Diet for a Healthy Plant
A study of plant nutrition using hydroponic systems

Overview
In addition to water, light and carbon dioxide, plants require an array of nutrients for growth, repair and proper function. In this experiment, students will explore the basic principles of plant nutrition and demonstrate plant nutrient deficiencies using hydroponic growth systems and Wisconsin Fast Plants.

Biology and agriculture concepts
- Plant nutrition
- Hydroponics
- Plant growth and development
The biology teacher can use this experiment to complement the teaching of plant nutrition, plant physiology and photosynthesis. The agriculture teacher can use this experiment for similar topics as well as with the discussion of alternative cropping systems and hydroponic technologies.

Background

The goal of this experiment is to help students understand the basic principles of plant nutrition.

Basic to this experiment is the preparation of five to eight nutrient solutions. These can be prepared using the recipes provided or alternatively, you can purchase pre-packaged mixtures from supply companies, such as the Carolina Biological Supply Co. Students can learn principles of measurement and dilution if they prepare their own solutions. These skills are important when dealing with agricultural chemicals or in the practice of scientific research.

These following nutritional recipes were developed by Hoagland in the 1930s. You may find other mixtures that serve the same purpose. We suggest that when mixing your solutions, add the calcium and iron components last as they will sometimes settle out of solution if they are too concentrated. Maintaining a pH of 6 will also help to keep these elements in solution. (Adjust pH with potassium hydroxide for all solutions except the potassium minus solution for which you should use sodium hydroxide.)

Solutions

1. Complete solution

<table>
<thead>
<tr>
<th>Solution</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 M KH₂PO₄</td>
<td>1 ml/liter</td>
</tr>
<tr>
<td>1 M KNO₃</td>
<td>5 ml/liter</td>
</tr>
<tr>
<td>1 M Ca(NO₃)₂</td>
<td>5 ml/liter</td>
</tr>
<tr>
<td>1 M MgSO₄ - 7 H₂O</td>
<td>2 ml/liter</td>
</tr>
<tr>
<td>Trace minerals</td>
<td></td>
</tr>
<tr>
<td>Iron solution</td>
<td></td>
</tr>
</tbody>
</table>

a) Trace minerals

<table>
<thead>
<tr>
<th>Substance</th>
<th>Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>boric acid</td>
<td>2.86 g / liter</td>
</tr>
<tr>
<td>MnCl₂ - 4 H₂O</td>
<td>1.81 g / liter</td>
</tr>
<tr>
<td>ZnSO₄ - 7 H₂O</td>
<td>0.22 g / liter</td>
</tr>
<tr>
<td>CuSO₄ - 5 H₂O</td>
<td>0.08 g / liter</td>
</tr>
<tr>
<td>H₂MoO₄</td>
<td>0.009 g / liter</td>
</tr>
</tbody>
</table>

b) 0.5 % iron (II) tartrate at the rate of 1 ml / liter.
Adjust the pH of the solution to 6 by adding H₂SO₄.
2. Nitrogen minus solution

\[\begin{align*}
0.5 \text{ M } K_2\text{SO}_4 & \quad 5 \text{ ml/liter} \\
1 \text{ M } \text{MgSO}_4 & \quad 2 \text{ ml/liter} \\
0.05 \text{ M } \text{Ca(H}_2\text{PO}_4\text{)}_2 & \quad 10 \text{ ml/liter} \\
0.01 \text{ M } \text{CaSO}_4 & \quad 200 \text{ ml/liter}
\end{align*}\]

Add trace minerals as for the complete solution.

3. Phosphorus minus solution

\[\begin{align*}
1 \text{ M } \text{Ca(NO}_3\text{)}_2 & \quad 4 \text{ ml/liter} \\
1 \text{ M } \text{KNO}_3 & \quad 6 \text{ ml/liter} \\
1 \text{ M } \text{MgSO}_4 & \quad 2 \text{ ml/liter}
\end{align*}\]

Add trace minerals as for complete.

4. Potassium minus solution

\[\begin{align*}
1 \text{ M } \text{Ca(NO}_3\text{)}_2 & \quad 5 \text{ ml/liter} \\
1 \text{ M } \text{MgSO}_4 & \quad 2 \text{ ml/liter} \\
0.05 \text{ M } \text{Ca(H}_2\text{PO}_4\text{)}_2 & \quad 10 \text{ ml/liter}
\end{align*}\]

Add trace minerals as for complete.

(If pH adjustment is necessary, use sodium hydroxide.)

5. Trace minus solution

Prepare as in the complete solution, but leave out the trace minerals.

