AGRONOMY FEEDS THE WORLD

Investigations in Plant/Soil Nutrition, Plant Stresses, Food Production, or Geography and Water

Teacher's Guide: Overview

Premise: One in nine people in the world are hungry, and as the population expands to 9 billion by 2050, food production must rapidly rise to the challenge to reduce hunger. Although food is a basic need for mankind, fewer citizens today are aware of the process of food production and its complexities than they were 30 years ago. Most students may not recognize the term 'agronomy.' Agronomy is a foundation of society because plant production is the basis for all food and feed for animals, in addition to fiber for textiles, fuel for industry, and many medicines. Agronomy is multidisciplinary and from the field to the table food production is impacted by the type of farm, transportation, health, economics, policy, and environment. A key science aspect of agronomy is the intersection with the environment and management decisions that farmers make to safely and efficiently produce food for the world. Understanding that agronomy is a biological system and the intricacies inherent to food production are foundational to understanding that crop production is impacted by ecoregions and management decisions. Critical thinking is fundamental to applying knowledge of biology, plant science, and agronomy to practical decision making about food production.

Objectives:

1. Understand what an ecoregion is and how crop production is impacted by ecoregions
2. Understand the roles of soils and nutrients and how they affect plant growth
3. Understand how plant stresses affect plant growth and management decisions
4. Understand the various decisions that have to be made from field to table.
5. Understand management practices used in particular ecoregions.
6. Demonstrate critical thinking by applying knowledge acquired to a practical real-world situation.

How Agronomy Feeds the World Works: This module consists of a lab inquiry embedded in classroom and online discussions. The lab may be used as a guided or open-ended inquiry and is flexible enough that either type (or both) can be used based on student abilities, course level, and time available. Unlike many labs, the inquiry is designed to produce results that students do not necessarily expect beforehand. By "rocking students' boats," the lab aims to capture the importance of the unknown in science and to demonstrate how unknowns lead to new models, hypotheses, and experiments. Worksheets can help students organize their ideas and reflect on their thinking, either on the computer or in handwriting.

Beyond lab activities, three other activities are essential to fully benefit from this module:

- **ScienceTalk:** an authentic classroom *dialogue* before and/or while experiencing lab activities,
- **ResearchBlogs**: regular *online contact* between students and scientist mentors, and
- **Storyboard Discussion:** an extended post-lab discussion in which students *share and reconcile data* within and across teams.

We have found that a teacher's commitment to dialogue and a focus on students' ideas and reasoning emphasizing the process of science, rather than correct answers, are important to building an open culture for science learning. Explanations using everyday vocabulary are valued over use of scientific vocabulary in the absence of explanations. Additional descriptions of teaching and learning strategies can be found on the "Roadmap Through a Science Project" section of the **PlantingScience** website.

Grade levels: Middle and high school biology, agriculture, AP biology, environmental science, AP environmental science, horticulture, botany, and other life science electives.

Class Time: A four-week investigation will allow enough time to complete the guided and open inquiry lab.

Computer Access: Optimally, daily while designing an experiment and every other class session thereafter; minimally, at least 4 times over the course of the full investigation period. Team blogs require logins.

Crosscutting Concepts & Practices from the Next Generation Science Standards:

CONCEPTS	SCIENTIFIC PRACTICES
• Matter is transported into, out of, and within systems (5-LS1-1) • A system can be described in terms of its components and their interactions (5-LS2-1) • Phenomena may have more than one cause, and some cause and effect relationships can only be described using probability (MS-LS1-4, MS-LS1-5) • Cause and effect relationships may be used to predict phenomena in natural or designed systems (MS-LS2-1) • The transfer of energy can be tracked as energy flows through a natural system (MS-LS2-3) • Science assumes that objects and events in natural systems occur in consistent patterns that are understandable through measurement and observation (MS-LS2-3) • Models can be used to simulate systems and interactions – including energy, matter, and information flows – within and between systems at different scales (HS-LS1-4) • Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system (HS-LS1-5)	• Support an argument with evidence, data, or a model (5-LS1-1) • Develop a model to describe phenomena (5-LS2-1) • Science explanations describe the mechanisms for natural events (5-LS2-1) • Construct a scientific explanation based on valid and reliable evidence (MS-LS1-5, MS-LS1-6) • Use an oral and written argument supported by empirical evidence and scientific explanation to support or refute an explanation or a model for a phenomenon or a solution to a problem (MS-LS1-4) • Science knowledge is based upon logical connections between evidence and explanations (MS-LS1-6) • Develop a model to describe phenomena (MS-LS2-3) • Analyze and interpret data to provide evidence for phenomena (MS-LS2-1) • Use a model based on evidence to illustrate the relationships between systems or between components of a system (HS-LS1-4, HS-LS1-5)

Disciplinary Core Ideas from the Next Generation Science Standards:

AGRICULTURE
HS-ESS2-2. Analyze geoscience data to make the claim that one change to Earth's surface can create feedbacks that cause changes to other Earth systems. http://www.nextgenscience.org/pe/hs-ess2-2-earths-systems **HS-ESS2-5.** Plan and conduct an investigation of the properties of water and its effects on Earth materials and surface processes. http://www.nextgenscience.org/pe/hs-ess2-5-earths-systems
PA SAS Standards: Science and Technology and Engineering Education:
S8.D.1.1.2 Describe natural processes that change Earth's surface (e.g., landslides, volcanic eruptions, earthquakes, mountain building, new land being formed, weathering, erosion, sedimentation, soil formation). **S8.D.1.1.3** Identify soil types (i.e., humus, topsoil, subsoil, loam, loess, and parent material) and their characteristics (i.e., particle size, porosity, and permeability) found in different biomes and in Pennsylvania, and explain how they formed. **S8.D.1.2.2** Describe potential impacts of human-made processes (e.g., manufacturing, agriculture, transportation, mining) on Earth's resources, both nonliving (i.e., air, water, or earth materials) and living (i.e., plants and animals). **S8.A.3.2.1** Describe how scientists use models to explore relationships in natural systems (e.g., an ecosystem, river system, the solar system). **S8.A.2.1.5** Use evidence from investigations to clearly communicate and support conclusions.

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Suggested Schedule of Activities: The core of **Agronomy Feeds the World** consists of student teams asking a research question and completing an experiment to answer it. This is more comprehensive for the classroom if half of the class makes inquiries on plant stresses and the other half on soil and plant nutrition. There is a guided and open inquiry, though this is flexible depending on student abilities, performance expectations, curriculum requirements, or time constraints. The module can be preceded by or extended with another inquiry, such as the Corn Competition or Wonder of Seeds, or continued after the experiment by maintaining a school garden.

Sample Topic	Pre-Activity Science Talk		Activity		Post-Activity Storyboard Discussion	
Exploring the Basics of Agronomy	What is agronomy?	**Blogging With Scientists & Peers**	Meet an Agronomist (in person or via web)	**Blogging With Scientists & Peers**	How does agronomy impact me?	**Blogging With Scientists & Peers**
Exploring the Complexities of Field to Table	What are the six key components of field to table?		Meet an Agronomist (in person or via web)		How do the concepts discussed relate to the six key components of field to table?	
Exploring Ecoregions, Introductory Soil Science and Plant Stress	How is crop production impacted by ecoregions, soils, and plant stress?		Meet an Agronomist (in person or via web) and attend an in- class lecture based on introductory materials		What ideas from the "Meet an Agronomist" Activity can be investigated in an open inquiry and incorporated into a storyboard discussion?	
Exploring Applied Agronomy	How can these agronomy concepts be tested out in experiments and applied to local issues?		Engage in guided and/or open inquiry		How could results and acquired knowledge be integrated into a prototype proposal or management plan?	

Suggested Assessment Schema: The module is designed so that students can be assessed *continuously* for changes in understanding. The pre-lab ScienceTalk, teacher interaction with teams during lab activities, lab journals and worksheets, and blogging online all serve as embedded formative assessment tools. The post-lab class Storyboard Discussion, a final individual reflection, and the post-experience survey serve as summative assessment tools. If desired, summative assessment in an exam format could involve written responses to questions such as:

- What is agronomy?
- What is an ecoregion? How is crop production impacted by ecoregion?
- What are biotic versus abiotic plant stresses? How do plant stress impact plant growth and influence management decisions?
- Describe crop management decisions from crop to table.

Additional Resources: Found on the PlantingScience website, the ***Agronomy Feeds the World Resources*** contains a bibliography of online videos, websites, books, and articles, organized by media type. Items may relate directly to biological processes, to classroom tools and techniques for teaching about the process, or to research on effective teaching and student misconceptions.

Coordinating with the Scientist Mentor: Please let your scientist mentor(s) know…

- your expected start and end dates for interacting with students online,
- how frequently your students meet,
- how often students will have computer access, and
- whether you plan to carry out a guided or open inquiry (or both).

Time Needed: PlantingScience will need to assist with securing an agronomist to speak with the class at least four to six weeks prior to the anticipated start date. At least four weeks will be needed to complete the plant stress and soils open inquiries; focusing only on the guided inquiry will take less time. One or two additional weeks will allow deeper exploration of the impact of soils and stress on plant yield. Up to eight additional will allow implementation of the alternative schemes described in more detail in the **Inquiry Lab** section on page 15.

Students should work in teams of 2-4, and individual team members are encouraged to post online. The image at left indicates opportunities for team **Research Blogging** in the schedule on the next page. Teams may blog from school or from home.

