always fun to go through the steps yourself. Let's make some sunflower butter!

Explore Materials List

- Sunflower seed kernels, salted (~2 cups)
- Food processor or high-powered blender
- Silicone spatula

With an adult's help, read the instructions for your food processor or blender. They contain sharp parts, and they can only be run for a certain amount of time before their motors need to cool off.

When you are ready, pour the sunflower seed kernels into the machine. With an adult's help, start it at a low speed or pulse the device (turn it on and off) to reduce motor stress.

Run the machine according to its instructions. At times, you will need to scrape the walls of the container with your spatula. Keep blending until the sunflower seed butter becomes a smooth, oily spread (like creamy peanut butter!). This may take 10 minutes or more.

Your sunflower butter is delicious with bread, crackers, rice cakes, or a variety of other foods. Store it in an airtight container.

Explain (~10 minutes)

Sunflower kernels are rich in protein and oil. This is true of many seeds, but crops which are valued most for their oil are called oilseed crops.

Pennycress (*Thlaspi arvense*) is one such oilseed crop. Its seeds are heated and crushed to extract the oil. About 35% of the seed is oil.

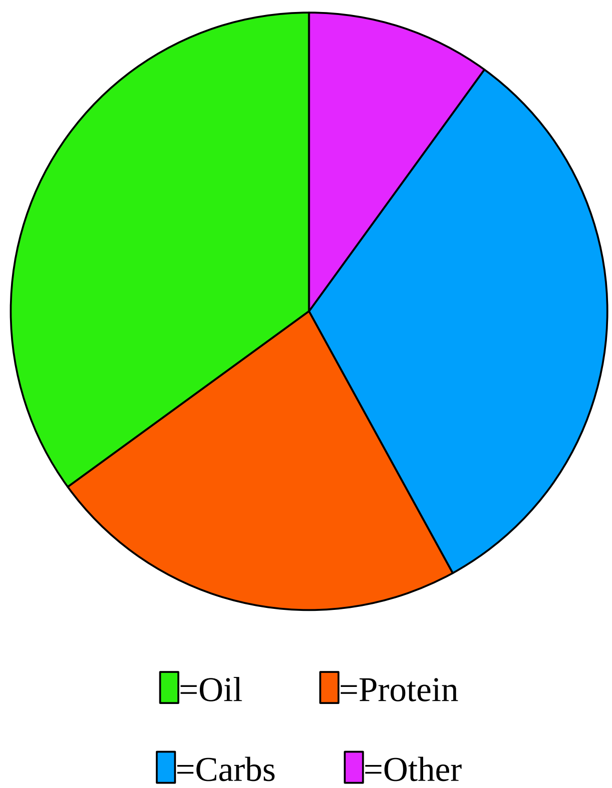
What do we do with the rest of the seed? About 10% is of the seeds are other materials like vitamins and minerals. About 23% of the whole seed is protein. The remainder is carbohydrates (carbs).

Subtract each number to find the amount of carbs in a pennycress seed.

100% - 35% Oil - 23% Protein – 10% Other =

____% Carbs

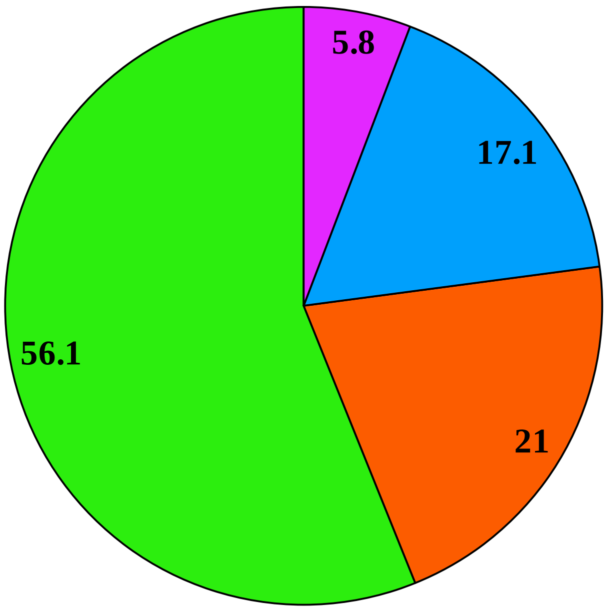
Use this information to complete the pie graph on the right.



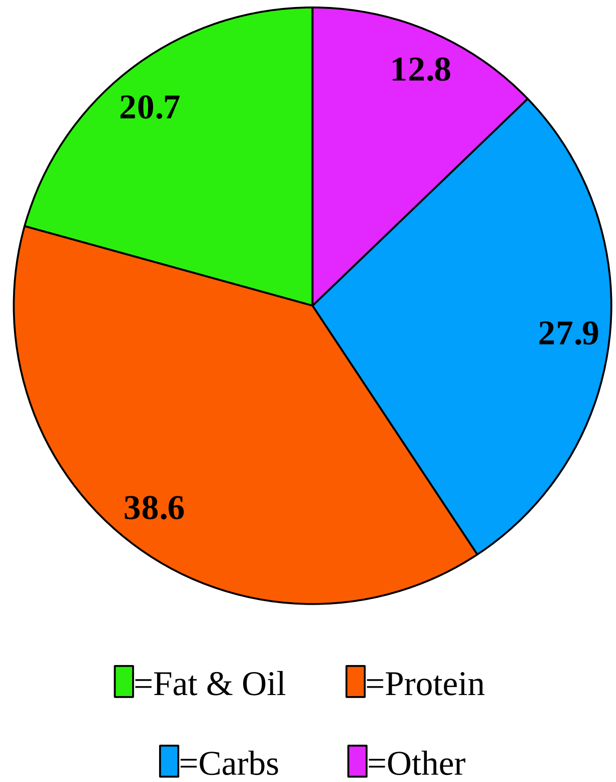
Label your pie graph sections with the percent.

Compare this to the nutrients in sunflower and soy seeds. These are graphed below.

Sunflower Seed Kernel Nutrient Content



Ground Soy Nutrient Content



What are these nutrients used for when they come from sunflowers or soybeans? Do a little research. Can the nutrients be used to make biodiesel, cooking oil, or animal feed?

Fat & Oil: ________________________________

Protein: ________________________________

Carbs: ________________________________

Look back at the amount of nutrients in each seed. For each crop, what is an ideal use of that plant's seed?