As mentioned earlier, you can purchase pre-mixed solutions from mail order catalog companies such as the Carolina Biological Supply Company. Carolina offers a nutrient set (product # 6606075) that includes 10 complete nutrient packets plus nutrient deficient packets for calcium, magnesium, potassium, nitrogen, phosphorus, sulfur, iron, and trace minerals. Each packet will make five liters of solution. Approximately one liter of each solution is needed for one experiment.
<table>
<thead>
<tr>
<th>Nutrient function and deficiency symptoms</th>
<th>Nitrogen</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function: Synthesis of organic compounds, including amino acids, proteins, coenzymes, nucleic acids and chlorophyll</td>
<td></td>
</tr>
<tr>
<td>Deficiency symptoms: General yellowing (chlorosis) and death of older leaves, growth is stunted, younger leaves remain green longer as the mobile nitrogen is translocated from older leaves. Stems of some plants will turn purple.</td>
<td></td>
</tr>
<tr>
<td>Excess: Very lush foliage with sappy, soft stems; delayed flowering, less disease resistance.</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Phosphorus</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function: Component of sugar phosphates, ATP, nucleic acids, phospholipids and coenzymes.</td>
</tr>
<tr>
<td>Deficiency symptoms: Stunted growth, dark dull leaves, abnormally hard stems and stalks, poor root system with little branching.</td>
</tr>
<tr>
<td>Excess: Symptoms similar to nitrogen deficiency.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Potassium</th>
</tr>
</thead>
<tbody>
<tr>
<td>Function: Protein synthesis, coenzyme, sugar and starch formation, and is needed for growth.</td>
</tr>
<tr>
<td>Deficiency symptoms: Yellowing and curling of lower leaves, drooping of younger leaves. Leaves become mottled and scorched looking. Soft stems, lack luster flowers, and more susceptible to disease (rusts and mildew).</td>
</tr>
<tr>
<td>Excess: Dark foliage, stiff stems and stalks.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Calcium</th>
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</thead>
<tbody>
<tr>
<td>Function: Component of cell walls, needed for cell growth and division.</td>
</tr>
<tr>
<td>Deficiency symptoms: Under developed roots, curled leaf edges, stunted dark plants, crinkled leaves.</td>
</tr>
<tr>
<td>Excess: Same as iron deficiency. Excess calcium interferes with the absorption of iron.</td>
</tr>
</tbody>
</table>
Magnesium

Function: Central part of chlorophyll, photosynthesis.

Deficiency symptoms: Shows up during late development. Plant is stunted, areas between veins yellow and may die. Delayed and lack-luster flowers.

Excess: Abnormally large, light colored leaves.

Iron

Function: Activator in chlorophyll synthesis, electron transport in photosynthesis and respiration.

Deficiency symptoms: Chlorosis of young leaves, starting at the tip. Leaves turn completely pale yellow. Stunted growth. Flower abortion.

Excess: No problems most of the time. Necrotic spots have been observed following application of sprays.

Sulfur

Function: Present in some amino acids and vitamins.

Deficiency symptoms: General yellowing of plant, reduced growth. Dark areas at leaf base. Veins turn yellow.

Excess: Reduction in growth and leaf size.

Manganese

Function: Coenzyme, chlorophyll synthesis.

Deficiency symptoms: Poor bloom, weak growth, yellowish checkered leaves.

Excess: Usually no problem. Sometimes chlorosis, uneven chlorophyll and iron deficiency.
Boron


Deficiency symptoms: Immobile-yellow leaves with green veins. Growing point dies, side shoots begin to grow then die. Leaves thicken, curl, deform, and become brittle. Leaves are small.

Excess: Usually no problem. Yellowing of leaf margins which progresses toward the mid-rib.

Zinc

Function: Enzymes, formation of chlorophyll and growth regulators.

Deficiency symptoms: Short internodes, stunted growth. Interveinal chlorosis in older leaves.

Excess: Usually no problem.

Trace minerals

Function: Needed in small amounts for many plant functions.

Deficiency symptoms: Vary depending on the element which is missing. This is rarely a problem when using a commercial fertilizer due to the high level of impurities.

Excess: Highly toxic. Causes rapid collapse and death of the plant.

Teacher Management

Preparation and activity time

Bottle construction, solution preparation and planting will take one class period. Daily measures will take 5 to 10 minutes while daily observations will take less than 5 minutes. Day 40 will likely require a full class period in order for students to collect data and graph the results. The following day should be used for follow up questions, comparing and graphing class data, and discussing possible extensions to this lab activity.
Lesson 4

Materials

Each group (4-6 students) will need:

5 green 1-liter bottles
Pellon wicking material
Vermiculite planting medium (fine grade if possible)
Nutrient solutions or chemicals to make nutrient solutions
50 Fast Plant Seeds
Scissors and grease pencils

Sources of materials

The Pellon wicking material can be purchased from your local fabric store. Be sure to wash the material before use -- it often is treated with a flame retardant that is toxic to plants.

Pre-measured packets of nutrient mixtures can be purchased from sources such as the Carolina Biological Supply Company.

Fast Plant seeds can be purchased from the Carolina Biological Supply Company.

Key Terms

Deficiency: A shortage of an element necessary for plant growth.

Hydroponics: The science of growing plants without soil. Commonly accomplished by the use an inert medium to which a balanced nutrient solution is added.

Inert: Material does not have active properties so it is not affected when it comes in contact with other substances.

