Fun with plants: understanding the functions of mineral elements

Overview

The aim of this project is to help students to gain deeper understanding on how and why mineral elements are necessary for plants to grow. Plants will exhibit certain symptoms of nutrition deficiency when suffering from malnutrition, which can be best studied by a water culture (hydroponics) system. This lesson starts with a brief introduction on what plant nutrition is and why fertilizer is important for plants. After the theory session, instructors and students will build seed starting and hydroponics experimental systems together. Different treatments, i.e. nutrient solutions that are absent of certain mineral elements, will be set up and students will be divided into small groups to observe how plants react and adjust under various environments. Students will spend time on 1) recording plant nutrient deficiency symptom; 2) maintaining hydroponics systems; 3) collecting plant morphological and physiological data.

Objectives

At the conclusion of the lesson, students will be able to:

- Tell the difference between macronutrients and micronutrients
- Understand the functions of N, P and K on plant development
- Identify typical deficiency symptoms on plant organs associated with the absence of essential elements
- Explain why water is an alternative medium for plants to grow
- Explain and apply basic hydroponics techniques
- Graph data of plant height, plant biomass and chlorophyll generated during the experiment

Length of Lesson

It will take 4-6 weeks to complete this lesson. Using seedlings rather than starting from seed starters will shorten this lesson (how much time you can save depends on what plants you select).

Grade Levels

Middle school (Grades 5-7) and high school

Standards covered
Based on “Science Grade Level Content Expectations” version 1.09, Michigan Department of Education, Office of School Improvement:

**Grade 5:**

*Life science:*

- **Organization of Living Things**

**K-7 Standard L.OL:** Develop an understanding that plants and animals (including humans) have basic requirements for maintaining life which include the need for air, water and a source of energy.

**Grade 6:**

*Life science:*

- **Organization of Living Things**

**L.OL.M.5** Producers, Consumers, and Decomposers – Producers are mainly green plants that obtain energy from the sun by the process of photosynthesis.

- **Ecosystems**

**L.EC.M.3** Biotic and Abiotic Factors- The number of organisms and populations an ecosystem can support depends on the biotic (living) resources available and abiotic (nonliving) factors, such as quality of light and water, range of temperatures, and soil composition.

**L.EC.06.31** Identify the living (biotic) and nonliving (abiotic) components of an ecosystem.

**L.EC.M.4** Environmental Impact of Organisms- All organisms (including humans) cause change in the environment where they live. Some of the changes are harmful to the organism or other organisms, whereas others are helpful.

**L.EC.06.41** Describe how human beings are part of the ecosystem of the Earth and that human activity can purposefully, or accidentally, alter the balance in ecosystems.

**L.EC.06.42** Predict possible consequences of overpopulation of organisms, including humans, (for example: species extinction, resource depletion, climate change, pollution).

*Earth science:*
● **Solid Earth**

**E.SE.M.1 Soil** - Soils consist of weathered rocks and decomposed organic materials from dead plants, animals, and bacteria. Soils are often found in layers with each having a different chemical composition and texture.

**E.SE.06.11** Explain how physical and chemical weathering lead to erosion and the formation of soils and sediments.

**E.SE.06.12** Explain how waves, wind, water, and glacier movement, shape and reshape the land surface of the Earth by eroding rock in some areas and depositing sediments in other areas.

**E.SE.06.13** Describe how soil is a mixture made up of weather eroded rock and decomposed organic material.

**E.SE.06.14** Compare different soil samples based on particle size and texture.

**Grade 7:**

**Physical science:**

● **Properties of Matter**

**P.PM.M.1** Chemical Properties- Matter has chemical properties. The understanding of chemical properties helps to explain how new substances are formed.

**P.PM.07.11** Classify substances by their chemical properties (flammability, pH, and reactivity).

**P.PM.M.2** Elements and Compounds- Elements are composed of a single kind of atom that is grouped into families with similar properties on the periodic table. Compounds are composed of two or more different elements. Each element and compound has a unique set of physical and chemical properties such as boiling point, density, color, conductivity, and reactivity.

**P.PM.07.24** Describe examples of physical and chemical properties of elements and compounds (boiling point, density, color, conductivity, reactivity).

● **Changes in Matter**

**P.CM.M.2** Chemical Changes- Chemical changes occur when two elements and/or compounds react (including decomposing) to produce new substances. These new substances have different physical and chemical properties than the original elements and/or compounds. During the chemical change, the number and kind of atoms in the reactants are the same as the number and kind of atoms in the products. Mass is
conserved during chemical changes. The mass of the reactants is the same as the mass of the products.

**P.CM.07.21** Identify evidence of chemical change through color, gas formation, solid formation, and temperature change.

**P.CM.07.22** Compare and contrast the chemical properties of a new substance with the original after a chemical change.

**P.CM.07.23** Describe the physical properties and chemical properties of the products and reactants in a chemical change.

**Life science:**

- **Organization of Living Things**

  **L.OL.M.2** Cell Functions- All organisms are composed of cells, from one cell to many cells. In multicellular organisms, specialized cells perform specialized functions. Organs and organ systems are composed of cells, and function to serve the needs of cells for food, air, and waste removal. The way in which cells function is similar in all living organisms.

  **L.OL.07.21** Recognize that all organisms are composed of cells (single cell organisms, multicellular organisms).

  **L.OL.07.22** Explain how cells make up different body tissues, organs, and organ systems.

  **L.OL.07.23** Describe how cells in all multicellular organisms are specialized to take in nutrients, which they use to provide energy for the work that cells do and to make the materials that a cell or organism needs.