Pennycress: ________________________________

Sunflower: ________________________________

Soy: ________________________________

Extend (~25 minutes)

Look back at the list of tasks you made in the Introduction activity. Each of these tasks are likely critical—without that task, peanut butter would not exist, or it would not reach the store.

Now consider the cost of peanut butter. If a jar of peanut butter costs $5.00, why is it worth $5?

Every time work is done to plant, harvest, move, grind, or package, value is added to the product.

This added value is not free. It costs the farmer money to plant, it costs truckers money to move materials, and it costs factories money to make the peanut butter.

Complete the table below, estimating the cost of each step and the value at each stage.

A few hints before you get started:

- Buying enough peanuts to make a 12 oz. jar of peanut butter only costs about $0.55.
- About half the cost of a jar of peanut butter is spent on the steps requiring shipping (seed to the farm, peanuts from the farm, jars to the factory, jars from the factory, and from the warehouse to the store).
- A grocery store will pay about $3 for a jar of peanut butter. The $2 the store adds to wholesale price is used to pay employees at the store, keep the lights on, and make a profit.

Step	Additional cost	Reason for cost	Total value
1. Farmer buys peanut seeds	$0.05	Seeds are bought from a dealer or saved from a previous harvest.	$0.05
2.			
3.			
4.			
5.			
6.			
7.			
8.			
9.			
10.			
11.			
12.			$5.00
Customer buys jar of peanut butter			

Reflect (~10 minutes)

Look back at the steps you developed in the Introduction one last time. What kind of jobs must be done for each step to be completed?

1.

2.

3.

4.

5.

6.

7.

8.

9.

10.

11.

12.

Which of these jobs do you think you might want to do? Why?

____

____

____

You've probably spent more time thinking about peanut butter today than ever before. What is something you'll remember from now on when you eat peanut butter, sunflower butter, or another seed butter?

____

____

____

This project was developed as part of the IPREFER project (Integrated Pennycress Research Enabling Farm and Energy Resilience) at Illinois State University.

IPREFER is supported by Agriculture and Food Research Initiative Competitive Grant No. 2019-69012-29851 from the National Institute of Food and Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the USDA.

Career Connection: Logistics Specialist

Logistics specialists oversee shipping, warehousing, and receiving. They often have offices in the warehouse. They manage tasks, schedules, and workers. They ensure that everything arrives and leaves their company on-time. To do so, they sometimes do manual work like moving boxes.

Logistics specialists can complete a high school education and rise through the ranks at a company. They can also earn certificates or degrees.

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Career Connection: Technical Editor

Technical editors help scientists share their findings. They proofread, edit and rewrite articles. They ensure accuracy and ease of reading. Some editors also create page layouts.

Most editors earn a bachelor’s degree in English, communications, or journalism. A bachelor's degree is not always required, though. Some editors gain training in an area of content focus like agriculture or biology.

Facilitator's Guide

Thank you for taking on the challenging and rewarding role of 4-H Cover Crop Science Project Facilitator. This guide is designed to help you use the modules in this book with groups instead of individuals.

Most of the modules were piloted with groups of youth working together. This guide provides insights from these experiences with youth in grades 3-8.

These modules can be used sequentially, may be combined with other project areas, or be used as part of a larger agriculture curriculum.

Background Information

What is a cover crop? A cover crop is planted off-season, or when the main cash crop is not being grown. As you will learn, cover crops have many benefits. They protect soil and provide food and shelter to many organisms.

Throughout this experience, we will investigate a variety of cover crops, but we will focus on one more than the others. Pennycress (*Thlaspi arvense L.*) is an oilseed cover crop which can offer all the benefits above. For more about current research, visit https://iprefercap.org/.

Pennycress can be harvested to make biofuels, cooking oils, and more. It is an appealing cover crop option for farmers.

Pennycress has not traditionally been used as a cover crop, but because it is being researched as we speak, it is the perfect place to start learning about cover crops. You will be learning about this specific cover crop alongside scientists throughout the Midwestern United States.

Scientists are exploring the potential of pennycress by working in a variety of teams.

The agronomy and crop management team is working to discover how to best plant and harvest pennycress, as well as how to minimize weeds and pests. We will explore this group's work in Modules 1A through 1C.

The breeding and genetics team is looking at how to help pennycress produce the most seeds with the most seed oil. We will look at this group's work in Modules 1D and 1E.

The ecosystems services team is working to identify the benefits pennycress has for soil, water, and pollinators. We will explore this group's work in Modules 2A and 2B.

The supply chain team is looking at how to take seeds and turn them into products like crayons, cooking oil, and biofuels. We will explore this group's work in Modules 2C and 2D.

How to Use This Book

This book contains 9 modules. Each module includes several hands-on or minds-on activities. Though each module can be completed on its own, youth will develop more knowledge and have a richer experience if the modules are used in order. In this way, they will build on their previous learning and form connections to prior explorations.

Section 1: How are Cover Crops Grown & Developed?

- Module A: A Plant Primer
  What do flower parts tell us about plants?
- Module B: Cover Crops in the Rotation
  When are cover and cash crops in the field?
- Module C: Planting & Harvesting
  How do we make machines for cover crops?
- Module D: Natural & Artificial Selection
  What do we do to improve crops over time?
- Module E: Gene Editing
  How can we accelerate artificial selection?

Section 2: What are the Benefits of Cover Crops?

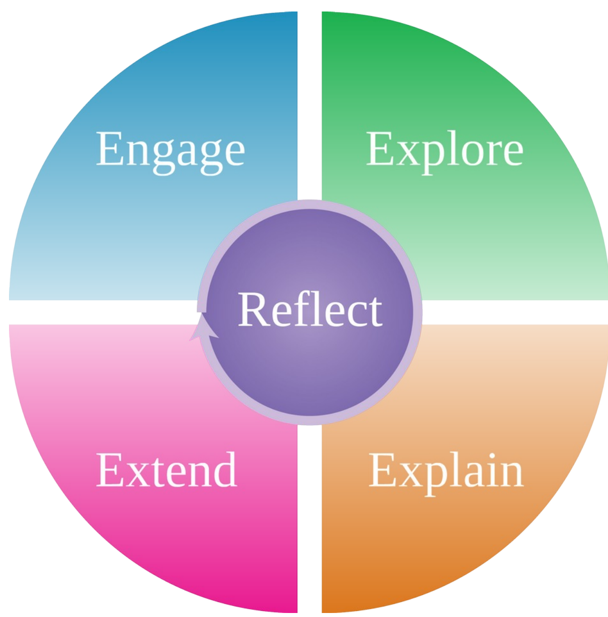
- Module A: Reducing Soil Erosion
  How do we keep land healthy?
- Module B: Pollinator Services
  Which pollinators might we see in our field?
- Module C: Cover Crop Products
  What can we make from cover crops?
- Module D: Crop Product Supply Chains
  What happens to a crop after harvest?