Nutrient: A chemical element or inorganic compound taken in by green plants that nourishes and promotes growth.

PH: A measure of acidity or alkalinity.

References


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Introduction

Hydroponics, or the science of growing plants without soil, has been used with varying degrees of success for the past 300 years. The culture of spearmint in rain and river water is documented as early as 1699.

In the 1830s, as people began to better understand plant nutrition, the use of hydroponics greatly increased. These early studies used either inert media (media lacking nutrients or other ingredients that affect plant growth) or plant supports and water without growing media. Nutrients were then varied to test what affect they had on the plant.

In this experiment, you will use vermiculite, an inert material, and soda bottles to construct a hydroponic growing system to grow Fast Plants, a rapidly growing species of *Brassica rapa*.

Since the early 1900s many growers have tried to use hydroponics for commercial food production. Today most growers still use the basic solutions formulated by Dr. D. R. Hoagland at the University of California in the early 1930s. Considered a pioneer in the field of hydroponics, Dr. Hoagland conducted extensive research on growing plants using hydroponics.

The potential for hydroponics is astounding. Yield studies suggest that tomatoes grown hydroponically can yield 180 tons per acre compared to the average land grown yield of 5-10 tons per acre.

Procedure

1. Obtain five 1-liter bottles and remove the labels.

2. Cut the bottles 2 inches below the shoulder. Invert the top portion and place back into base. (See directions for the Terraqua column in the Bottle Biology Basic introductory section.)

3. Remove the bottle caps and drill or pinch a hole in each. Next, push a strip of water soaked wicking material through the hole. Leave enough wicking sticking out of the cap to reach the bottom of the lower unit of your growing system.
4. Label each of the five growing systems as one of the following: Control, N minus, P minus, K minus, and trace nutrient minus.

5. Fill the upper unit of each growing system with the same amount of vermiculite planting medium.

6. Sprinkle 10 Fast Plant seeds onto the vermiculite in each growing system. Add a small portion of additional vermiculite to cover the seeds.

7. Obtain your nutrient solutions and water the seeds with 200 mls. of the appropriate solution. A squirt bottle works best and minimizes disruption of the vermiculite. Excess solution will accumulate in the lower unit and will be constantly available to the plants via the wicking system.

8. Place your growing systems under a light source.

9. Water the systems from above with nutrient solutions for the first 6 days. Vermiculite should be kept moist at all times.

10. Follow the instructions on your data collection sheet.
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Name: ____________________________

Day 1: Plant Fast Plant seeds.
Prepare nutrient solutions.

Hypothesis: What do you think the plants will look like under the different nutritional conditions? Will they all flower? What color will the leaves be?

Day 4: Record germination.

<table>
<thead>
<tr>
<th>Control</th>
<th>- N</th>
<th>- P</th>
<th>- K</th>
<th>- T</th>
</tr>
</thead>
<tbody>
<tr>
<td># of plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>% germination</td>
<td></td>
<td></td>
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</tbody>
</table>

Observations: ____________________________________________________________
____________________________________________________________________
____________________________________________________________________

4-10 / Plant nutrition
Day 7: Measure plant height.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td># of plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average plant height</td>
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Observations: ________________________________
_________________________________________________________________
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Day 14: Measure plant height.
Pollinate.

<table>
<thead>
<tr>
<th></th>
<th>Control</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>T</th>
</tr>
</thead>
<tbody>
<tr>
<td># of plants</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average plant height</td>
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Observations: ________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
_________________________________________________________________
Day 21: Replenish nutrient solutions.

Observations: ____________________________________________
________________________________________________________
________________________________________________________
________________________________________________________

Day 28: Replenish nutrient solutions.

Observations: ____________________________________________
________________________________________________________
________________________________________________________
________________________________________________________

Day 42: Measure plant height. 
Count the number of pods per plant. 
Calculate the average number of seeds per pod. 
Make sure to harvest the pods from each group separately.

<table>
<thead>
<tr>
<th>Control</th>
<th>- K</th>
<th>- P</th>
<th>- N</th>
<th>- T</th>
</tr>
</thead>
<tbody>
<tr>
<td>Average plant height</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td># of pods/plant</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Average # of seeds /pod</td>
<td></td>
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</tbody>
</table>

Observations: ____________________________________________
________________________________________________________
________________________________________________________
________________________________________________________
Lesson 4

Results and discussion

- Do your results support your hypotheses?
- If you were to do the experiment again, would you change the procedure in any way?
- How do the seed yields compare between the different nutritional diets?

Extensions

Can you think of ways to continue discovering more about plant nutrition? Try designing experiments to help answer the following questions.

- How would different growing media effect plant growth?
- What would be the optimal nutrient balance to maximize seed yield?
- Would the results of these experiments differ if you use green bottles versus clear?
- Do seeds produced by plants grown in nutrient deficient conditions germinate at the same rates as the original parent plants? Will they show symptoms of deficiency even if grown under optimal conditions?