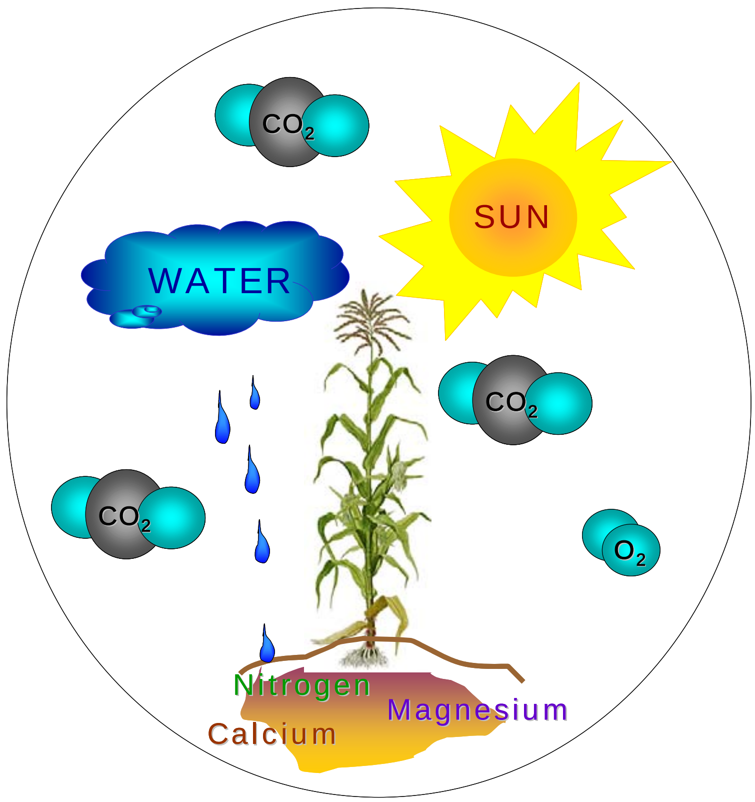
GLOBE Carbon Cycle

Plant-A-Plant: Hands-on Photosynthesis Experiments

July 29, 2007, Preliminary Version

What do the Plants Need to Grow?



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Abstract:

The Plant-A-Plant Activity is under development as a part of the Carbon Cycle Project. Plants constitute a very important part of the global carbon cycle representing a large carbon pool in their biomass.

This activity is designed for the exploration and validation of the necessary sources for plant growth and it demonstrates how CO_2 is incorporated into plant biomass. It will help students understand how plants grow and what resources they need for their growth and biomass accumulation.

Currently, our team is focused on the development of hands-on experiments in which students cultivate their own plants, while manipulating environmental conditions. Students will alter essential resources such as atmospheric carbon dioxide and make experimental observations of the changes in plant growth. The first set of experiments are shown here.

Plant-a-Plant Objectives

Activity will lead students to:

- Formulate their own hypotheses about plant growth and effects of different resources on it
- Conduct experiments based on given information
- Record observations and measurements
- Evaluate obtained data
- Make conclusions based on obtained data and evaluate the validity of the original hypotheses

Prospects and Plans:

- The present experiments are going to be tested by 10 pilot schools in the U.S. and 10 in the Czech Republic during 2007/2008.
- Development of supporting texts and materials.
- New additional experiments of all 4 types are going to be designed and verified for different levels of difficulties during 2007/2008.

Background:
What do the plants need to grow?

The major requirements for plants to grow are light, water, and carbon dioxide. 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 carbon dioxide 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 that plant dies. If you were to dry a plant 45-50% of the plant mass, also called biomass, is made up of carbon.

PHOTOSYNTHESIS
PHOTOSYNTHESIS

$$6\ CO_2 + 12\ H_2O \xrightarrow{\text{LIGHT + chlorophyll}} C_6H_{12}O_6 + 6\ O_2 + 6\ H_2$$

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, 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. If there is not enough nitrogen available, plant growth will be limited even if there is more than enough light, water and CO_2.

What affects the rate of photosynthesis?

Photosynthetic rate is a parameter describing the amount of carbon dioxide that is consumed by a leaf, measured in units of g (CO_2) m^2. The rate of photosynthesis can be affected by many factors. The most important factors are: sunlight, temperature, water, availability of CO_2 and O_2 or any factor that influences the production of chlorophyll and other chemical compounds taking part in photosynthesis (i.e. other macro and micro nutrients – nitrogen, magnesium).