A Note to the Project Helper

The help and support of an adult project helper can make a huge difference in the life of a young person! This might be an adult relative, a teacher, a 4-H leader, or a family friend. Knowledge of education or agriculture may be helpful, but any caring adult can fill this role.

As the young person works through the modules, the project helper can make sure activities are done safely. They can also provide support as the young person gathers materials and information. They might encourage reflection by asking additional questions as well as provide positive guidance and feedback. They should challenge the young person to continue their growth through new opportunities and constructive appreciation.

The modules in this book are arranged in an inquiry-based format that follows these stages:



- Introduce/Engage – Youth are introduced to the topic through pictures, web searches, readings, and other activities. This activity develops a driving question that will guide the rest of the module.

- Explore – Youth do an activity, monitor results, observe phenomena, and/or collect data related to the driving question.
- Explain – Youth analyze their results, observations, and data to develop an answer to the driving question.
- Extend – Youth apply their new knowledge to a different context. They make connections to the driving question.
- Reflect – Youth think through what they knew before and what they know now. Reflection can take place at every stage of the module, but specific reflection questions are given at the end.

These stages work together in a cycle, and some modules walk through the stages more than once.

Each module also highlights a career connection. These show how today's cover crop science learning can be the first step on a path to the future.

This project book centers around cover crop science, and it strives to help young people gain knowledge and skills in this topic. However, it is important to note that this project is also a vehicle for more holistic positive youth development (PYD). This matches the goal of all 4-H programming.

PYD strives to foster behaviors and attitudes in young people that will allow them to thrive throughout their life.

National 4-H Council has summarized essential elements of PYD with the acronym BIG-M. BIG-M stands for Belonging, Independence, Generosity, and Mastery. As a project helper, you can look for ways to build upon these elements within the project work.

Belonging
- Develop a healthy and caring relationship with your young people.
- Ensure a physically and emotionally safe environment during project work.
- Remind young people that they are part of something bigger. This project brings youth into current, ongoing cover crop research taking place throughout the Midwestern U.S.

Independence
- Allow young people to ask their own questions. They should follow their own unique areas of interest as you explore cover crops together.
- Serve in a supporting role as youth make their own decisions about their path through the project.
- Use the Career Connections to help young people see how their current and future decisions can impact their future.

Generosity
- Ask young people how they can use their new skills and knowledge to give back to their larger community.
- Discuss the ways cover crops and other sustainable agriculture practices benefit everyone. Planet and climate health are important to all of us!
- Help young people brainstorm and carry out a service project or educational campaign focused on cover crops.

Mastery
- Encourage young people to share or exhibit their new skills and knowledge.
- Challenge young people to deepen their skills and knowledge with further project work or further opportunities.
- Recognize effort, attitude, perseverance, and a willingness to try new things.

Educational Standards

The modules in this book support addressing many different educational standards. The following list is a great start for formal educators who would like to use this book as a part of a unit of instruction in science, technology/engineering, math, language, the social sciences, or the visual arts.

Module 1A: A Plant Primer

- CCSS.ELA.RI.6.1. *Cite textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text.*
- NGSS.MS-LS1-1. *Conduct an investigation to provide evidence that living things are made of cells; either one cell or many different numbers and types of cells.*
- NGSS.MS-LS1-3. *Use argument supported by evidence for how the body is a system of interacting subsystems composed of groups of cells.*

Module 1B: Cover Crops in the Rotation

- CCSS.ELA.RI.6.1. *Cite textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text.*
- NGSS.MS-LS1-5. *Construct a scientific explanation based on evidence for how environmental and genetic factors influence growth of organisms.*
- *NGSS.MS-LS2-5. Evaluate competing design solutions for maintaining biodiversity and ecosystems services.*

Module 1C: Planting & Harvesting Processes

- NGSS.MS-ETS1-3. *Analyze data from tests to determine similarities and differences among several design solutions to identify the best characteristics of each that can be combined into a new solution to better meet the criteria for success.*
- STEL-7Q. *Apply the technology and engineering design process.*

Module 1D: Natural and Artificial Selection

- NGSS.MS-LS1-5. *Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.*

Module 1E: Gene Editing

- CCSS.ELA.RI.6.1. *Cite textual evidence to support analysis of what the text says explicitly as well as inferences drawn from the text.*
- NGSS.MS-LS1-5. *Construct a scientific explanation based on evidence for how environmental and genetic factors influence the growth of organisms.*
- NGSS.MS-LS3-1. *Develop and use a model to describe why structural changes to genes (mutations) located on chromosomes may affect proteins and may result in harmful, beneficial, or neutral effects to the structure and function of the organism.*

Module 2A: Soil Erosion Reduction

- NGSS.MS-ESS2-2. *Construct an explanation based on evidence for how geoscience processes have changed Earth's surface at varying time and spatial scales.*

Module 2B: Pollinator Services

- NGSS.MS-LS1-4. *Use argument based on empirical evidence and scientific reasoning to support an explanation for how characteristic animal behaviors and specialized plant structures affect the probability of successful reproduction of animals and plants respectively.*

Module 2C: Cover Crop Products

- NCAS.VA:Cr2.1.6a. *Demonstrate openness in trying new ideas, materials, methods, and approaches in making works of art and design.*
- NCAS.VA:Cr2.1.7a. *Demonstrate persistence in developing skills with various materials, methods, and approaches in creating works of art or design.*
- NGSS.MS-PS1-2. *Analyze and interpret data on the properties of substances before and after the substances interact to determine if a chemical reaction has occurred.*
- NGSS.MS-PS1-3. *Gather and make sense of information to describe that synthetic materials come from natural resources and impact society.*

Module 2D: Crop Product Supply Chains

- CCSS.MATH.K-12.MP.2. *Reason abstractly and quantitatively.*
- CCSS.MATH.7.RP.2. *Analyze proportional relationships and use them to solve real-world and mathematical problems. Recognize and represent proportional relationships between quantities.*
- NSS-EC.5-8.2.3. *Apply the concepts of marginal benefit and marginal cost.*

Facilitation Guide for Module 1A: A Plant Primer

Learning Objectives

- *What do flower parts tell us about plants?*
- Plant structures have different jobs.
- Plants use flower structures for reproduction.
- Different plants have similar structures, but differences in structures benefit each plant in its environment.

