Plant-A-Plant Hands on Photosynthesis Experiments

Purpose

- To demonstrate that certain environmental factors are essential for plant growth and thus carbon storage.
- To complete the scientific process including hypothesis formation and a discussion of experimental results with peers.

Overview

During the Plant-A-Plant Classroom Experiments students will observe how seeds grow into sprouts and then use and derive experiments that manipulate environmental conditions to investigate how different factors (water, light, temperature, mineral nutrients, and carbon dioxide) affect plant growth. Students will document plant growth and record observations. Results will be assessed by comparing plant height, color, root:shoot ratios, biomass, and carbon stored.

Student Outcomes

Students will be able to:

- Describe the limiting factors of plant growth, and how a change in these factors can result in a change in biomass or carbon storage.
- Formulate a reasonable hypothesis.
- Design and conduct a simple experiment using maize plants
- Gain skills in scientific observation, measurement, calculation, and documentation
- Practice analyzing, interpreting, and discussing experimental results.

Questions

Content

- See *Student Laboratory Questions* for each of the experiments.

Science Concepts

Grades 9-12

Scientific Inquiry

- Identify questions that can be answered through scientific investigations
- Design and conduct a scientific investigation
- Formulate and revise scientific explanations and models using logic and evidence
- Communicate and defend a scientific argument.

Science in Personal and Social Perspectives

- Humans have a major effect on other species

NGSS (Black- covered directly, gray-addressed, but not directly covered)

- *Disciplinary Core Ideas*
  - Gr.6-8: LS2.A, LS2.C, LS1.B, LS1.C, ESS3.C
  - Gr.9-12: LS1.B, LS2.B, LS2.C
- *Science and Engineering Practices*
  - Asking Questions
  - Planning and carrying out investigations
  - Analyzing and interpreting data
  - Using mathematics and computational thinking
  - Constructing explanations
  - Engaging in argument from evidence
  - Obtaining, Evaluating, and Communicating Information
- *Crosscutting Concepts:*
  - Cause and Effect
  - Scale, Proportion, and Quantity
  - Energy and Matter
  - Structure and Function

Time/Frequency

Approximately 14 days after seed germination (See *Appendix*), 5-10 minutes a day until harvest and analysis.

Level

Secondary (High School)

Materials and Tools

- See *MaterialsList.xls* and/or the materials list for each individual experiment
- Total materials will depend on the number of replicates of each experiment

Prerequisites

- Experimental design – replicates/controls
- Proper use of laboratory equipment

Preparation

- Seed germination: the teacher or the students will need to use the *Seed Germination Laboratory Guide* and *Data Sheet.* Calculate the number of seeds to plant based on the required seedlings per replicate and the desired number of replicates for each experiment.
- Review harvest instructions. Student directions call for the use of a traditional drying oven, however if one is not available, you will find instructions for microwave use below.
- Copy the *Laboratory Guide and Student Worksheets* (1 per group).
- Gather materials.

Background

Plants play a crucial role in the global carbon cycle representing both a large carbon pool, as carbon stored in plant biomass, and a large carbon flux in which plants take up carbon (dioxide) with water and sunlight during photosynthesis. The Plant-A-Plant Classroom Experiments allow students to explore the necessary resources needed for plant growth and demonstrate how carbon dioxide (CO_2) is incorporated into plant biomass.

The Plant-A-Plant activities can be done individually or as part of a larger unit on the carbon cycle. The knowledge students' gain about the storage of carbon in biomass and the limiting resources for plant growth provide solid background for both the Carbon Cycle Field Activities and the Carbon Cycle Modeling Activities. The Biomass Units activity specifically supports the biomass concepts covered in Plant-A-Plant and can easily be performed before the completion of experiments.

Plant Growth from a Seed

A plant seed contains its own life support system. When stimulated to germinate, seeds use stored food reserves and surrounding oxygen to grow into sprouts. A sprout is a tender, often edible, seedling that is produced following seed germination. As the sprout begins to develop and use up its stored reserves, the seedling becomes totally dependent on environmental sources of energy and material. Plants need light, carbon dioxide, water and additional mineral nutrients to continue growth after germination.

What keeps plants growing?