Suggested plan: A calendar-style outline for carrying out a single, open inquiry is provided on the next pages. The plan that is shown assumes that the class meets daily for 45-60 minute periods. Classes on a block schedule can follow a plan similar to that for the daily schedule, with the initial agronomist visit, scientist prompt, and brainstorming taking place on Monday of Week 1*. Students can then to come in

the lab for about 20 min on Thursday of Week 1 to "plant" the seeds after preparations on Wednesday. During Weeks 3 and 4, students may be required to monitor on non-class days, or on class days only, depending on teacher preference. Wednesday of Week 4 provides good timing for final data collection, team data analysis, and team storyboard preparation for discussion on Friday. Alternatively, the inquiry could be extended into Week 5 to avoid having students come to the lab on days when they do not have class.

*Allow at least half of two class periods for experimental design, then 10-15 min per class.

Sample Outline for an Open Inquiry:

	Mon	Tue	Wed	Thu	Fri
Week 1	***Scientist Prompt:*** ***How does agriculture play a part in your community? What kinds of crops are grown locally? What is your climate like?*** **Register, set up team web-site, & make "introduction" post to scientist.** **Optional: Pre-test (your own), review online communication expectations.** **Teacher: Tell students that Agronomist is coming. Students could create questions for scientist in advance.**	**ScienceTalk: What is agronomy?** **What are the six key components of field to table?** **How is crop production impacted by ecoregions, soil, and plant stress?** **Activity: Meet an Agronomist (in person or via the web)** ***Scientist Prompt:*** ***How does agronomy affect you?*** ***How does food get from the field to your table?*** ***What new questions do you have about agronomy?***	**Blog: Reflect on yesterday's Science Talk with the Agronomist. Share something you thought was really cool. Ask a question about it or what the Mentor thinks about it.** **Teacher: Discuss ecoregions, soil, and plant stress in greater depth. Discuss final project components.** **Optional: As a homework assignment, give each student a zip-lock baggie to collect local soil from near his/her house.**	**Immersion Activity: Students will explore different kinds of soils, additives, etc. They will compare their wet and dry textures and view them under a dissecting microscope. (Students could explore the local soils they brought in for homework as well.)** **Begin brain-storming about ideas for an experiment. Generate testable questions related to today's immersion activity and yesterday's discussion about ecoregions, soil, and plant stress.**	**Activities: Implement Nutrient Holding Capacity Teacher Demo and Water Holding Capacity Guided Inquiry.** **Blog: Describe today's activities and results. Come up with additional testable questions.** ***Scientist Prompt:*** **How would you plan out an experiment to answer your testable question?**

	Mon	Tue	Wed	Thu	Fri
Week 2	Teacher: Discuss proper experimental design. Go over the five problem experiments provided by PlantingScience. **Write up a research plan. Ask Mentor for feedback.**	**Read scientist's notes. Modify the research plan based on feed-back, and send your updated plan to your Mentor.** Activity: Create an experiment poster proposal for tomorrow's Skype.	Activity: Skype with Scientists: Teams will present their experiment proposal posters to the Mentors and receive feedback.	Activity: Edit research plan based on Skype feedback. Prepare materials. Weigh, sterilize, and soak seeds. **Blog: Add experiment information to website. Contact scientist for questions or troubleshooting.**	Activities: Plant seeds in soda bottle planters. Begin working on prototype proposal or management plan. **Upload photos of set-up and journal entry containing ideas from today's activity.**
Week 3	Activity: Observe seed(ling)s & record data. Continue working on final project. **Blog: Upload photos & data from ongoing experiment; contact scientist for questions or troubleshooting. Update journal.**	Activity: Observe seed(ling)s & record data. Continue working on final project.	Activity: Observe seed(ling)s & record data. Continue working on final project. **Blog: Upload photos & data; contact scientist for questions or troubleshooting. Update journal.**	Activity: Observe seed(ling)s & record data. Continue working on final project.	Activity: Observe seed(ling)s & record data. Continue working on final project. **Blog: Upload photos & data; contact scientist for questions or troubleshooting. Update journal.**

	Mon	Tue	Wed	Thu	Fri
Week 4	**Activity:** Observe seed(ling)s & record data. Continue working on final project. **Blog:** Upload photos & data from ongoing experiment; contact scientist for questions or troubleshooting. Update journal.	**Activity:** Observe seed(ling)s & record data. Continue working on final project.	**Activity:** Last day of data collection. Analyze data, then prepare storyboard.	**Blog:** Wrap up with research conclusions & ideas for new experiments (summative). **Storyboard Discussion:** Share & reconcile understandings of ecoregions, soil, and plant stress. Connect concepts to local applications.	**Activity:** Skype with Scientists: Teams will present their prototype proposals or management plans to the Mentors and receive feedback.

What factors impact food production from field to table?

Can food grow anywhere? What variables affect crop yield? How can climate change affect plant growth? Is it "better" to choose crops to fit the soil or change the soil to fit the crops?

OPEN OR GUIDED INQUIRY ON AGRONOMY

GOALS & TIMELINE (see **Planner** for sample schedule options)

Goals:

1. Understand what an ecoregion is and how crop production is impacted by ecoregions
2. Understand the roles of soils and nutrients and how they affect plant growth
3. Understand how plant stresses affect plant growth and management decisions
4. Understand the various decisions that have to be made from field to table.
5. Understand management practices used in particular ecoregions.
6. Demonstrate critical thinking by applying knowledge acquired to a practical real-world situation.