Modified Materials Lists

Explore 1: We recommend 1 flower, tweezers, and hand lens for every 2 learners.

Explore 2: Learners can work in groups of 2-4, or you can use microscopes if they are available.

Modified Instructions

Skip the *Introduction*.

Explore 1: ~10 minutes as modified. Have learners use the diagram to guide their dissection and identify plant parts. As they work, have them think about the function each part might play. Having learners record their thoughts on the function of each structure may help them to engage more deeply in the activity.

Explain 1: ~10 minutes. Print Appendix A: Plant Function Poster Cards and place the functions on a blank wall. Give each learner one of the plant structure pages, then ask them to come to the front of the room and place it next to the job their plant part provides. As learners place their page, ask the group to vote by show of hands if they are in agreement. If the answer matches, confirm that it is correct; if not place the word aside and say that you will circle back when there are fewer choices. Be careful to provide respectful feedback and not to fault learners for their answers. Many plant parts also have multiple functions, with different functions in different plants, so these "best answers" on the right aren't the only correct answers. Continue until all matches are made.

Complete *Explore 2* (~40 minutes), *Explain 2* (~5 minutes), *Extend* (~35 minutes), and *Reflect* (~10 minutes) as time and materials allow.

1. Petals	→	C. Attracts pollinators
2. Sepals	→	F. Protects the flower before ...
3. Filament	→	G. Holds the anther up at ...
4. Anther	→	E. Produces pollen
5. Stigma	→	A. Sticky platform that ...
6. Style	→	B. Holds the stigma up ...
7. Ovary	→	H. Produces ovules, matures ...
8. Ovule	→	D. Matures into a seed that ...
9. Pollen	→	I. Produces sperm after...

Facilitation Guide for
Module 1B: Cover Crops in the Rotation

Learning Objectives

- *How do cover crops fit between cash crops?*
- Different plants have different growing seasons.
- Farmers plan their year around the growing season of their cash crop.
- Cover crops like pennycress can be used between cash crops to ensure there is always something growing in the field.
- Growing cover crops has benefits, but there are drawbacks too. For example, cover crop seed is not free, and it takes time to plant and/or terminate cover crops.

Modified Instructions

Introduction: ~10 minutes. Answer the first question as a whole group. Learners will likely figure out that cover crops are crops that cover the earth. From there, have learners brainstorm benefits and drawbacks in pairs before sharing ideas with the whole group.

Explore: ~15 minutes. You may run the activity as-written or assign learners a specific cover crop to explore.

Explain: ~10 minutes. You may choose to project or print the Appendix B: Crop Sequencing Poster Cards and have learners work in groups of 2 or 3.

Extend (~10-30 minutes) and *Reflect* (~5 minutes) are best completed by individual learners. These are also ideal opportunities to bring families into the conversation!

Facilitation Guide for Module 1C: Planting & Harvesting

Learning Objectives

- *Why do we build different farm machines?*
- Separating seeds by hand is difficult.
- Using tools makes separating seeds faster and easier.
- Machines combine tools to better do work.
- Engineers design adjustable machines so they can be used with a variety of seeds and plants.

Modified Materials List

For the *Introduction* and *Explore* activities, we recommend materials for every 2 learners.

For the *Extend* activities, we recommend materials for every 4 learners. In addition to the normal materials, consider adding 8 pieces of construction paper (in 2 colors) for each group, as well as a 12-inch ruler and some scissors.

Modified Instructions

Introduction: ~10 minutes. Explain the goal of the simulation: to separate seed [rice] as quickly and cleanly as possible. Give learners 5 minutes to work with their choice of a spoon or fork. Have learners estimate how long it would take them to separate all the rice in the cup. In a whole group, have learners discuss the pros and cons of using a spoon or fork as well as the strategies that helped them to be successful.

Explore: ~15-20 minutes as modified. Have learners work with a partner to try new strategies in one or two more 5-minute trials. Be sure to have learners predict total time with each strategy and calculate actual total time. Having learners share their most fruitful strategies after each iteration will help all groups find success and emphasize the collaborative nature of engineering communities.

Explain: ~20 minutes as modified. Use this as a guide for a whole group discussion. Emphasize that this is how engineers do their best work—working collaboratively and through informed trial-and-error! Watch the video together.

Extend: ~20-35 minutes. After predicting which processes will bridge the Explain and Extend activities, continue by watching the video. If math is a focus, it may be instructive to note how units canceled out in the calculation:

$$\frac{\cancel{\text{lbs}}}{\cancel{\text{acre}}} * \frac{\text{seeds}}{\cancel{\text{lbs}}} * \frac{\cancel{\text{acre}}}{\text{inch}} = \frac{\text{seeds}}{\text{inch}}$$

After completing the rest of the Extend activity, consider having learners map the size of the mature plants as well. A soybean plant which is planted according to the dimensions in the module will have an oval shape measuring approximately 20 inches by 2 inches. A domesticated pennycress plant will be more circular, measuring 3 inches in diameter. Have participants cut these shapes and place them under the seeds, then discuss plant density, when and how plants can share space, and the amount of bare earth.

Reflect: ~20 minutes. This activity can be completed as-written.

Facilitation Guide for Module 1D: Natural & Artificial Selection

Learning Objectives

- *What do we do to improve crops over time?*
- Plants can change over the course of generations through natural and artificial selection.
- Changes in plants are observed in their phenotypes, or their visible traits.
- Wild plants have phenotypes which help them survive in the wild.
- Humans use artificial selection to breed plants with phenotypes that are best for human use. (For example, shape, size, and location of different plant structures.)

Modified Instructions

Skip the *Introduction* and *Reflect* activities.

Explore: ~20 minutes as modified. Begin by having small groups compare the plant structures in corn and teosinte. Appendix C: Illustration of Corn and Teosinte is available to project or print. A 3D Model of a Teosinte Cob is also available if you want to conduct a hands-on comparison to a real ear of corn. Follow that with a whole group discussion of the vocabulary from the beginning of the module, especially phenotypes and alleles. Finish by reading the passage at the top of page 3 aloud.

Explain: ~20 minutes. Have learners complete the first table on their own, then pair up and compare. Have learners continue in pairs or small groups to complete the second table.