The major requirements for plants to grow are light, water, and carbon dioxide (CO_2).
These components are used in the process of photosynthesis. Photosynthesis (derived from Greek *fós, fótos* – 'light' and *synthesis* – 'fusion', 'composition') is a process, where absorbed sunlight is converted to chemical energy, which is then used to incorporate CO_2 and water into carbohydrates. Carbohydrates are simple and compound sugars, such as cellulose, that make up the main plant structure. This process of taking CO_2 out of the atmosphere and converting it to carbohydrates actually locks up the carbon in plant tissues, storing it until the plant dies. If you were to dry a plant, 45-50% of the plant mass, also called biomass, would be made up of carbon.

In addition to light, water and carbon dioxide, plants also require small amounts of other nutrients and minerals for plant structure and function. For example, plant proteins require nitrogen and sulfur while chlorophyll, necessary for photosynthesis, requires magnesium. Of these nutrients, nitrogen is the most important, representing up to 5% of plant dry mass.

What affects the rate of photosynthesis? (Limiting Factors)

Photosynthetic rate is the parameter that determines the amount of carbon dioxide absorbed by a leaf, measured in units of g (CO_2) per m^2. The rate of photosynthesis can be affected by any of the factors discussed above including sunlight, temperature, water, availability of CO_2 and oxygen (O_2) or the macro and micro nutrients that influence the production of chlorophyll and other chemical compounds taking part in photosynthesis. Photosynthetic rate is always, or nearly always, being limited by the availability of at least one factor. A factor is regarded as a limitation to growth when even though all other factors are in normal concentrations; the process of photosynthesis is slowed down, altered or stopped.
After students conduct their experiments they may need additional background in-

formation to help them understand some of their results. Some research has been provided by the Czech Science Team from Charles University in Prague (see appendix), however additional student-directed literature research may be required.

Notes on Implementation

The four basic Plant-a-Plant experiments can be conducted by individuals, small groups or as a class. Individual experiments can be performed independently, in succession or in conjunction with others. Students should be able to draw conclusions between experiments. Initially the experiments (and this teacher guide) are structured to support teachers and students through the inquiry process as they as they gain new skills and concepts. Ultimately we hope that students will be able to perform open inquiry investigations so they are provided with the most authentic science experience.

As you read through the 5Es below you will notice that we have indicated in **bold** which stage of the scientific process students are engaged in. See the GLOBE Model for Student Scientific Research (in the Student Inquiry document in the Resources section of GLOBE Carbon Cycle webpage) for further details on each stage.

What To Do and How To Do It

ENGAGE	**Grouping:** Class	**Time:** Varies

- Students **Observe Natural Phenomenon** (seed germination and growth):
  - Use the *Seed Germination Laboratory Guide* and *Data Sheet* to set up seeds for observation.
  - Every day (for 7 days, or until seedlings have 2 leaves) different students record their observations on the class data sheet kept next to the seed germination trays. They should also make note of any water added or other events that take place during the germination period.

EXPLORE	**Grouping:** Small Groups	**Time:** Varies

- Part 1: **Pose a Research Question** using the *4-Question Strategy.* This activity should generate ideas for potential plant investigations based on students' own observations.
- Part 2: **Review an Investigation Plan** using the *Review Investigation Plan-Light*.
  - Tell students they will be conducting the Light investigation (a structured investigation that provides a good base for future laboratory experiments) or select a Plant-A-Plant investigation that best relates to your content goals and the interests of your students (based on the questions they developed using the 4-Question Strategy).
  - In later lessons students will develop their own investigation plan according to the outline given by the GLOBE Model for Student Scientific Research (GMSSR).
- Part 3: **Conduct Investigation** following the selected Student Laboratory Guide.
  - Divide the class into groups and have each group perform 1 complete replicate (control and all treatments) of the same experiment.

**During the investigation students should plant more seeds for germination to be used in follow-up experiments. They will also need to make calculations on average seed weight, etc. (See *Seed Germination*).

EXPLAIN	**Grouping:** Class/Small Groups	**Time:** 60 Minutes

- **Analyze Data** as a class using the Data Summary and Analysis Sheet.
  - Compile and average the replicate data from each group
  - Graph important results
  - Briefly summarize and discuss the meaning of the results.
- **Identify New Research Questions** based on results from the class experiment.