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, and 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. Another case when CO_2 cannot diffuse into the leaves is under high air humidity. When the air is saturated with water vapor, water inside the leaf cannot diffuse out through the stomates therefore making no room for CO_2 to diffuse in. Any time where CO_2 is prevented from entering the leaf it quickly becomes the limiting factor of photosynthesis.

*As a note, increased concentration of CO_2 in the air is known to reduce the opening of stomata, i.e. lowering stomatal conductance. When stomata are more closed, water vapor is not evaporating (leaving the leaf) as quickly, so the plants need less water.

How does increased CO_2 concentration in the air 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, which is decreasing. As research began on this topic it seemed that a higher concentration of carbon dioxide in the air would be a positive change to our environment. Consequences for farmers seemed to be wonderful – greater photosynthesis would lead to greater biomass production, thus higher crop yield, and 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 carbon dioxide in the atmosphere has steadily increased so has the intensity of research on the effects of CO_2 on plant growth. To date there have been hundreds of CO_2 investigations around the world. Some of **indirect effects of 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 are decreased. The most important of these is nitrogen, which is typically incorporated in 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. And it is important to remember that a change at one level of the food web often affects the entire ecosystem. Therefore it is possible that the decline in nutritional quality of biomass due to increased CO_2 can contribute to animal species extinction at the global scale.
2. **Increased biomass production will likely increase the requirement of nutrient and minerals**. Increased mineral and nutrient requirements by plants is likely to quickly deplete them from the soil. Severely depleted soils can become infertile for plant growth. The imbalance in nutrient uptake from the soils can have many complex consequences, which are difficult to estimate.
3. **Increased allocation of biomass into root systems has been observed.** Increased allocation to roots though to 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 (prevent the use) of mineral nutrients for plant roots or change rates of decomposition. These potential effects, as all matters dealing with the soil are difficult to quantify and understand.

In addition, there are **indirect consequences of decreased stomatal conductance** caused by increased CO_2 concentration in the air.

1. Lower transpiration flow lowers transport of mineral nutrition from roots to leaves. This can lead to lowered biomass production caused by nutritional deficit in aboveground plant parts.
2. Lower transpiration rate means lowered evapotranspiration of water from leaf surface. However, the increased CO_2 increases total amount of plant biomass resulting in greater leaf area for water to be evaporated from. Thus it is difficult to predict the future water consumption by whole ecosystems.
3. Evapotranspiration is important for cooling leaf surface under high temperature. If transpiration is lowered, the leaf surface temperature increases. Increased temperatures have been shown to increase both respiration rate and plant growth. This can result in premature senescence (loss of leaves/death) of plants even before formation of yield (seeds/fruits).

Hands-on Photosynthesis Experiments

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.

Following are four experiments demonstrating how different environmental resources affect plant growth.

Experiment 1 - CARBON DIOXIDE

Question: How much CO_2 is needed for plant growth?

CO_2 is a limiting factor for photosynthesis. A factor is regarded as limiting when even though all other factors are readily available, the process of photosynthesis is slowed down or stopped when such a factor is not great enough abundance. Slowing down photosynthesis means that biomass accumulation also slows, ultimately decreasing the amount of carbon that can be stored in that plant.

Effect of CO2 on plant growth: Garden in a bottle

This experiment is designed to observe, how the amount of CO_2 affects maize growth. To ensure that the increase in biomass is due to photosynthesis production during transplanting the seedling to the bottle we remove the seed coats containing the own nutrient support system of a plant. The amount of air with CO_2 available to plants is determined by the volume of the plastic bottle in which the plants are cultivated. In one bottle we do not manipulate air content and keep CO_2 in concentration available in the ambient air. In the second bottle we decrease CO_2 concentration by adding a chemical (NaOH), which absorbs CO_2, into the bottle before closing it. Specific observations of plant size, leaf color and change in plant biomass should be recorded.

What do we need?