Sample sequence:

- *Days 1-3:* Create teams; set up team ResearchBlog and make first entry; ScienceTalk and Meet an Agronomist
- *Day 4-5:* Implement immersion activity, teacher demo, and guided inquiry
- *Day 6-7:* Begin open inquiry: Develop research question and experimental design; ResearchBlog; create poster proposal
- *Day 8:* Skype with Scientists and Presentation of Team Experiment Proposals
- *Day 9:* Refine experimental design; weigh, sterilize, & soak seeds; ResearchBlog
- *Day 10:* "Plant" seeds; begin work on prototype proposal or management plan
- *Days 11-17:* Collect data regularly; ResearchBlog; continue work on storyboards
- *Days 18-19:* Analyze data; finish storyboards; Storyboard Discussion; final ResearchBlog
- *Day 20:* Skype with Scientists: Storyboard

Student Handouts:

Agronomy Feeds the World Student's Guide
Brainstorming Page worksheet
About our Research Question worksheet*
Experimental Design worksheet
Making Sense of the Data worksheet
Student Roadmap (*optional*)

Background: Students will generate ideas about agronomy in four key areas: field to table, geography and water, plant nutrition and soil fertility, and plant stresses. Students' ideas can be taken from their own experiences, discussed in everyday language, and translated into biologically meaningful conceptual models. Students may develop a specific research question, design an experiment, and draw conclusions from the data to refine their working model of ecoregions, soil, and/or plant stresses. The teacher's role is to (a) help students use sound reasoning and evidence to develop an experimental design that clearly addresses a research question and will allow students to build explanations based on the results, while also (b) facilitating connections to deeper concepts and scientific practices.

Activity 1: SCIENCETALK (Allow 20 min to half a class period; follow up with ResearchBlog)	
Juicy Questions: • **What is agronomy?** • **Can food grow anywhere?** • **What does a plant need to grow?** • **Do plants need soil to grow?** • **Is soil just dirt?** • **Can climate affect plant growth?** • **Does growth always mean being taller?** • **What are good measures of growth?** • **What stresses out a plant?** • **What is needed to grow plants on Mars?** • **Is it better to choose plants to fit the environment or change the environment to fit the plants?** • **How are we going to feed 9 billion people by 2050?** The ScienceTalk and subsequent lab inquiry will emphasize **farm to table, geography and water, plant nutrition and soil fertility, and plant stressors** by selecting Juicy Questions accordingly.	**See *Agronomy Feeds the World* for video and material resources** **Video Resources:** http://www.ted.com/index.php/talks/richard_preston_on_the_giant_trees.html (First 4.5 min). **Bruce Bugbee** **Soil Science Society of America videos produced for the 2015 International Year of Soils:** Soils and Climate (https://www.youtube.com/watch?v=T4A_rMlHcyE) (2:55) Soils support Agriculture (https://www.youtube.com/watch?v=GGV2jlg_P4M) (2.5 min).

Key Features of and Suggestions for the ScienceTalk:

The key features of a ScienceTalk, beyond the Juicy Questions, are shown below in *red*. Many suggestions for implementing these features are shown, but feel free to develop your own approach suited to the class.

1. Engage and explore prior knowledge:

- Introduce the concept of agronomy
  - Show a video from ***Agronomy Feeds the World Resources*** to open a conversation (e.g. Soils Support Agriculture).
  - You may focus on the role of **agronomy** to **feed** a growing population.
- Connect the topic to everyday life and its relevance to society and probe for prior knowledge
  - Show a video from ***Agronomy Feeds the World Resources*** to open a conversation (e.g. Soils Sustain Life).
  - Talk about the ongoing increase in the human population (9 billion people by 2050).
  - What will it take to feed 9 billion people by 2050? Where will this food come from?
  - Start with a question such as "What is your favorite meal?" (e.g. salad, pizza).
  - Discuss where all the ingredients for that meal come from. For an example, see the ***Agronomy Feeds the World*** Resources page (e.g. Agriculture in the Classroom).
  - Brainstorm with students about how we get food from the field to the table. Incorporate 6 key topics: food and farm, food and transportation, food and health, food and economics, food and policy, food and environment.
- Connect the topic to geography and the environment
  - Show a video from ***Agronomy Feeds the World Resources*** to open a conversation (eg, Soils and Climate).
  - What is an ecoregion? (ie water, temperature, soil)
  - Ask the students what the unique components of their ecoregion are?
  - Ask the students whether all their meal ingredients could be grown in their ecoregion? Why or why not? (goal: limiting factors such as water, temperature, soil)
  - Can climate affect plant growth?
  - Demonstrate the National Geographic web resource on how much water is used in different regions with different crops. See the ***Agronomy Feeds the World*** Resources page.