ELABORATE **Grouping:** Small Groups **Time:** Varies

- **After students have performed one plant experiment they should be ready for a less teacher directed approach. How much freedom you provide students will depend on their prior experience performing experiments and using inquiry.
- **Pose a Research Question** from the list they developed during the *4-Question Strategy* or new questions that arose from the previous experiment.
- **Develop an Investigation Plan (options for different levels of inquiry) using the *Review Investigation Template* or Pre-Lab Instructions in the** *Student Laboratory Guide*.
  - Students may choose an investigation plan from the Plant-A-Plant list of experiments if they think it will answer their proposed research question.
  - Students may modify an existing Plant-A-Plant experiment to suit their needs.
  - Students may develop a new investigation plan that specifically addresses their question.
  - In the second two cases student may need to develop their own data tables based on the independent and dependent variables they have selected to measure.
- **Conduct Investigation** following a *Student Laboratory Guide* or similar process as the class example (establish prior knowledge, hypothesis formation, etc.). We have provided Laboratory Guides and Data Sheets for all Basic experiments, which can be used or not depending on the desired level of structure.
- **Analyze Data** by making calculations, compiling replicates, and graphing interesting relationships. Use the *Data Summary and Analysis Template*.
- **Document Conclusions**, which includes a discussion and conclusion about results (What questions were answered? What knowledge was gained? How does your experiment relate to other class topics, i.e. limiting factors to growth, carbon cycle, climate change?), assesses the initial hypothesis and **Identifies New Research Questions** that arose. See the GLOBE Document Conclusions webpage (www.globe.gov/do-globe/for-students/be-a-scientist/steps-in-the-scientific-process/document-conclusions) for further information.

EVALUATE **Grouping:** Small Groups **Time:** 90 Minutes

- **Present Findings** to classmates through a group presentation (see Presentation Rubric in Appendix), or culminating project/paper.
  - See the GLOBE Present findings webpage (www.globe.gov/do-globe/for-students/be-a-scientist/steps-in-the-scientific-process/present-findings) for further information.
- **Peer Review** could be used to have each group closely evaluate the work of another group.

Assessment

- Students can be evaluated individually on the completeness and thoughtfulness of their journal entries concerning initial experimental design, hypothesis development and evaluation, and new scientific questions that developed as a result of their completed experiment.
- Lab groups can be evaluated on the completeness of the student worksheets and calculations.
- Lab groups can be evaluated on their class presentation (see rubric in the appendix).

Adaptations

- If you do not have access to a laboratory scale with an accuracy of 0.01 grams, you may want to consider growing more plants and weighing the whole set of plants from one treatment together.

Extensions

- After students have performed basic Plant-A-Plant Experiments (light, water, carbon dioxide, and mineral nutrition):
  - Lingering questions can be used by students to design their own experiments

- ◦ Advanced Plant-A-Plant Experiments can be completed (Mineral Nutrition II, CO_2 Increase, Soil Respiration, and Photosynthesis).

Reference/Resource

- Cothron, J. H., Giese, R. N., & Rezba, R. J. (2006). Students and Research: Practical Strategies for Science Classrooms and Competitions. Dubuque: Kendall/Hunt Publishing Company.

APPENDIX

Time/Frequency (specifics)

Table 1: Approximate time needed for each stage of the Basic Plant-A-Plant Experiments		
Stage of the Experiment	Duration (Days)	Details of Activities
Cultivation • Water Experiment • Light Experiment • Mineral Nutrient Experiment • CO_2 Decrease Experiment	 11 11 16 14	Preparation of materials for the experiment and planting (1-2 class periods); daily watering and recording of plant growth (10 minutes per day)
Harvest	1	Preparation of plants for drying
Drying	1	Creation of aluminum "envelopes" and drying of plants in drying oven for 8-12 hours at 90°C.
Evaluation/ Interpretation	1-2	Record final results, review hypothesis, answer essential questions.

Suggested Fertilizer Composition for Mineral Nutrition Experiments

Table 2: Detailed elemental composition of the tested fertilizer Kristalon Start.					
Nutrient	Form	%	Nutrient	Form	%
N	total	19.0	B	not specified	0.025
	NO_3^-	11.8	Mo	not specified	0.004
	NH_4^+	7.2	Fe	not specified	0.07
P	P_2O_5 soluble in mineral acid	6.0	Cu	not specified	0.01
K	K_2O	20.2	Mn	not specified	0.04
Mg	MgO	3.0	Zn	not specified	0.025

Plant Harvest – Oven and Microwave drying

Drying in oven

If you have access to a lab oven or a regular hot-air oven, dry the samples in aluminium foil.