Extend: ~25 minutes as modified. Complete the activity as a whole group. Show learners Appendix D: Wild Cabbage Poster. Ask them to draw what the plant would look like if we selected for the plant structures below. After 1-2 minutes to work, show the vegetable match from Appendix E: Artificial Selection of Wild Cabbage Posters. Repeat. End by viewing SciShow's *Kale, Cauliflower, and Brussels Sprouts are the Same Species*.

leaves and stems	→	Chinese kale
flower bud clusters	→	cauliflower
buds along the stem	→	brussels sprouts
stem and root	→	kohlrabi
flower buds and stem	→	broccoli
leaves	→	kale
buds at the leaf end	→	cabbage

Facilitation Guide for Module 1E: Gene Editing

Learning Objectives

- *How can we accelerate artificial selection?*
- Genetic mutations drive both natural and artificial selection.
- CRISPR-Cas9 is a gene-editing technology which causes a mutation in specific genes.
- Crops can be domesticated more quickly with the use of gene editing technology.

Modified Materials Lists

For *Explore*, we recommend 100 candies per every 2 learners.

Modified Instructions

Introduction: ~25 minutes if modified. If literacy is a focus, consider using the article on which the Introduction is based: How can we save bananas from a deadly disease?. The concepts participants need to understand ahead of the later activities are identified by the three questions in the Introduction of this Cover Crop Science module.

Explore: ~15 minutes as modified. Have learners work in pairs. As one learner places 20 random candies in a line, their partner can make the matching strand of DNA, then roles can switch.

Explain: ~10 minutes. Have the partners continue working together, reading and completing the table.

Extend: ~20 minutes. Provide each learner in a pair with an image from Appendix F: Secret Seed Posters. Instruct one partner to describe their seed while the other sketches what they think the seed looks like, then switch roles. Suggest that both the images and sketches should be kept secret until both drawings are complete. When the groups have completed their sketches, they can identify the key differences between seeds and complete the questions in the module.

Reflect: ~10 minutes. Complete as-written.

Facilitation Guide for Module 2A: Reducing Soil Erosion

Learning Objectives

- *How do we keep land healthy?*
- Erosion is the movement of earth materials.
- When soil is removed from the land through erosion, it becomes difficult to grow crops.
- Plants are the best way to reduce soil erosion, but some plants are better than others at preventing soil erosion.

Modified Materials Lists

For *Explore*, we recommend materials for every 3-4 learners.

Modified Instructions

Introduction: ~15 minutes. To facilitate this activity, we provide Appendix G: Erosion Photo Posters. The optional Appendix H: Erosion Definitions is available if you don't have time or resources for learners to conduct their own research.

Explore: ~45 minutes in groups. Learners can work in teams of up to four. It works well for learners to choose (or be assigned) roles.

- One learner can be the "sculptor," or the participant who gets their hands messy shaping and re-shaping the sand hills.
- Another learner can be the "pourer," or the participant who pours the water into the sandbox in the same place and same speed every time.
- A third learner can be the "collector," or the participant who holds the cup to collect critical sand and water.

- Finally, a fourth learner can be the "mover" and/or "key observer," responsible for moving the sandbox to the table and on the table between trials as well as determining the amount of sand collected in each trial.

Before each collector begins their first collection, we encourage you to have the collector show you their method. Especially if you are using a plastic sandbox, the water will be attracted to the static charge of the plastic and it can be difficult to collect. The cup needs to be held perfectly flat (with the top perpendicular to the floor) and pressed flush against the box without lifting the box. This is easiest to accomplish by pressing the cup up from the bottom instead of holding the cup by its sides.

Explain: ~20 minutes as modified. LIFE Magazine's Scenes From an American Dust Bowl comes from the 1954 Dust Bowl, which is less commonly known than the 1930s Dust Bowl. Ask learners what they know about the 1930s Dust Bowl, then explain that dust storms are recurrent events. There are some fears that a new dust bowl may hit in the next 10 years! Ask learners to brainstorm ways to help hold soil in place.

Extend (~35 minutes) and *Reflect* (~10 minutes) can be adjusted to meet your time constraints.

Facilitation Guide for Module 2B: Pollinator Services

Learning Objectives

- *Which pollinators might we see in our field?*
- Pollinators play an important role in plant reproduction, and in making fruits and nuts.
- Different flowers have traits to attract different types of pollinators.
- Cover crops like pennycress can provide food sources for pollinators when cash crops are not growing.

Modified Instructions

Introduction: ~10 minutes. In place of the written Introduction, show the Six Pollinators Video. As participants are watching, ask them what organisms they are seeing and why the organisms are at the flower. (Most are after nectar, but the bees may also be collecting pollen. Both are food sources: nectar is a better source of sugar and pollen is a better source of protein.)

Explore/Explain: ~35 minutes when combined as modified. Show learners the first of Appendix I: Pollinator Introduction Posters without an organism and ask them to guess the primary pollinator. Reveal the correct answer using the corresponding photo, then discuss why that pollinator is interested in the flower.

- Bats use tongues to lap up nectar. Bats are usually nocturnal, so they are attracted to light colors which stand out in the darkness. They can fly and hover, but they usually like sturdy flowers which can support their weight.
- Bees have a proboscis (a long tube they

use like a straw). Bees also collect pollen, which they make into a protein-rich "beebread." Bees are attracted to bright colors and large, flat flowers.

- Birds who drink nectar usually have long beaks and sometimes long tongues so they can reach into deep, narrow flowers.
- Butterflies have a proboscis which allows them to reach into deep, narrow flowers as well. They can see but not smell, so they are attracted to bright flowers.
- Flies also have a proboscis. They are often attracted to strong, sour smells. They like lighter colored flowers with nectar that is easy to access.
- Moths have a proboscis. Moths are nocturnal and they have limited vision, so they are attracted to light colors which stand out in darkness. They also respond well to stronger smells.

Then, use Appendix J: Flower Photo Posters to play a game like Family Feud to guess the top three pollinators for each flower. Answer values appear in the table below.

Image A	Flies 72% .. Moths 20% .. Bats 7%
Image B	Moths 68 .. Bats 11 .. Bees 5
Image C	Butterflies 63 .. Bees 25 .. Moths 12
Image D	Moths 50 .. Flies 31 .. Butterflies 19
Image E	Bees 72 .. Butterflies 17 .. Flies 10
Image F	Butterflies 44 .. Bees 33 .. Birds 22
Image G	Birds 75 .. Butterflies 18 .. Moths 8
Image H	Bats 58 .. Moths 33 .. Birds 10

Extend (~30 minutes) and *Reflect* (~20 minutes) can be completed as-written and as time allows.