- Connect the topic to plant growth and soil fertility.
  - Show a video from ***Agronomy Feeds the World Resources*** to open a conversation (e.g. Soils Protect the Natural Environment).
  - What does a plant need to grow? Do plants need soil to grow? Is soil just dirt?
  - Explore the basics of soil (eg CLORPT, soil texture, macronutrient, nutrient cycling and the role of microorganisms), proper nutrient management (goal: sources and rates).

- Highlight current issues in growing plants (eg Lake Erie and/or Gulf of Mexico and eutrophication, growing plants in space, vertical farms, hydroponics, etc). See the ***Agronomy Feeds the World*** Resources page.

- Connect the topic to plant stressors.
  - Show a video from ***Agronomy Feeds the World Resources*** to open a conversation (e.g. Plant Stress).
  - What stresses out a plant?
  - Brainstorm plant stressors. Group student responses as biotic (introduce disease triangle) and abiotic (introduce duration, frequency, timing and severity)
  - How do we reduce stress in plants? (goal: adaptation, acclimation, cultural practices)

Scientific Inquiry Guiding Question:

Is it better to choose plants to fit the environment or change the environment to fit the plants?

2. Introduce scientific inquiry and experimental design concepts:

- Facilitate a discussion of what it means to conduct a good experiment.
  - This is a prelude to the teacher conducting the guided-inquiry experiment.
  - The discussion will lead to questions about good experimental design.
  - Write students' ideas on the board or have them take notes for when they design their experiments.
  - Discuss the steps in experimental design: state the problem, identify the factors, develop hypotheses, design your experiment, collect your data, analyze and communicate results. Make sure to consider number of treatments, number of replicates, randomization, use of a control, independence between variables, etc. See the ***Agronomy Feeds the World*** Resources page (e.g. Experimental Design Tutorial for Teachers and Designing a Controlled Plant Experiment videos).
  - Does growth always mean being taller? What are good measures of growth? See the ***Agronomy Feeds the World*** Resources page (e.g. Plant Growth Measurement Practices document).

- Don't forget:
  - *Data skills* include careful observing, note taking, data recording, and summarizing data.
  - *Social skills* include teamwork, sharing and building on ideas, and explaining results with and to others.

- If desired, nudge students toward inquiries that use experiments that require similar measurements. Team-to-team consistency will allow easy comparison among teams.

Activity 2: INQUIRY LAB (Allow at least half of two class periods for experimental design, then 10-15 min per class.)

Purpose:

- To understand water holding capacity (WHC) and nutrient holding capacity of different soil textures.
- Apply concepts of soil properties to develop an open inquiry around local soil type and soil problem(s).

Understandings from Part 1:

- Sand has a coarse texture and soils with increased sand content have lower nutrient holding capacity and will filter less dye.
  - **Essential Question:** Which type of soil texture will allow more nutrients to leach out?
- Clay has a fine texture and increased clay content will enhance filtration and result in a clearer leachate.
  - **Essential Question:** Which type of soil texture will have a higher nutrient holding capacity?

Understandings from Part 2:

- Soils with increased sand content have a coarser texture and hold less water. Water transfers through sandy soils more quickly than soils with a finer texture (more clay) because the pore size is larger. Super fine texture like pure clay drain very slowly, and water may pool on top of soil.
  - **Essential Question:** What soil properties affect how much water it can hold and how fast water will drain?

- Students will understand that their local soil is a mixture of different soil textures (sand, silt, and clay) with a water holding capacity and filtering rate that falls between sand and clay.
  - **Essential Question:** How fast does our local soil filter water and what inferences can you make about its texture based on the observed filtration rate?

Optional Elaborations for Part 1 and Part 2:

Teacher- OR student-led: *Because this is an introductory immersion experience, Parts 1 and/or 2 can be set up as demos for the class to view, or for student teams to carry out independently. Time may be the determining factor.*

Design of lab activities: *Different materials may be used, based upon availability or teacher discretion:*

- Pure sand compared with pure clay
- Comparisons among pure sand, pure clay, local soil, potting soil
- Mix soil types (i.e., from sand, clay, and potting soil) to develop to 'soil texture'

Part 1 PROCEDURE: Nutrient Holding Capacity Experimental Design:

Suggested Recommendation: Teacher Demo Instructions:

1. Set up the experiment ahead of time.
2. Prepare each bottle by cutting it in half. The top will be inverted and used as a funnel so that leachate will collect in bottom half. (We used 16.9 oz. Aquafina bottles and cut them along the fourth crease/line up from the bottom of the bottle, which is about 11 cm from the bottom.)
3. Label each bottle top and bottom with the type of soil that will be used for that treatment. Sample treatments:
   - Three types of soil: pure sand, pure clay, and local soil
   - Different percent mixes sand and clay (50% each sand and clay by volume
   - Mixes of sand and clay with potting soil and other materials like compost
4. Add a filter to the inside of each 'funnel.' **For clay soils, add two coffee filters.**
5. Mix in 1 packet of Kool-Aid® powder to the same volume of each soil type.
6. Add an equal volume of soil (with Kool-Aid® mixed in) to each bottle, on top of the filter.
7. *Create a control:* Create a control bottle for the students to compare the initial color of the Kool-Aid® with the color of the leachates. Mix one packet of purple Kool-Aid® with the same volume (200 ml) of water used in the experiment. For the control bottle, discard the top "funnel" half of the bottle and display the Kool-Aid® in the "bottom" half. In addition, students will be able to compare the initial amount of water (200 ml) with the amount that filtered through each soil type to determine water holding capacity.