Cut the leaves (and especially tree needles) into pieces. It will make drying faster and more effective.

For drying out 1 g of fresh leaf weight, you will need around 5-6 hours in a hot-air oven at 80°C . If you can't dry everything at once, take out the dried samples and store them in a well-ventilated, open place or in a dessicator. Continue the drying as soon as possible.

Drying in microwave

If you are using a microwave, dry leaves in PAPER bags or envelopes. Only place up to 10 samples into the oven at once, in a single layer so that they don't overlap.

Turn the oven on at maximum heat for 30 seconds, then open it for 3 minutes to ventilate out the humidity. Repeat this 8 times so that the overall time of drying is 4 minutes, overall process including ventilating the oven does not take more than 15 minutes.

> **Tip**
>
> Weigh fresh leaves, dry them and weigh them again on the same piece of aluminium foil (paper bag). Use a permanent marker to write the number and mass of the sample **and** mass of the aluminium foil on each package.

Calculation of water and dry biomass in leaves:

dm = dry mass, fm = fresh mass

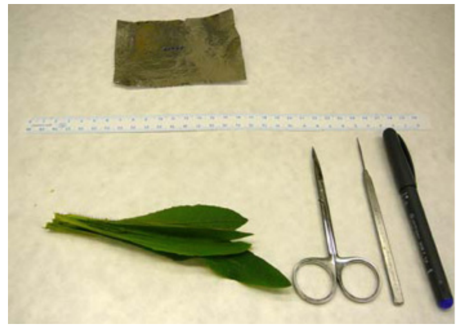
% of dry biomass = (dm / fm) x 100

% of water = (1- (dm / fm)) x 100

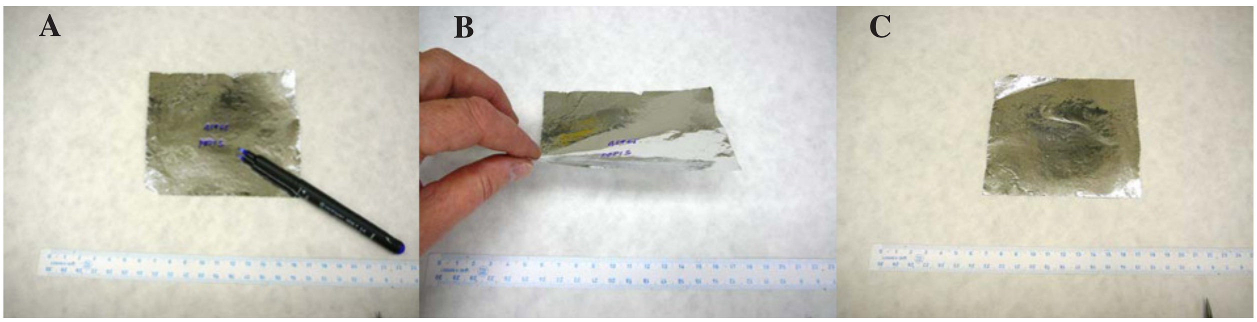
Preparation procedure for dry mass determination

Material and Tools

- Aluminum foil (15x15 cm)
- Plant material (leaves, roots...)
- Scissors
- Needle or pin
- Permanent marker



Preparation of the aluminum foil



<u>Fig A:</u>

- Cut a square of aluminum foil approximately 15x15cm
- Weigh the foil
- Write the weight of the aluminum square onto the foil, also write the description or code of the plant sample with the permanent marker.

<u>Fig B:</u>

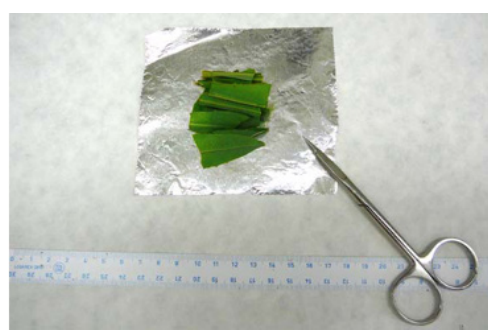
- Turn the foil upside down.