Facilitation Guide for Module 2C: Cover Crop Products

Learning Objectives

- *What can we make from cover crops?*
- Ink is one of many products that can be made from cover crops.
- Making ink requires water, oil, and a bit of chemistry knowledge.
- Most products require many ingredients, each of which have a job to do.

Modified Materials Lists

If you choose to complete the *Pre-Introduction* described below, you will need foods (or food packaging) which have plant oils and proteins which could come from cover crops, as well as distractors. For example:

- Butter crackers, granola, ranch dressing, milk chocolate morsels all usually contain plant oils which could come from an oilseed cover crop like pennycress.
- Tuna in water, oranges in gelatin, yogurt, ketchup, and raisins usually contain no ingredients from cover crops.

The *Explore* materials can be gathered for every 4 participants (and the *Extend* for every 2 participants) if you choose to crowd-source data instead of having each learner gather their own.

Modified Instructions

Pre-Introduction: ~10 minutes. If you're looking for an active lead-in activity, consider the following. Set up a relay race where participants race to sort and deliver products to a basket or hula hoop. Learners are responsible for sorting the items according to whether or not the item includes ingredients from an oilseed cover crop like pennycress. A list of products is available in the Modified Materials List above.

Introduction: ~15 minutes. Complete the Introduction as-written, though a little extra time may be required to distribute and measure materials.

Explore: ~15 minutes as modified. The Explore activities can be distributed, with each learner completing one experiment instead of four. Be sure the results of each experiment are shared with the whole group.

Extend: ~20 minutes as modified. Similar to the modified Explore, this activity can be done with pairs of learners testing different pigment sizes.

Reflect: ~30 minutes as modified. If time permits, consider conducting additional experiments or exploring other ways to make ink or paints, especially using flowers like dandelions to make watercolor.

Facilitation Guide for Module 2D: Crop Product Supply Chains

Learning Objectives

- *What happens to a crop after harvest?*
- Many steps are required to make any product and get it to its end user.
- It costs time and money to make a product, from planting and harvesting raw materials to selling and delivering those materials.

Modified Instructions

Introduction: ~15 minutes. This can be completed as a whole group if you prefer.

Explore: ~5 minutes as modified. This can be completed as a concurrent demonstration during Introduction, Explain, and Extend.

Explain: ~15 minutes if modified. As an alternative to the labeling activity, have learners create their own pie graph(s).

Extend: ~30 minutes as modified. We recommend that the Extend activity be completed as a whole group.

Reflect: ~10 minutes. Complete in small groups or as individuals.

This project was developed as part of the IPREFER project (Integrated Pennycress Research Enabling Farm and Energy Resilience) at Illinois State University.

IPREFER is supported by Agriculture and Food Research Initiative Competitive Grant No. 2019-69012-29851 from the National Institute of Food and Agriculture. Any opinions, findings, conclusions, or recommendations expressed in this publication are those of the authors and do not necessarily reflect the view of the USDA.

Petals

Sepals

Filament

Anther

Stigma

Style

Ovary

Ovule

Pollen

A. Sticky platform that catches pollen

B. Holds the stigma up at a height likely to catch pollen from different flowers

C. Attracts pollinators

D. Matures into a seed that can begin the next generation

E. Produces pollen

F. Protects the flower before it opens

G. Holds the anther up at a height most likely to effectively transfer pollen

H. Produces ovules, matures into the fruit

I. Produces sperm after successful travel through the stigma and style

 Pennycress single flower growth chamber. (2019). IPREFER.

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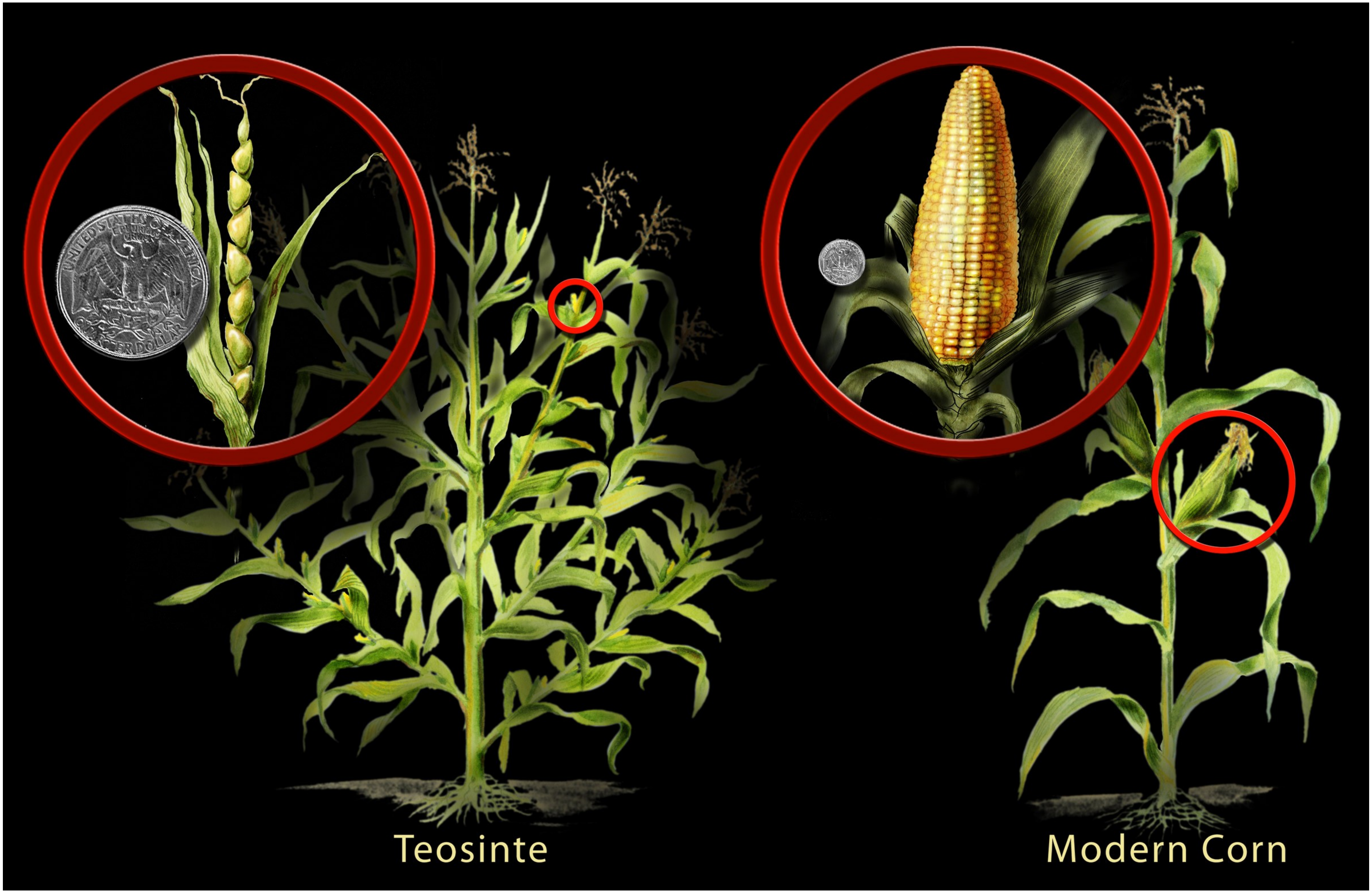
 Mature pennycress pods with seeds, Macomb, IL 2014. IPREFER.