During Class:

1. *Review with students:* Particles of nitrates and other nutrients are dissolved in the water in soil. Some nutrients are taken up through plant roots, while other nutrients are removed from the soil as it drains, either by moving across the surface (runoff) or filtering down to groundwater (leaching).
2. Ask students to predict what will happen: Which soil texture(s) will produce leachate? Will the leachate(s) be the same color?
3. Tell students to write down their hypotheses about the following 2 essential questions:
   - Which type of soil texture will allow more nutrients to leach out?
   - Which type of soil texture will have a higher nutrient holding capacity?
4. Add 200 ml of water to each soil type and then **wait 20-30 minutes** to observe leachate. **While waiting, students can do Part 2 in their teams.**
5. After 20-30 minutes, have students compare the leachates from each soil type. Ask them: What are observable differences between the leachates (volume, color, clarity, etc.)?
6. Have students write their conclusions after the hypotheses they generated earlier. Discuss the students' conclusions, and clear up any misconceptions.
7. Tell students to write down at least 3 new questions that popped in their minds, based on the results of this experiment.

Part 2 PROCEDURE: Water Holding Capacity Experimental Design:

Suggested recommendations:
Have students work in teams, each with a different soil type. Recommended soil types include: sand, clay, local soil, potting soil, mixture of soils or compost.

Before the activity:

1. Ask students to predict which soil type will hold the most water and how variable water holding capacity will be among the soils.
2. Tell students to write down their hypotheses about the following 2 essential questions:
   - How does soil texture affect how much water it can hold and how fast water drains?
   - How fast does our local soil filter water, and what inferences can you make about its texture based on its filtration rate?

Team Experimental Design Instructions:

1. Prepare bottle with coffee filter and soil as described above.
2. Every 5 minutes, slowly add 50 ml of water to the soil. To ensure water filters through the soil, add water directly on top of soil and not along the edge of the filter.
3. After 20 minutes, stop adding water. **Wait 10 minutes** for the soil to drain **While waiting, complete steps 5-7 of the Nutrient Holding Capacity demonstration (above).**
4. After the 10-minute drain period, pour leachate into graduated cylinder to measure the volume.
5. Each group records their leachate volume and soil properties (i.e.: soil type (sand, clay, etc.), soil texture (fine, coarse)) in a data table on the chalkboard.
6. Create a graph using all teams' measurements. Be sure to label the x-axis and y-axis and include a title.
7. Analyze the graph, and record conclusions.

After the activity:

1. Conduct a class discussion about each team's results and conclusions. Clear up any misconceptions.
2. Tell students to write down at least 3 new questions that popped in their minds, based on the results of this experiment.

Potential Problems for Part 1 and Part 2:

- Do not add a greater volume of water than the bottle or graduated cylinder can hold.
- Make sure water properly flows through the soil. If you add water too quickly it will overflow and not interact with the soil.

Pour water **slowly** directly over the soil, not along the edge of the filter. The purpose of the filter is to keep the soil in the funnel.

Takeaways:

- Every soil has a unique composition and texture.
- Soil types vary by region and have different general nutrient- and water-holding capacities.
- Soil properties affect which inputs (water, fertilizer, etc.) are applied to cropland, as well as how much and how often these inputs are needed.

- Looking at your local soil, what type of problems may a farmer face if he/she had a field with this soil type? (Will fertilizer wash away when it rains? Will water drain before plants are able to use it? Is this the best soil to be growing in?)

Incorporate these concepts into an open inquiry.

Resources:

- Sample Lab Exercise (Determining Impurity/Nutrient Holding Capacity) http://www.doctordirt.org/teachingresources/soilfilter
- "Soil is a Filter" YouTube Video, showing possible lab set-up, procedure, & results: https://www.youtube.com/watch?v=Ve2eXis0j9I
- "Soil is a Filter Annotated" YouTube Video, showing the lab in the last video from another perspective: https://www.youtube.com/watch?v=ex9WiWdOwaI
- "Water Cycle Experiment" YouTube Video, showing water holding capacity of bare vs. covered topsoil: https://www.youtube.com/watch?v=og9cQKxlFnE

References:

- Image on Page 1: http://www.coolgarden.me/wp-content/uploads/2015/11/watering-garden1.jpg
- *Agronomy – Grow with It!* Textbook: Quote from page 57

Inquiry Types & Sample Research Topics

Mold the Inquiry to Fit Your Class:

This inquiry can be a launching point for experiments taking many directions at many different grade levels. For lower-level students, you may wish to limit the inquiry topic to either **germination** or **plant growth**, not both. For an open inquiry, guiding students from expansive "why" questions to testable "how" questions is critical. The ***Student Roadmap through an Investigation*** provides help for students developing their own research questions. Once teams have chosen their research questions, you may have the class gather and hear each other's choices. Have each team justify their question with evidence whenever possible. This will prepare them for the later Storyboard Discussion on their experimental findings and models for seed germination or seedling growth.