<u>Fig C:</u>

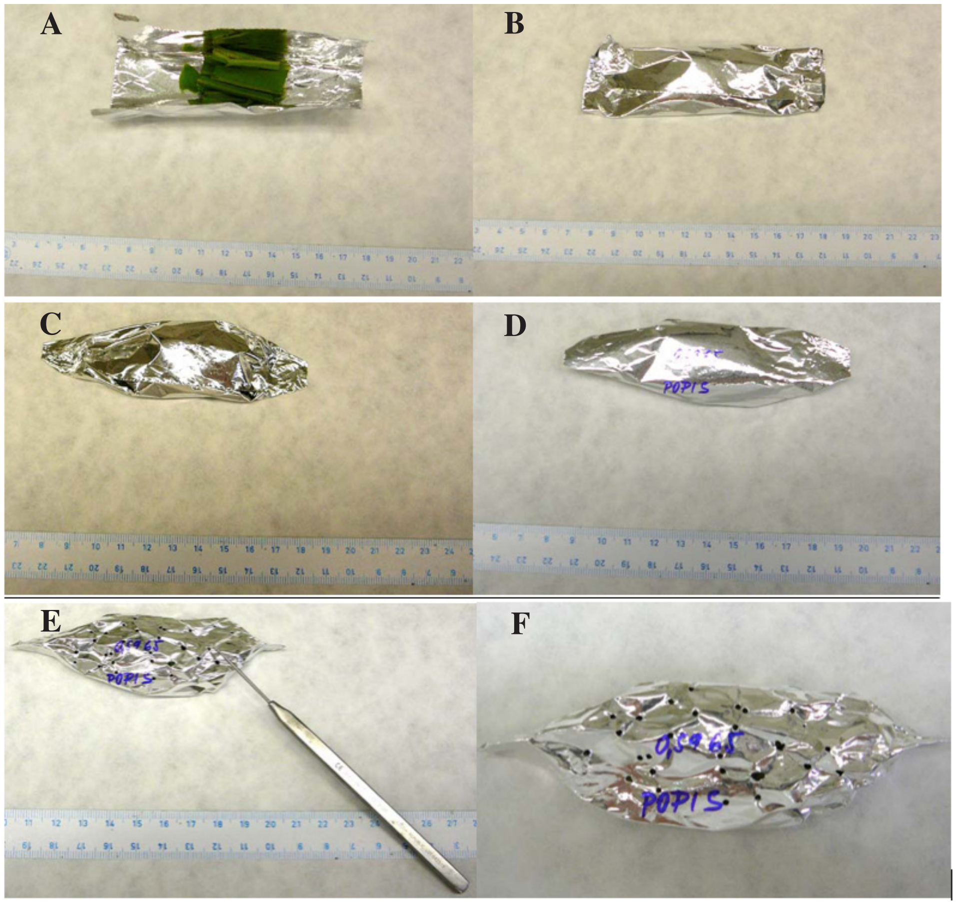
- The description should be on the lower side (in the future outside of the packet)

Preparation of the plant material

- Cut the leaves or roots to segments of appropriate size: length of segments should be approx. one third of the aluminum square length (5cm)



Preparation of the aluminum packet with plant material



<u>Fig A:</u>

- Raise the edges of the aluminum foil above the plant material

<u>Fig B:</u>

- Wrap the plant material into the aluminum foil square

<u>Fig C:</u>

- Tighten together the ends of the aluminum wrap

<u>Fig D:</u>

- Turn the packet upside down and check the visibility of the label

<u>Fig E:</u>

- Use the needle or pin and make at least 20 small holes through the aluminum foil.

<u>Fig F:</u>

- Make sure that the holes are small enough (you must not lose any piece of plant material from the packet) and that the holes are abundant – HOLES ARE IMPORTANT: the water vapor escape through them from the packet, which enables to gain DRY mass of the plant material.
- Do not damage the label when making holes!

Background for Basic Plant-A-Plant Experiments

Water Experiment Background

Question: How is water important to plants?

Evapotranspiration (ET) is the sum of evaporation and plant transpiration. Transpiration accounts for the movement of water within a plant from roots to leaves and the subsequent loss of water as vapor through stomata. Evaporation accounts for the movement of water to the air in vapor form, from the surface of different objects such as soil, water bodies, and plant leaves. Evapotranspiration is an important part of the water cycle.

Plants are composed mostly of water; on average 95% of a plant's fresh weight is water. Tree leaves are often up to 90% water while some mosses are nearly 99% water. In contrast, cereal grains such as wheat or rye contain only about 12% water. While this is a small percentage of water compared to plants, these grains still have enough water available for germination, development, and growth of a seedling.