 Pennycress flower stalk, *Macomb IL 2014*. IPREFER.


Teosinte
Modern Corn

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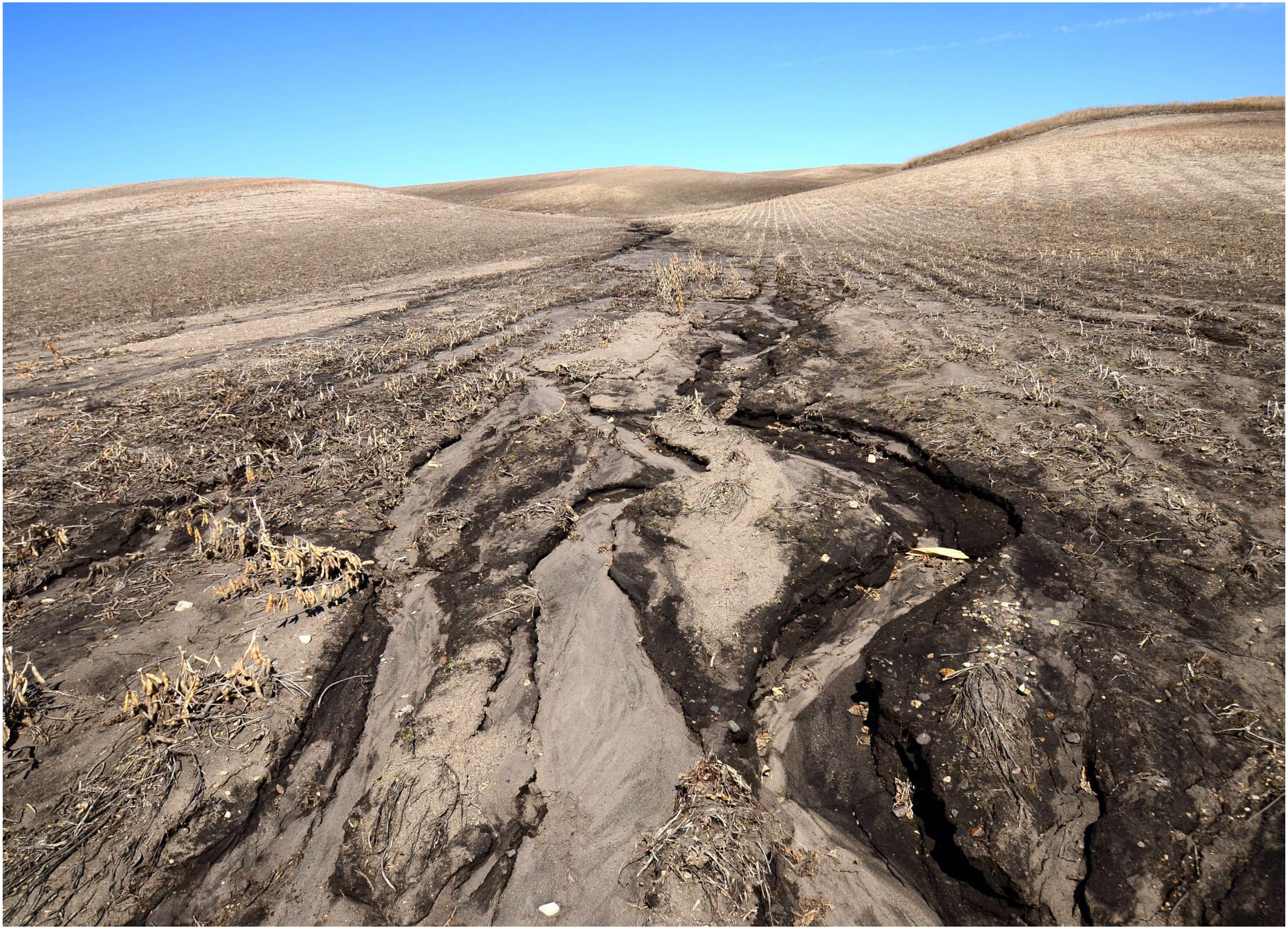

 Wupperman, M. (2017, August 19). *Grass beside the sea*. CC0.

 Hagaman, M. (2016, March). *A seaside cow in Co. Mayo.*

SCHOLASTIC

What causes valleys to form? Why do streams and lakes get muddy after a rain storm? Why are the rocks at the bottom of a river usually round? The answer to all these questions is EROSION!

Erosion is the process by which the surface of the Earth gets worn down. Erosion can be caused by natural elements such as wind and glacial ice. But anyone who has ever seen a picture of the Grand Canyon knows that nothing beats the slow steady movement of water when it comes to changing the Earth.

The key to erosion is something called "fluid flow." Water, air, and even ice are fluids because they tend to flow from one place to another due to the force of gravity. Of the three, liquid water is the most common agent of erosion because there's so much of it on the surface of the Earth.

Tomecek, S. (2020, February 10). *What is Erosion?* Scholastic. https://teacher.scholastic.com/dirt/erosion/whateros.htm

NATIONAL GEOGRAPHIC RESOURCE LIBRARY | ENCYCLOPEDIC ENTRY

Erosion is the geological process in which earthen materials are worn away and transported by natural forces such as wind or water. A similar process, weathering, breaks down or dissolves rock, but does not involve movement. Erosion is the opposite of deposition, the geological process in which earthen materials are deposited, or built up, on a landform. Most erosion is performed by liquid water, wind, or ice (usually in the form of a glacier). If the wind is dusty, or water or glacial ice is muddy, erosion is taking place. The brown color indicates that bits of rock and soil are suspended in the fluid (air or water) and being transported from one place to another. This transported material is called sediment.