How Much Guidance Should a Guided Inquiry Provide?

Due partly to an increasing disconnect from nature in the U.S. population, many students struggle with grounding questions in a biologically meaningful context. You may therefore wish to provide more structure by using a *guided inquiry*. You might have all teams design their own experiment, but assign the entire class a single research question or assign related questions to different teams. You could assign a general research area, within which teams develop their own, more specific research questions. Examples of appropriate questions and research areas are listed below, color-coded by biological process.

Lower-Level Students: *Research questions (and related measurements):* ● **How long does it take for seeds to germinate?** (days to germination; students must define an appropriate benchmark for germination) ● **Do different seed species germinate at the same rates?** (days to germination) ● **Are the germination rates advertised on seed packets accurate?** (days to germination) ● What is the effect of seed depth in potting soil? (**days to germination or percent germination**; **days to *shoot* emergence or percent emergence**) ● **How fast do seedlings of a particular species grow?** (seedling length over time) *Research areas:* ● **Germination success** or **growth rate** under different environmental conditions with **one** test variable. ● **Rate and volume of seeds' water absorption**, based on species or environmental conditions. ● Effects of biological variation among the seeds in a given species on **germination** and **growth**. ● **Whether changes to the seed coat influence germination.** ● **Whether changes to the cotyledons influence growth.**	**Upper-Level Students:** *Research questions:* ● **Does fresh/dry mass change as seeds germinate?** (Measure at multiple time points.) ● **How does seedling dry mass relate to length over time?** (Measure at multiple time points.) ● **Does the anatomy of dark-grown seedlings differ from that of light-grown seedlings?** (Encourage quantitative measurements as well.) ● Does sowing seeds at different densities affect their **germination** or **growth**? ● Does **germination** or **growth** of transgenic and organic seeds differ? ● Does **germination** or **growth** differ for seeds from invasive and native species, and does it depend on whether the species are grown separately or together? *Research areas:* ● ***Tropisms*: how do seedlings respond to a changing orientation with respect to gravity, light, or touch?** ● *Environmental science:* how do pollutants affect **germination** and **growth**? ● *Ecology:* What seeds are present in the seed bank in a local field or forest? Compare their **germination** and **growth** patterns. ● *Physiology:* Links to **The Power of Sunlight**; When do respiration and photosynthesis begin?

Other Materials (per team)

Part 1: Nutrient Holding Capacity Experimental Design:

Materials Required:

- 4 (or more) clear 12-20 oz. water or soda bottles, cut in half, to separate top from bottom: (one more bottle than soil type is needed to allow for a control "bottom" that will only have dyed water (and no soil))
- 3 (or more) soil types: (variable amount based on bottle size/number, but enough to fill the top half of each bottle)
- 4 (or more) packets purple Kool-Aid®: 1 packet **per** soil type **plus** one for the control
- 4 (or more) triangular coffee filters
- Water (200 ml per bottle)
- Sharpie/labeling markers

Procedure:

Follow procedure in "AFW-Guided Inquiry" file.

Part 2: Water Holding Capacity Experimental Design:

Materials Required:

- 1 water bottle (prepared the same way as above) per group
- 1-2 coffee filters (2 are needed for clay) per group
- 1 graduated cylinder per group
- Stop watch (time keeper)
- Bucket for soil disposal
- Water

Experimental Design

Suggested Requirements: Regardless of whether the inquiry is guided or open, students should design their own experiments to address their research question. Encourage students to plan to record both quantitative and qualitative data. Drawings or photos of seeds and seedlings at different stages are useful for monitoring unexpected changes, and including at least one set of measurements will give students experience with summarizing data.

Available Methods and Tools: You might help students think about their options during this phase by putting out the tools and instruments that they can have access to in conducting their experiments. If students have ideas that require other tools or instruments and they can bring them to class or you can acquire them easily, consider expanding the options on a team-by-team basis.

Refining the Experimental Design: After teams have drafted their research plans, they should post them to the team blog for feedback from their scientist mentor. Students often have constructive ideas on how to improve each other's work at this point, so you could also ask teams to read each other's blogs and provide feedback online. Remind students to focus on constructive criticism aimed toward improving the experiments. Teams can then modify their experiments based on feedback.