During growth, however, plants consume remarkably more water than the amount they contain. The transpiration coefficient (Tc) expresses the mass of water, which is taken up by a plant from the soil and evapotranspirated by leaves to the air, per unit of plant biomass accumulation during the same time period. Transpiration coefficients can range in value between 300 and 12,000; smaller transpiration coefficients indicate more ideal growing conditions for plants. While transpiration coefficients are often used in agricultural practices a more common variable used is its inverse, water use efficiency (WUE). WUE is expressed as the ratio of biomass production per unit of water consumed.

While there are many reasons that water is important to plants, below are a few of the most important:

1. Metabolic processes in plant cells take place in water.
2. Water mediates the uptake of mineral nutrients from the soil and their transport throughout the plant.
3. Water plays a key role in temperature regulation by cooling the plant surface during transpiration.
4. Water is a donor of electrons and protons during photosynthesis.
5. Water is the primary source of atmospheric oxygen, which is a result of water splitting during photosynthesis. This process was extremely important during Earth's early history.

Light Experiment Background

Question: Why do plants need light?

Light is electromagnetic radiation that has a wavelength range from 400 (violet) to 770 (red) nanometers (nm) and may be perceived by the normal unaided human eye as a color or light. Light is a term that is used in relationship with the perception by the human eye; when referring to plants the more correct term is radiation or irradiation.

Sunlight entering the outer part of Earth's atmosphere can be divided into three major spectral parts according to its wavelength:

1. Ultraviolet (UV) radiation: wavelengths shorter than 380 nm. The majority of this radiation is absorbed by the ozone layer in the upper part of the atmosphere and only 1-2% reaches the Earth's surface. UV radiation is detrimental to important compounds of living organisms.

2. Visible radiation: wavelengths from 360 to 720 nm. This is the only radiation used by plants for photosynthesis and thus it is also known as photosynthetically active radiation (PAR). 45% of incoming sunlight is visible radiation.

3. Infrared radiation: wavelengths longer than 700 nm. Greater than half of incoming solar radiation is in the infrared wavelengths.

When moving through the Earth's atmosphere sunlight is either scattered by particles in the air, such as carbon dioxide or water vapor molecules, or is reflected back into space. Only about one half of total incoming sunlight reaches the surface of the Earth. Once at the Earth's surface, some sunlight is absorbed and some (approximately 10 to 25%) is reflected back to the atmosphere as heat (very long wavelengths).

Solar radiation affects plants both directly and indirectly. Directly, radiation enables photosynthesis, serves as a signal for numerous physiological processes, determines how plants develop including the size and composition of plant structures, and determines the direction of plant growth. Plants can also be directly affected in a negative way, particularly if large amounts of incoming radiation are in the UV wavelengths. The indirect effect of solar radiation on plants is mediated through its effect on weather and climate of the Earth and the microclimates of a given ecosystem or locality. Generally, plant photosynthetic apparatus is only designed to function well over a narrow range of temperatures. When overheated, different molecules engaged in photosynthesis (e.g. pigments and membranes) stop functioning normally. During a time of increasing global temperatures this may become a serious concern for plants around the world.

One of the most obvious, but important, relationships of light to plants is its role in photosynthesis. Light activates the synthesis of chlorophyll, a green leaf pigment, which is required for photosynthesis. As plants photosynthesize they are able to grow – gaining mass in their roots, stems and leaves.

Mineral Nutrition Experiment Background

Question: Why are nutrients necessary for plant growth?

Mineral elements do not constitute a large fraction of a plant. Mature plants growing in fields, gardens or pots are typically 95% water by weight. The remaining 5% of the plant's weight is typically assessed by completely drying a plant in a drying oven at 90°C for 8-12 hours. The dry matter of the plant biomass is composed mainly (90%) of organic compounds including carbohydrates, proteins, and lipids while the remaining 10% are inorganic compounds. The most prominent element, important to plant structure and function, that makes up these compounds is carbon, which constitutes 45-50% of total dry mass. Carbon along with Oxygen (44%) and Hydrogen (6%), while extremely important, are incorporated into plants during photosynthesis and are therefore historically not the subject of studies about plant mineral nutrition. Plant mineral nutrition studies focus on the uptake of other elements essential for plant life.