  **L.OL.07.24** Recognize that cells function in a similar way in all organisms.

  **L.OL.M.6** Photosynthesis- Plants are producers; they use the energy from light to make sugar molecules from the atoms of carbon dioxide and water. Plants use these sugars along with minerals from the soil to form fats, proteins, and carbohydrates. These products can be used immediately, incorporated into the cells of a plant as the plant grows, or stored for later use.

  **L.OL.07.61** Recognize the need for light to provide energy for the production of carbohydrates, proteins and fats.

  **L.OL.07.62** Explain that carbon dioxide and water are used to produce carbohydrates, proteins, and fats.

  **L.OL.07.63** Describe evidence that plants make, use and store food.
**Earth science:**

- **Earth Systems**

**E.ES.M.4** Human Consequences- Human activities have changed the land, oceans, and atmosphere of the Earth resulting in the reduction of the number and variety of wild plants and animals, sometimes causing extinction of species.

**E.ES.07.41** Explain how human activities (surface mining, deforestation, overpopulation, construction and urban development, farming, dams, landfills, and restoring natural areas) change the surface of the Earth and affect the survival of organisms.

**E.ES.07.42** Describe the origins of pollution in the atmosphere, geosphere, and hydrosphere, (car exhaust, industrial emissions, acid rain, and natural sources), and how pollution impacts habitats, climatic change, threatens or endangers species.

**Materials**

- Seeds (lettuce, radish or basil)
- Seed starters (peat pellets, see photos below)
- 3 or 6 gallon containers (a Tupperware or a garbage can)
- Net pots (cut the lids of containers to fit the net pots.) **Notice:** It’s better to have 6-15 net pots per containers. (see photos below)
- Hydroton clay (see photos below)
- Solutions (please refer to “Resources” to learn how to prepare each nutrient solution.)
- Aquarium air pumps and air stones
- pH paper or pH meter
- pH Up and pH Down (or prepare Potassium Hydroxide and Hydrochloric Acid by yourself)
- Chlorophyll meter
- PPM meter/EC meter
- Aluminium foil
- Tape
Seed starter

Net pots, Hydroton clay and seedlings

A hydroponics system

Background

Plants uptake different mineral elements to grow and develop. Various symptoms, such as yellowing leaves and rotten sprouts, will occur when plants lack necessary nutrition. It is difficult, however, to observe those symptoms with fertilized soil as nutrients are ample and sometimes even excessive. Also, it is unclear how fertilizers ingredients (such as N, P and K) contribute to the metabolism of plants in fertile soil environments. With the help of hydroponics techniques,
plants can be cultured in nutrient solutions that are absent of certain elements, which will allow students to watch corresponding unique deficiency symptom on plants and thus gain better understanding on the functions of fertilizers.

Hydroponics is not a new concept. The origin of hydroponics could date back to around 600 B.C. The Hanging Gardens of Babylon was considered to design follow the principles of hydroponics. Francis Bacon (22 January 1561 – 9 April 1626), an English philosopher, published his work on growing plants without soil in 1627, which intrigued great research interests on hydroponics since then. In 1929, Frederick Gerick, a scientist of University of California Berkeley, successfully grew massive tomato in his back yard with nutrient solutions without soil. He is also believed to be the person who created the term “hydroponics”. Later on, Dennis Hoagland and Daniel Arnon, two other scientists from University of California Berkeley redeveloped Frederick’s formula and created the famous “Hoagland Solution”, which is still widely used today.

Compared to traditional soil cultivation, hydroponics has great advantages in water or resources limited area in the world. Japan, where arable land is at a premium, has at least 150 hydroponics factories at present. As hydroponic lettuce requires only 1% and 25% of the soil culture based water and fertilizer demand, Japan’s indoor farming will be able to produce 10% of the total national lettuce production in the future. Another example is Israel. As Israel is scant in water resource for crop production, Israeli has developed advanced hydroponics techniques long time ago in the dry and barren environment. Combining the drop irrigation method, both nutrients and water are provided at a predetermined rate given to the specific need of the crop, which is regarded as one of the most phenomenal advancements in agriculture within the past 30 years.

**Activities of the session**

1. Go over all the lab supplies needed for this project.
2. Have a discussion on how to design this experiment: which plants to grow, how many plants to grow in each reservoir, how much nutrient solutions to use, what’s the function of each solution, etc.
3. Teach students to use seed starters and understand what germination rate is. Then plant seeds and discuss how to guarantee higher germination rates.
4. Assemble the hydroponics system and cover the containers with aluminum foil. Ask students: what is the volume of each container (reservoir)? What are the treatments? Why pH of the solution is important? Will concentrations and pH of the solutions change over time? What is the function of the air pump?
5. Weekly measurement of plant growth: the height of the plants, the leaves of the plants, element deficiency symptoms, the chlorophyll concentrations of the leaves.
6. Keep records on the changes of pH and PPM (part per million) or EC (electrical conductivity) of the solution for the first week. Learn the importance of refill solutions.
7. Maintain the hydroponics system appropriately every week.

**Resources**


**Extensions and Modifications**

1. Covering the reservoir with Aluminum foil: the reason we do that is because we want to prevent algae. However, algae itself isn’t really “bad”. Algae can compete with plants for nutrients but this influence is actually very small. What does matter is the decomposing of dead algae would attract fungus gnats, which can induce severe fungal disease of plants such as *Pythium*.
2. In high school or higher levels, it would be interesting to analyze the nutrient dynamic in different plant tissues and design solutions formula based on the different element uptake rates by plants. That is actually what modern hydroponics companies and factories will do today.

**Assessment**

Students will be assessed based on the weekly lab report and final presentations (graph data and interpret the results). Please refer to the worksheet accompanies this course plan.