Alternatively, reviews can be carried out in the classroom, with teams presenting their experimental designs to the class or circulating amongst each other to hear each other's plans and give feedback. Discuss comparing data across teams. Will the types of measurements and units planned create comparable data? Does it matter? If so, how can students change their experiments to allow easy comparisons within the class or with other classes doing the inquiry?	
Logistics	**Technical Notes**
Detailed procedures for carrying out experiments and considerations of **lab safety** are described in the ***Agronomy Feeds the World Student Guide***. Students should **work in teams** of 2-4. Each team will design and carry out experiments separately from the others to answer their own or a selected research question, based on the type of inquiry you choose. Students should each have a **research journal** to record their ideas and observations throughout the inquiry. As they use their journals, students will reveal their thinking and conceptual models. Ensure that your students: 1. journal and collect data regularly, 2. post related information on their team blog, and 3. communicate with scientists and peers regularly.	**Biological relevance:** Students may resist changing biologically irrelevant questions despite encouragement. For example, students are often interested in trials using soda. Since soda is a complex, variable mixture of chemicals that plants rarely encounter in nature, we discourage this type of experiment. Helping students see the environment from a plant's perspective will improve the scientific soundness of their research plans. **Troubleshooting:** Helping students realize that experiments don't always work first time – even for scientists – is important, as problem solving and troubleshooting are highly valued in science-related and other workplaces. However, don't let students get bogged down in technical debugging at the expense of thinking about the big ideas.

Activity 3: STORYBOARD DISCUSSION (Allow 1 class each to prepare & discuss.)

What is the purpose of a storyboard? Storyboarding consolidates evidence so students can consider how their data fits into **Agronomy Feeds the World**. By **sharing** their stories and allowing others to **question** their conclusions, students learn to **reconcile** evidence as scientists do. This is sometimes referred to as ***scientific thinking***. For general information about the content of a good storyboard and suggestions about how students can use storyboards to build skills in scientific thinking, writing, and discussion, see the document **What is a Storyboard Discussion?**

Preparing storyboards:

Key features for teams to consider as they prepare storyboards for **Agronomy Feeds the World** may include:

- Clearly stating whether the team studied **plant stress**, **nutrient management**, or both.
- Describing the team's thinking about the biological process(es) they studied before *and* after the experiment, in addition to agronomic implications.
- Summarizing quantitative data (i.e., mean and standard deviation) from different treatments instead of showing all individual measurements.
  - For example, instead of presenting multiple, individual fresh weights for replicates of crop plants, present the average growth rate for each treatment.
- Presenting clear visual comparisons of data to describe what the team observed.
  - For example, repeatedly measuring seedling height over time might best be graphed with time on the x-axis and height on the y-axis, with each plant or treatment given a unique data marker.
- Finding informative, concrete ways to present qualitative data.
  - For example, photographs may be the simplest way to show differences in leaf colors or leachate volumes.
- Being able to verbally describe how the information presented in the storyboard connects to **plant stress** or **nutrient management** in addition to being able to connect the storyboard to the broad topic of agronomy and the six field to table concepts.

Class discussion:

A set of ground rules for productive discussion is provided in **What is a Storyboard Discussion?** Here, the discussion should center on data to:

(a) explain how **plant stresses** and **nutrient management** affect crop production, and

(b) develop critical thinking skills linking past experience and empirical observations in an experimental context.

Key questions to build inquiry skills:

- What constitutes evidence?
- How does the team's data fit into their assumptions/hypotheses about their ecoregion and problem.
- In what ways was the team's experimental design limited? Could it be improved or supplemented with another?
- What remains unknown?

Juicy biological questions:

Can any crop grow anywhere? Why or why not?
Teams should be able to discuss their answers based partly on their observations during this guided inquiry.

Is it "better" to choose crops to fit the region or change the region to fit the crops?
Students should be able to discuss the intricacies of this question based on their background, results from the guided inquiry, and with their management plans and/or proposals in mind.

Student biases & alternative conceptions:

Inquiry process skills: Students might have selected a question for which they already knew the answer, "adjusted" data to meet their expectations, or concluded that contradictory data confirms their predictions. Weighting assessment towards process skills and away from correct answers may help discourage such biases.

Students may find it difficult to distinguish between what they **think or infer** is happening and what has **actually** happened. Even before the Storyboard phase, provide students with feedback on research journal entries and encourage communication with scientist mentors and peers to assist them in developing this skill.

Biological knowledge: Students commonly believe that:

- If there are no symptoms a crop is healthy.
- Height is the same as yield.
- More fertilizer always leads to increased crop yields.

Some of the above alternative conceptions may have been directly tested in a team experiment. Others might come out in the Storyboard Discussion and can be more quickly addressed in conversation or by comparison to other teams' findings.

Product: At the end of the discussion, the class should arrive at a **consensus** for the role(s) **plant stress** and/or **nutrient management** play in agronomy and management decisions. The class should also relate these concepts to the six field to table components and begin Activity 4a or b based on these discussions.

Students should upload their storyboards to the website for the mentor to review and discuss. When possible students should present either a PowerPoint or handmade storyboard to their mentor over Google Hangout.