Exploration of Beneficial Species Interactions between Legumes & Rhizobia:

What does a plant need to survive & thrive?

Inquiry Overview

Species Interactions (Mutualism): *What is the interaction between legumes & rhizobia?*
The classic mutualism between plants in the legume family and nitrogen-fixing bacteria (termed rhizobia) is one of the economically and ecologically important species interactions on Earth. Through this beneficial species interaction nodules are formed on legume roots which house the rhizobia. Rhizobia convert atmospheric nitrogen into a form that is available to the plant (ammonia). In return the plant provides the rhizobia with a source of organic carbon through sugars produced via photosynthesis.

Prior Knowledge:
Photosynthesis: *How do plants get their energy to grow?*
Photosynthesis is a process plants use to store energy from the sun by converting atmospheric carbon dioxide into sugars. This lesson will build on student prior knowledge of the inputs and outputs of photosynthesis to understand the mutualistic relationship between rhizobia and legumes and bacteria's role in converting atmospheric nitrogen into a form that plants can use.

Extension:
Energy cycling: How does this help them survive and thrive?
Biological nitrogen fixation is one of the most important processes for life on Earth. Moreover nitrogen is the primary nutrient that limits plant growth and development. Rhizobia fix available nitrogen (N_2) into a form that plants can use (NH_3). After having students see part of the nitrogen cycle occurring, students can compare this cycle to other energy cycles (ex: carbon cycle).

Learning Objectives

Students will do the following:

- Make predictions about the effect of rhizobia bacteria on grass and clover plants.
- Plan and carry out an investigation to test the effect of soil with and without rhizobium bacteria on grass and clover plant growth.
- Make observations & record qualitative and quantitative data from the growing plants.
- Analyze and interpret data to make claims about the effects of rhizobia on clover and grass plant growth.

- Develop, revise, and use a model based on evidence to illustrate and explain the mutualistic relationship between legumes and rhizobia bacteria.

Next Generation Science Standards Disciplinary Core Ideas for High School Life Science that could be addressed with this lesson:

- LS2.A: Interdependent Relationships in Ecosystems
- LS2B Cycles of Matter and Energy Transfer in Ecosystem
- LS2.C: Ecosystem Dynamics, Functioning, and Resilience
- LS4D Biodiversity and Humans

Next Generation Science Standards Disciplinary Core Ideas for Middle School Life Science that could be addressed with this lesson:

- LS1-6 Matter and Energy in Organisms and Ecosystems
- LS2-3 Matter and Energy in Organisms and Ecosystems
- LS1-5 Growth, Development, and Reproduction of Organisms

Common Core Math Standards that could be addressed with this lesson:

- **MP.4** Model with mathematics.
- **6.RP.A.3** Use ratio and rate reasoning to solve real-world and mathematical problems.
- **6.EE.C.9** Use variables to represent two quantities in a real-world problem that change in relationship to one another; write an equation to express one quantity, thought of as the dependent variable, in terms of the other quantity, thought of as the independent variable. Analyze the relationship between the dependent and independent variables using graphs and tables, and relate these to the equation.
- **6.SP.B.5** Summarize numerical data sets in relation to their context.

Common Core Language Arts Standards that could be addressed with this lesson:

- **RST.6-8.1** Cite specific textual evidence to support analysis of science and technical texts.
- **RST.6-8.7** Integrate quantitative or technical information expressed in words in a text with a version of that information expressed visually (e.g., in a flowchart, diagram, model, graph, or table).
- **RST.6-8.8** Distinguish among facts, reasoned judgment based on research findings, and speculation in a text.
- **RI.8.8** Trace and evaluate the argument and specific claims in a text, assessing whether the reasoning is sound and the evidence is relevant and sufficient to support the claims.
- **WHST.6-8.1** Write arguments to support claims with clear reasons and relevant evidence.
- **WHST.6-8.2** Write informative/explanatory texts to examine a topic and convey ideas, concepts, and information through the selection, organization, and analysis of relevant content.
- **WHST.6-8.9** Draw evidence from literary or informational texts to support analysis,

reflection, and research.

- **SL.8.1** Engage effectively in a range of collaborative discussions (one-on-one, in groups, and teacher-led) with diverse partners on grade 8 topics, texts, and issues, building on others' ideas and expressing their own clearly.
- **SL.8.4** Present claims and findings, emphasizing salient points in a focused, coherent manner with relevant evidence, sound valid reasoning, and well-chosen details; use appropriate eye contact, adequate volume, and clear pronunciation.
- **SL.8.5** Integrate multimedia and visual displays into presentations to clarify information, strengthen claims and evidence, and add interest.

Next Generation Science Standards Cross-Cutting Concepts* and Science & Engineering Practices+ that could be addressed with this lesson:

- Cause & Effect*
- Energy & Matter*
- Structure & Function*
- Stability & Change*
- Asking Questions+
- Developing & Using Models+
- Planning & Carrying Out Investigations+
- Analyzing & Interpreting Data+
- Constructing Explanations+
- Obtaining, Evaluating & Communicating Information+

ASPB Principles of Plant Biology that could be addressed with this lesson:

Principle 1. Plants use the same biological processes and biochemistry as microbes and animals. Yet plants are unique because they mix the sunlight's energy with chemicals for growth. This process of photosynthesis makes the world's supply of food and energy.
Principle 2. Plants require certain inorganic elements from soil for growth. Plants play an essential role in the circulation of these nutrients within the biosphere
Principle 5. Plants, like animals & many microbes, respire & utilize energy to grow & reproduce.
Principle 7. Plants exhibit diversity in size and shape ranging from single cells to giant trees.
Principle 11. Plant growth and development are under the control of hormones and can be affected by external signals such as light, gravity, touch or environmental stresses.
Principle 12. Plants live in and adapt to a wide variety of environments. Plants provide diverse habitats for birds, beneficial insects and other wildlife in ecosystems.