Essential elements required by plants in relatively large amounts are called macronutrients and include nitrogen (constituting 1.5% of dry biomass on average), potassium (1.0%), calcium (0.5%), phosphorus (0.2%), magnesium (0.2%), sulfur (0.1%), and silicon (0.1%). Micronutrients are required by plants in smaller amounts, but are no less important to overall plant function. Micronutrients include: chlorine (constituting 100 parts per million, or ppm, of dry biomass on average), iron (100 ppm), boron (20 ppm), manganese (50 ppm), zinc (20 ppm), natrium (10 ppm), copper (6 ppm), nickel (0.1 ppm), and molybdenum (0.1 ppm). Other elements taken up by plants, either non-essential or often toxic to plants, are, for example, aluminum and other heavy metals. Scientific studies have also found that required macro and micronutrients can also become toxic to plants at excessively high levels.

With so many elements present in the soil, water and air how do scientists determine which elements are essential to plants and which are not? Three criteria are typically used in making this determination: (1) if the plant is unable to complete its normal life cycle or develops abnormally without a supply of that element, (2) the element cannot be replaced by another, or (3) the element plays a role in plant metabolism and/or plant physiology.

Carbon Dioxide Experiment Background

Question: How much CO_2 is necessary for plant growth?

How does CO_2 concentration in the air affect photosynthesis?

Generally speaking, the more CO_2 available in the air, the greater the rate of photosynthesis. Plants take in CO_2 via pores called stomata. Stomata regulate the rate at which gases, including CO_2, enter and leave the leaf. This process is called stomatal conductance. When open, stomata allow CO_2 to enter the leaf for photosynthesis; they also allow water, H_2O, and free oxygen, O_2, to escape. Despite CO_2 availability, environmental conditions can sometimes prevent CO_2 from entering the leaf. For example, when plants are wilting they close their stomata to prevent water loss. This also prevents the diffusion of CO_2 into the leaves. CO_2 is also not able to diffuse into the leaves under high air humidity. When the air is saturated with water vapor, water inside the leaf cannot diffuse out through the stomates, thereby making no room for CO_2 diffusion into the leaf. Any time that CO_2 is prevented from entering a leaf it quickly becomes a limiting factor in photosynthesis.

Scientific studies have shown that increased concentrations of CO_2 in the air reduce the opening of stomata, i.e. lowering stomatal conductance. When stomata are more closed, water vapor does not evaporate from the leaf, as quickly, so the plants need less water.

How does increased CO_2 affect individual plants and terrestrial ecosystems?

Increased concentration of CO_2 in the air affects three main physiological processes in plants: photosynthesis, which is increasing, and photorespiration and stomatal conductance, both of which are decreasing. As research began on this topic it seemed feasible that a higher concentration of CO_2 in the air would be a positive change to our environment. Consequences for farmers seemed to be promising – greater photosynthesis would lead to greater biomass production and higher crop yield. At the same time water consumption by plants would be lower, enabling farmers to reduce irrigation and save money. However, plants are very complex systems and their reactions to changes in environmental factors are rarely simple and linear.

As the concentration of CO_2 in the atmosphere has steadily increased so has the intensity of research on the effects of CO_2 on plant growth.

Some of the indirect effects of an increased concentration of CO_2 on plants are discussed here:

1. The quality of plant-accumulated biomass is changing. When more carbohydrates are produced by photosynthesis, due to greater CO_2 availability, the proportion of other nutrients in the biomass is decreased. The most important of these is nitrogen, which is typically incorporated into the plant as proteins. A decrease in plant protein actually means a decrease in the nutritional value of those plants. Because CO_2 has increased globally both agricultural and natural ecosystems are affected. Humans may have access to additional forms of food that will supplement the loss of nutrition, but herbivores feeding on these plants may no longer be able to survive. It is also important to remember that a change at one level in the food web often affects the entire ecosystem. Therefore it is possible, that a decline in the nutritional quality of biomass due to increased CO_2 could contribute to a global scale extinction of animal species.

2. Increased biomass production will likely increase nutrient and mineral requirements. Increased mineral and nutrient requirements by plants are likely to quickly deplete them from the soil. Severely depleted soils can become infertile for plant growth. An imbalance in nutrient uptake from soil can have many complex consequences,

which are difficult to estimate.