- maize seeds
- a laboratory scale (accuracy of 0.01 gram)
- plastic trays or plates for seed germination and planting
- gardening pearlit (pearl-stone) or sand
- empty, clean, and clear plastic 1 liter soda bottles. Make sure to rinse the bottles, but do not wash them in detergent as it may inhibit maize growth.
- Complex fertilizer including microelements (See table 1).
- Distilled water
- CO_2 absorbent (NaOH = sodium hydroxide)
- aluminum foil - for light treatments only

Procedure:

1. Weigh 100 maize grains, determine the mean weight of one (approximatelly 0.25-0.40g). Be sure to prepare more than enough grains. It is necessary to prepare enough grains: 8 bottles in total – 4 for normal CO_2 concentration and 4 for decreased CO_2 concentration (each 5-6 plants).
2. Place the grains on the tray with sand or pearl-stone.
3. Saturate the sand or pearl-stone with distilled water.
4. Use an upside down empty tray to cover the growing tray. Between the two trays the air humidity will increase, creating a better environment for seed germination.
5. After about 7 days at room temperature, the grains should have a root long enough to be planted.
6. Prepare 0.2g/l fertilizer solution.
7. Pour 50 ml of fertilizer solution (0,2 g/l) to each bottle.
8. Carefully remove the remaining coats and parts of unused seed from the developing seedling with root and shoot in order to stimulate the plant to photosynthetize.
9. Put 6 maize plantlets into each of the 8 bottles. Put 2g of NaOH in small vial into 4 of the 8 bottles to simulate decreased CO_2 concentration, be careful to keep NaOH separately from nutrient solution and plants. Securely tighten the cap and do not reopen during the experiment.
10. You can test the effect of light simultaneously if you have enough of bottles (8 more) and cover half of them with aluminum foil.
11. Cultivate in bottles in room temperature for two weeks and record differences between treatments.
12. After two weeks of growth, harvest the plants.
13. Weigh and record the fresh mass of the whole plant.
14. Separate the plants into two parts, removing the root from the maize grain and shoot.
15. Weigh small pieces of aluminum foil and the wrap the plant segments individually. Carefully label.
16. Place aluminum wrapped plants in the oven at 90°C overnight.
17. Weigh the plants in their foil packets and subtract the weight of the aluminum foil to get dry mass of the plant segments.
18. To achieve dry mass of whole plant, add the individual plant segment weights.
19. Calculate the mean whole plant dry mass for each of the treatments.
20. Compare the mean plant dry mass across treatments, and to the original maize grain weight.
21. Calculate following plant characteristics for each treatment:
    dry weight of whole plant
    percentage of water in whole plant
    the biomass increment
    root : shoot ratio
22. Compare the parameters across treatments.

Ask questions before you start! (Form your own hypotheses)

1. How much CO_2 does the air contain?
2. How does lower CO_2 concentration in the air affect plant growth?
3. Where is and how the CO_2 stored in the plant body?
4. How does CO_2 from the air get into the cells of plant leaves?
5. Do the roots need CO_2 as well as leaves?

Experiment 2 – LIGHT

Question: Why do plants need light?

According to a physical definition light is an electromagnetic radiation that has a wavelength range from 400 (violet) to 770 (red) nm and may be perceived by the normal unaided human eye as a color or light. *Note – one nanometer corresponds to 10^{-9} m.

Regarding terminology - light is a term, which should be used in relationship with perception by the human eye. In relation to plants the more physical term radiation or irradiation should be used.

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

1. **Ultraviolet (UV) radiation**: wavelengths shorter than 380 nanometers. The majority of this radiation is absorbed by the ozone layer in the upper part of atmosphere and only 1 - 2 % reaches the Earth surface. UV radiation damaging to life with the shorter the wavelength being more detrimental to important compounds of living organisms.
2. **Visible radiation:** wavelength 360 to 720 nm. This is the only radiation, which can be used by plants for photosynthesis and thus it is termed **photosynthetically active radiation** (PAR) and it has range 400 – 700 nm. 45% of incoming sunlight is visible radiation.
3. **Infrared radiation**: wavelengths longer than 700nm. Greater than half of incoming solar radiation is in the infrared wavelengths.

When moving through the Earth's atmosphere sunlight is partly scattered on different particles in the air, such as carbon dioxide molecules or water vapor molecules, partly is reflected back to the space and only about one half of it reaches the surface of the Earth. Part of this sunlight is absorbed by the Earth surface and part (10 – 25 %) is again reflected to the atmosphere.