Evers, J. (Ed.). (2022, May 20). *Erosion*. National Geographic. https://education.nationalgeographic.org/resource/erosion/

WIKIPEDIA
The Free Encyclopedia

Soil erosion is the denudation of the upper layer of soil. It is a form of soil degradation. This natural process is caused by the dynamic activity of erosive agents, that is, water, ice (glaciers), snow, air (wind), plants, and animals (including humans). In accordance with these agents, erosion is sometimes divided into water erosion, glacial erosion, snow erosion, wind (aeolean) erosion, zoogenic erosion and anthropogenic erosion such as tillage erosion.[1] Soil erosion may be a slow process that continues relatively unnoticed, or it may occur at an alarming rate causing a serious loss of topsoil. The loss of soil from farmland may be reflected in reduced crop production potential, lower surface water quality and damaged drainage networks. Soil erosion could also cause sinkholes.

Soil Erosion. (2022, May 28). Wikipedia. https://en.wikipedia.org/wiki/Soil_erosion

IOWA STATE UNIVERSITY
Extension and Outreach
Integrated Crop Management

Soil erosion: An agricultural production challenge

Encyclopedia Article

Soil erosion is a gradual process that occurs when the impact of water or wind detaches and removes soil particles, causing the soil to deteriorate. Soil deterioration and low water quality due to erosion and surface runoff have become severe problems worldwide. The problem may become so severe that the land can no longer be cultivated and must be abandoned. Many agricultural civilizations have declined due to land and natural resource mismanagement, and the history of such civilizations is a good reminder to protect our natural resources.

Erosion is a serious problem for productive agricultural land and for water quality concerns. Controlling the sediment must be an integral part of any soil management system to improve water and soil quality. Eroded topsoil can be transported by wind or water into streams and other waterways. Sediment is a product of land erosion and derives largely from sheet and rill erosion from upland areas, and to a lesser degree, from cyclic erosion activity in gullies and drainageways.

Al-Kaisi, M. (n.d.). *Soil erosion: An agricultural production challenge.* Retrieved June 7, 2022 from Iowa State University Extension and Outreach. https://crops.extension.iastate.edu/encyclopedia/soil-erosion-agricultural-production-challenge.

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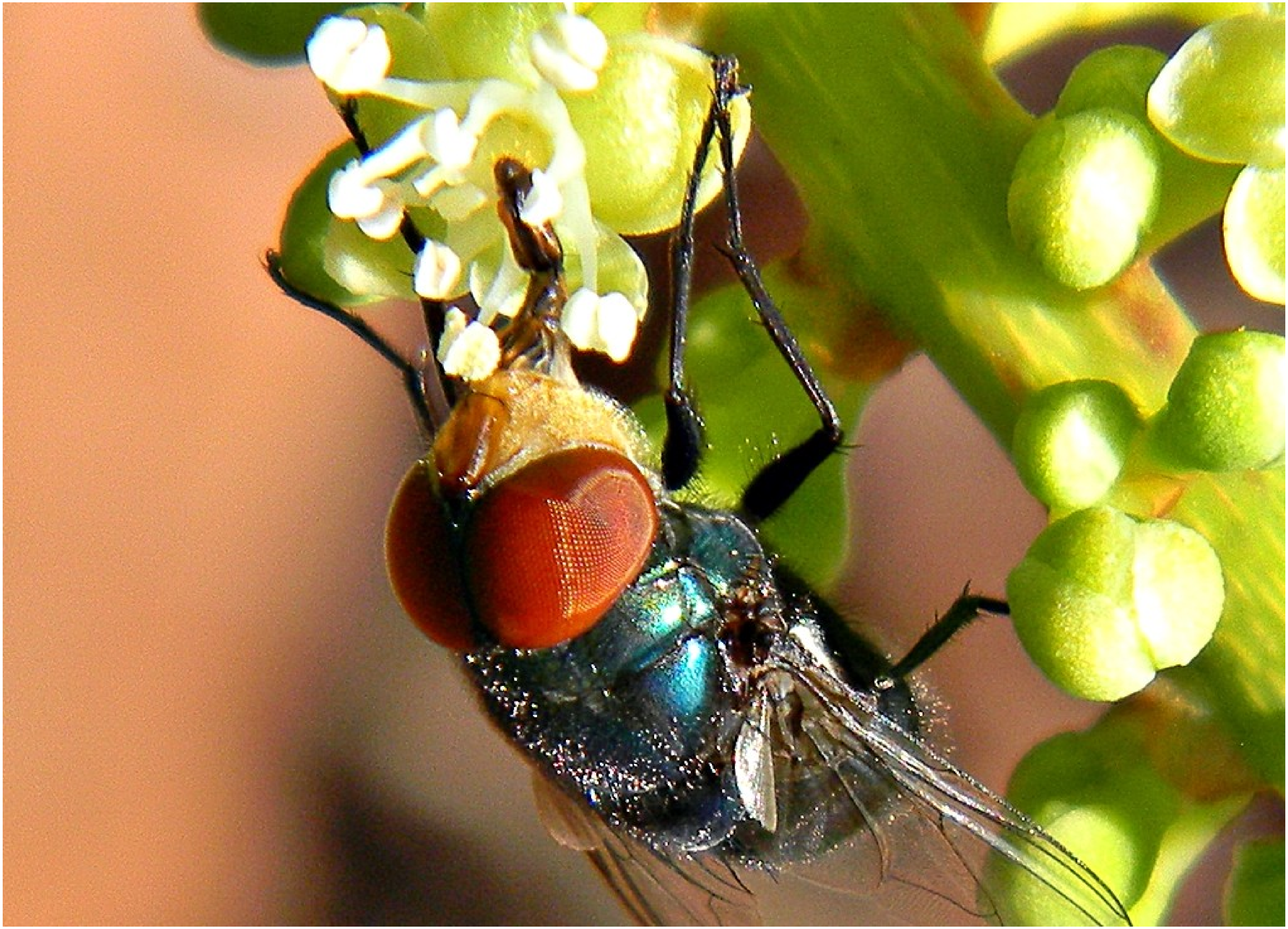

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