3. Increased allocation of biomass into root systems has been observed. Increased allocation of biomass and carbon to roots enriches soil organic matter, which would likely have favorable consequences on soil physical and chemical properties. Simultaneously, increased availability of organic matter in soils can stimulate development of soil flora and fauna. This may cause immobilization of mineral nutrients, preventing uptake by plant roots and use by plants. Additional soil flora and fauna may also change the decomposition rates of soil organic matter. These potential effects, as with all matters dealing with soil, are difficult to quantify and understand.

In addition, there are indirect consequences of decreased stomatal conductance caused by increases in atmospheric CO_2 concentration:

1. Lower transpiration rates limit the transport of mineral nutrients from roots to leaves. Transpiration is the evaporation of water from the aboveground parts of plants. It also cools the plant and enables mass flow, or mass transfer, of water and mineral nutrients from the roots of the plant to the stem, flowers and leaves. Mass flow is caused by a decrease in water pressure in the upper parts of the plant due to transpiration of water from plant stomata to the atmosphere. A decrease in transpiration would result in a decrease in mass flow. This can cause nutritional deficiencies in aboveground plant parts and lead to a decrease in biomass production.

2. Lower transpiration rates also mean lower evapotranspiration of water from the leaf surface. In contrast, higher CO_2 concentrations increase the total amount of plant biomass resulting in greater leaf area for water to be evaporated from. Thus, it is difficult to predict future water consumption of entire ecosystems.

Evapotranspiration, the sum of evaporation and plant transpiration, is an important mechanism for cooling the leaf surface under high temperatures. If transpiration is decreased, then the leaf surface temperature increases. Increased plant temperatures have been shown to increase both respiration rate and plant growth. Temperature changes at this scale can result in premature plant senescence (loss of leaves or even plant death) even before the formation of seeds or fruits.

Presenter: Project: Date:

Presentation Scoring Rubric

Criteria	Points	Advanced	Competent	Not Yet Competent
Content • Introduction • Research Question • Hypothesis • Experimental Steps • Results • Discussion • Conclusion/ Summary		• Attention-getting introduction that provides relevant background information • Clearly explains research question and hypothesis • Experimental steps described in sufficient detail • Results are clear and include observations, calculations graphs and/or tables • Discussion interprets trends and patterns seen in results and links back to research question and hypothesis • Conclusion ties presentation together and leaves audience with a memorable message • Outside work referenced correctly	• Introduction provides relevant background information • Research question and hypothesis stated • Experimental steps included, but described in not enough or too much detail • Results are clear and include some of the following: observations, calculations graphs and/or tables • Discussion interprets trends and patterns seen in results • Includes Conclusion	• No introduction • Research question or hypothesis unclear • Experimental steps non-existent or barely described • Results are confusing and do not include observations, calculations graphs and/or tables • Discussion unorganized, unclear or irrelevant to topic • No Conclusion
Report Quality • Organization • Visuals • Grammatical/ Spelling errors		• Presentation is polished, organized and cohesive • Presenter creatively integrated visuals to amplify message • Contains no mechanical errors	• Presentation is somewhat organized • Visuals added to content and purpose of presentation • Some spelling and grammatical errors	• Little attention to organization and detail • Visuals detracted from content or purpose • Many spelling and grammatical errors
Body Language • Eye contact • Posture and Gestures • Attire		• Strong eye contact with audience • Posture was commanding and purposeful, appears relaxed, gestures enhance presentation • Is appropriately dressed	• Eye contact with audience • Has good posture, uses gestures effectively • Is appropriately dressed	• Little or no eye contact with audience • Poor posture, movements still or unnatural • Is inappropriately dressed
Elocution • Rate and volume of speech • Articulation and pronunciation		• Presenter was easy to hear and understand, used expression and emphasis • Voice sounded natural • Presenter pronounced words clearly, correctly and without vocal fillers	• Presenter was mostly easy to hear and understand • Voice sounded natural • Presenter pronounced words clearly and correctly	• Presenter was hard to hear or understand • Voice or tone unnatural, distracted from presentation • Presenter pronounced words incorrectly and had excessive use of vocal fillers
Overall Impact • Energy • Enthusiasm • Creativity		• Demonstrates a positive feeling • Engages audience • Overall presentation was creative and exciting	• Demonstrates positive feeling during most of presentation • Engages audience	• Appeared bored or showed negativity throughout presentation