Solar radiation affects plants directly and indirectly. Directly it enables photosynthesis, it serves as a signal for numerous physiological processes, it determines how plants develop including the size and composition of structures, and it determines the direction of plant growth. Too much light can also be harmful to plants especially if large proportions are in the UV wavelengths. The indirect effect of solar radiation on plants is mediated through its effect on weather and climate of Earth and the microclimates of a given ecosystem or locality. Generally, plant photosynthetic apparatus is only designed to function well over a rather narrow range of temperatures. When overheated, different molecules participating in photosynthesis (e.g. pigments and membranes) rapidly denature (i.e. they cook).

Light induces green color of leaves through synthesis of chlorophyll: Effect of light on plant growth and development.

To grow, i.e. to produce biomass via reactions of photosynthesis, the light is essential for plants as a source of energy. The light also activates the synthesis of green leaf pigment – chlorophyll, which plays one of the crucial roles in the photosynthetic process.

The present experiment is designed to explore how the absence of light affects maize growth. We will observe the plant size, color of the leaves and increase in biomass.

What do we need?

- maize seeds
- a laboratory scale (accuracy of 0.01 gram)
- plastic trays or plates for seed germination and planting
- gardening pearlit (pearl-stone) or sand
- pots or containers for planting maize, volume about 0.75 litres (possible to use soda or milk containers with the top cut away, wrapped in alluminium foil to ensure, that roots are in the dark)
- complex fertilizer including micronutrients (see Table1).
- distilled water
- large dark containers or paper boxes as a cover for plants

Procedure:

1. Weigh 100 maize grains, determine the mean weight of one (approximatelly 0.25-0.40g). Be sure to prepare more than enough grains. It is necessary to prepare enough grains: in total you will have eight pots – 4 light treatment and 4 dark treatment (each holding 5-6 plants).
2. Place the grains on the tray with sand or pearl-stone.
3. Saturate the sand or pearl-stone with distilled water.
4. Use an upside down empty tray to cover the growing tray. Between the two trays the air humidity will increase, creating a better environment for seed germination.
5. After about 7 days at room temperature, the grains should have a root long enough to be planted.
6. Prepare a solution of 0.5g/l fertilizer to use when watering plants throughout the experiment.
7. Fill pots or containers (volume about 0.75 liters) with clear sand or pearl-stone and put the plantlets in, about 6 plantlets per container. Label the containers with treatments names – e.g. "D" for dark.
8. Cover cultivation containers with the large dark containers or paper boxes to prevent light from entering. Choose the cover carefully – Plants will grow even in the dark, but they need sufficient room. Make sure the cover is dark on the inside and rather light or reflective on the outside to prevent high temperatures inside the box. You can use aluminum foil to make the outer surface light-reflecting. Make sure to prop the cover up off the table when placed over the plant so fresh air (enough CO_2) can enter.

9. Store the plants at room temperature for two weeks and water with 100 ml of the 0.5g/l fertilizer solution every two days for two weeks
10. During the cultivation observe and record differences between the treatments. Some differences should be visible after the 5th day of cultivation.
11. After two weeks of growth, harvest the plants.
12. Weigh and record the fresh mass of the whole plant.
13. Separate the plants into two parts, removing the root from the maize grain and shoot.
14. Weigh small pieces of aluminum foil and the wrap the plant segments individually. Carefully label.
15. Place aluminum wrapped plants in the oven at 90°C overnight.
16. Weigh the plants in their foil packets and subtract the weight of the aluminum foil to get dry mass of the plant segments.
17. To achieve dry mass of whole plant, add the individual plant segment weights.
18. Calculate following plant characteristisc for each treatment:
    - dry weight of whole plant
    - percentage of water in whole plant
    - the biomass increment
    - root : shoot ratio
19. Compare the parameters across treatments.

Ask questions before you start! (Form your own hypotheses)

1. What is the nature of the light?
2. What the light gives to plants?
3. Do the plants need sunlight?
4. Is light a source of energy for plants?
5. Do plants grow at night?
6. How would growth be possible if there is no light at night?

Experiment 3 – WATER

Question to answer: Why do plants need to drink to be alive?

Let us explain some terms first. **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 the vapor form from the surface of different objects such as the soil, water bodies, etc. Evapotranspiration is an important part of the water cycle.

Plants are mainly composed of water. Leaves are composed of up to 90% water and some mosses are almost entirely water, 99%! In contrast, cereal grains are composed of only 12% of water and they are still capable of germination, growth and development into a seedling.