Safety Considerations:

Safety precautions include wearing protective eyewear when using chemicals for testing, closed-toe shoes, and other protective clothing and sunscreen; and having a first aid kit. The soil may contain organisms that could be an irritant to skin, so students should wash their hands thoroughly after touching the plants and soil.

Materials Preparation

Review the At-A-Glance to see pacing and slides presentation. This lesson can be taught with students working individually and in groups. Consider how you will group students prior to starting the lesson based on the number of containers, seeds and grow lights you have.

Slides Presentation for High School and Middle School Classrooms

Teacher Background

About Legumes

The mutually beneficial species interaction between plants in the legume family (e.g., beans, peas, lentils, clover, etc.) and symbiotic nitrogen fixing bacteria (collectively termed rhizobia) is one of the most economically and ecologically important interactions on Earth. Nitrogen is the primary nutrient that limits plant growth and is therefore the main component of synthetic fertilizer used for agriculture. Ironically our atmosphere is predominantly composed of nitrogen gas, but it is not in a form that is accessible to plants. However, through this mutualism legume plants receive an organic form of nitrogen that they can use from symbiotic rhizobia. Legumes develop specialized root organs called nodules, which house the rhizobia and are the site of nitrogen fixation. Nitrogen fixation is a process where atmospheric nitrogen is converted to ammonia, which is a usable form of nitrogen for plants. In return plants provide sugars, a source of carbon, to the rhizobia that are produced by the plants through photosynthesis. This symbiosis is why farmers often practice crop rotations where legumes (i.e., soybeans) are grown one year followed by a non-legume, typically corn which requires a large amount of nitrogen, the following year. The mutualism with rhizobia allows legumes to inhabit very nutrient poor soils where other plants are unable to thrive.

About the Nitrogen Cycle

The nitrogen cycle is a biogeochemical process that describes how Nitrogen moves and changes in Earth's ecosystems. Nitrogen is one of the essential elements for the growth and development of living organisms, including plants, animals, and microorganisms. Even though the air is primarily composed of nitrogen (roughly 78%), it cannot be taken in through breathing and it can only be used after it has been fixed by bacteria and taken up through plant roots and transferred to plants.

The nitrogen cycle consists of many steps that change nitrogen from its atmospheric form (N_2) into different forms that can be utilized by plants and animals.

1. **Nitrogen Fixation:** The cycle begins with nitrogen fixation, where atmospheric nitrogen (N_2) is converted into a different form, either ammonia (NH_3) or nitrate (NO_3-). This process is completed by nitrogen-fixing bacteria (called **rhizobia**), which can be found in soil on its own or when they form symbiotic relationships with certain plants, such as legumes (e.g., soybeans, clover) or some trees. These bacteria have the ability to convert atmospheric nitrogen into ammonia through biological processes.

2. **Nitrification:** Once ammonia is produced, it undergoes nitrification, which involves two steps. First, ammonia is converted into nitrite (NO_2-) by nitrifying bacteria and adding oxygen. Ammonia is toxic to many organisms, so this first step is especially important. Next, nitrite is further oxidized to nitrate (NO_3-). Nitrate is a more readily available form of nitrogen for plants and is used by plants to promote growth. Many plants that are not growing tall are found to have nitrogen deficiencies.

3. **Assimilation:** In the assimilation process, plants and microorganisms take up nitrate and ammonia from the soil and convert them into organic nitrogen compounds, such as amino acids and proteins.

4. **Ammonification:** When organisms die, or when their waste decomposes, organic nitrogen compounds are broken down by decomposers such as bacteria and fungi. This process is known as ammonification, where the organic nitrogen is converted back into ammonia.

5. **Denitrification**: Denitrification is the final step of the nitrogen cycle, where some types of bacteria change nitrate back into atmospheric nitrogen. They convert nitrate into nitrogen gas (N_2), which is released back into the atmosphere, completing the cycle.

The other elements that plants rely on are potassium and phosphorus, and people who are testing soil quality to determine if plants will grow successfully normally look at the NPK (nitrogen, phosphorus, potassium) levels to determine if it needs to be amended with compost or synthetic fertilizers.

Vocabulary used in this inquiry

Nitrogen Cycle
Photosynthesis
Rhizobia
Mutualism
Bacteria
Photosynthesis
Legume
Grass
Glucose
Carbon Dioxide
Oxygen
Sunlight
Nodules
Nitrogen Fixation

Materials you will need

- Cups (2 per group). Cups should have drainage holes added to the bottom to allow excess water to drain out.
- Inoculated Clover Seeds ~15 per group
- Non-inoculated Clover Seeds ~15 per group
- Rye Grass Seeds ~ 15 per group
- 1 small tray per group
- 1 large tray for each class to store plants
- Grow lights (If you do not have a sunny window)
- Light timer for grow lights
- 1 ziplock bag per group to mix soil (reuse for each class)
- Potting Soil ~1/2 cup per group
- Sand ~1 cup per group
- *Optional: Pinto Bean Seeds