However, during their growth, plants are consuming a remarkably higher amount of water than they contain. The **transpiration coefficient** (T_c) expresses the amount of water, which is taken up by a plant from the soil and evapotranspirated by leaves to the air during a period of accumulation per a unit of plant biomass. Transpiration coefficients can range in value from 300 to 12,000. Another commonly used value in plant water consumption is **water use efficiency** (WUE)**.** WUE is the inverse of the transpiration coefficient and expresses the amount of biomass formation per amount of water flow through a plant in a given time period.

The importance of water for plants:

1. Water is the environment for metabolic processes in plant cells
2. Water mediates uptake of mineral nutrients from soil and their transport throughout the plant body
3. Water participates in regulation of plant temperature by cooling plant surface during transpiration
4. Water is a donor of electrons and protons during photosynthesis
5. Water is a source of oxygen

Effects of water on plant growth.

The present experiment is designed to test how the amount of water affects the growth of maize. We will observe plant growth and record the period it takes for a given water supply to be consumed. Results will be assessed by comparing plant size and weight.

What do we need?

- maize seeds
- a laboratory scale (accuracy of 0.01 gram)
- plastic trays or plates for seed germination and planting
- gardening pearlit (pearl-stone) or sand
- plates or flat dishes
- glass jars or beakers (400 ml)

- plastic or rubber tubes (about 50 mm in diameter)
- complex fertilizer including microelements (See Table 1).
- distilled water

Procedure:

1. Weight 100 maize grains, determine the mean weight of one (approximatelly 0.25-0.40g)
2. Place the grains on the tray with sand or pearl-stone.
3. Saturate the sand or pearl-stone with distilled water.
4. Use an upside down empty tray to cover the growing tray. Between the two trays the air humidity will increase, creating a better environment for seed germination.
5. After about 7 days at room temperature, the grains should have a root long enough to be planted.
6. Prepare 0.2g/l fertilizer solution.
7. Divide jars into three groups and fill them with fertilizer solution:
   - 150 ml of solution (control without plants),
   - 150 ml solution (with plants),
   - 300 ml with plants.
8. Put 2-3 narrow pieces of plastic tubes about 15 cm long on the top of the each jar, cover with plastic plate and carefully turn upside down. This is done to ensure that your jar will be above plastic plate with holes for free water moving from and to the jar. The solution should partly stay in the jar (check with picture A and B, Figure plate 4).
9. Cover the space in the plate outside of the jar with sand or pearl stone (approximately 110 ml) and place there 10 maize plantlets.
10. Do not forget, that there should be one control set of jars and plates without plants. The water lever decreases in this jar as well, which shows that the loss of water from the jar is not only due to plant but the water partly evaporates.
11. Cultivate the plants and harvest them as soon as they become dry.
12. Weigh and record the fresh mass of the whole plant.
13. Separate the plants into two parts, removing the root from the maize grain and shoot.
14. Weigh small pieces of aluminum foil and the wrap the plant segments individually. Carefully label.
15. Place aluminum wrapped plants in the oven at 90°C for overnight.
16. Weigh the plants in their foil packets and subtract the weight of the aluminum foil to get dry mass of the plant segments.
17. To achieve dry mass of whole plant, add the individual plant segment weights.
18. Calculate following plant characteristisc for each treatment:
    dry weight of whole plant
    percentage of water in whole plant
    the biomass increment
    root : shoot ratio
19. Compare the parameters across treatments.

Ask questions before you start! (Form your own hypotheses)

1. Are plant leaves able to take in water from the air?
2. how much water is needed to produce 1 kg of plant dry matter?
3. What is proportional amount of water in a leaf?

Experiment 4 – MINERAL NUTRIENTS

Question to answer: Why are nutrients needed for plant growth?

Mineral elements do not constitute a large fraction of the plant body. Wet weight, or the weight of live plants, is primarily made of water (up to 95 %). The remaining part of their biomass after drying represents **plant dry matter** or **dry weight of plants**. The dry matter of plant biomass is mainly composed of organic compounds (carbohydrates, proteins, lipids etc) and the remaining 10% are inorganic compounds. The main portion of elements in biomass are carbon (45%), oxygen (44%) and hydrogen (6%). All these three elements are gained by plants during photosynthesis. Plant mineral nutrition studies focus on uptake of other elements, which are essential for plant life but make up a much smaller component of the plant by weight.

Biogenous or **essential elements** required by plants in relatively large amounts are called **macronutrients** or **macrobiogenous elements** and they include nitrogen (constituting 1.5% of plant body on average), potassium (1.0%), calcium (0.5%), phosphorus (0.2%), magnesium (0.2%), sulphur (0.1%), and silicon (0.1%). **Micronutrients** or **microbiogenous elements** are required by plants in much smaller amounts though their supply is still very important. Micronutrients include, chlorine (constituting 100 ppm* of plant body in the average, iron (100 ppm), boron (20 ppm), manganese (50 ppm), zinc (20 ppm), natrium (10 ppm), copper (6 ppm), nickel (0.1 ppm), molybdenum (0.1 ppm). There are also some other elements taken up by plants, which are non-essential and quite often toxic to plants, such as aluminum and heavy metals. In some cases excess micronutrients may also be toxic to plants. *(ppm means parts per million = 0.000001 or 0.00000001 %)

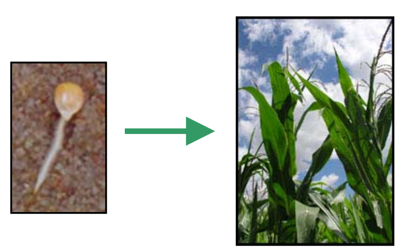
It is important to define the criteria determining that an element is essential for a plant. They are: (1) If without supply of that element the plant is unable to complete its normal life cycle or develops abnormally, (2) the element cannot be replaced by another one, (3) The element has a function in plant metabolism and physiology. This last criterion is the most important – understanding the functions of a given element or its compound in a plant proves to be its essential importance for plants.

Nutrients necessary as a plant food for plant growth: Effect of nutrient availability on plant growth

In this experiment we consider how the absence or addition of essential nutrients affects the growth of maize. We will observe the plant size, presence of nutrient-deficiency symptoms such as leaf yellowing, and assess the increase of plant dry weight over time.

What do we need?

- maize seeds
- a laboratory scale (accuracy of 0.01 gram)
- plastic trays or plates for seed germination and planting

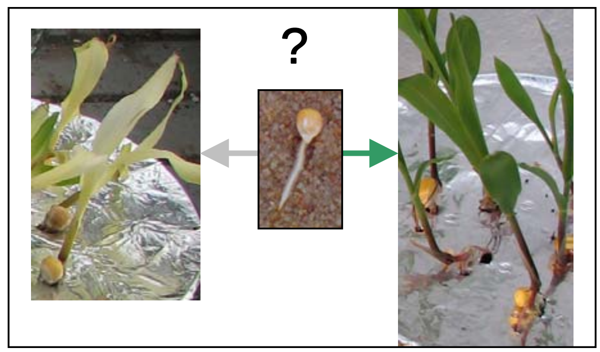


- gardening pearlit (pearl-stone) or sand
- pots or containers for planting maize, volume about 0.75 litres (possible to use soda or milk containers with the top cut away, wrapped in alluminium foil to ensure, that roots are in the dark)
- complex fertilizer including micronutrients (listed in table)
  suggested Kristalon Start (NU3 B.V. Vlaardingen, The Netherlands)
- distilled water

Table 1: Detailed element 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


Gardening pearl-stone



Procedure:

1. Weigh 100 maize grains, determine the mean weight of one (approximatelly 0.25-0.40g). Be sure to prepare more than enough grains. You will need at least 6 for each separate treatment, including a control.
2. Place the grains on the tray with sand or pearl-stone.
3. Saturate the sand or pearl-stone with distilled water.
4. Use an upside down empty tray to cover the growing tray. Between the two trays the air humidity will increase, creating a better environment for seed germination.
5. After about 7 days at room temperature, the grains should have a root long enough to be planted.
6. Prepare fertilizer solutions with increasing concentration (0.1g/l, 0.5g/l and 1.0g/l). Do not forget you will also have a control, where only distilled water will be added.
7. Fill pots or containers (volume about 0.75 liters) with clear sand or pearl-stone and put the plantlets in, about 6 plantlets per container. Label the containers with treatments names – e.g. “DW” for distilled water, “0.1” for 0.1g/l of fertilizer
8. Water the plants every two days with approximately 100 ml of the given solution and plant them in room temperature for thirteen to sixteen days. During the cultivation observe and record differences between the treatments. Some differences should be visible after the 5th day of cultivation.

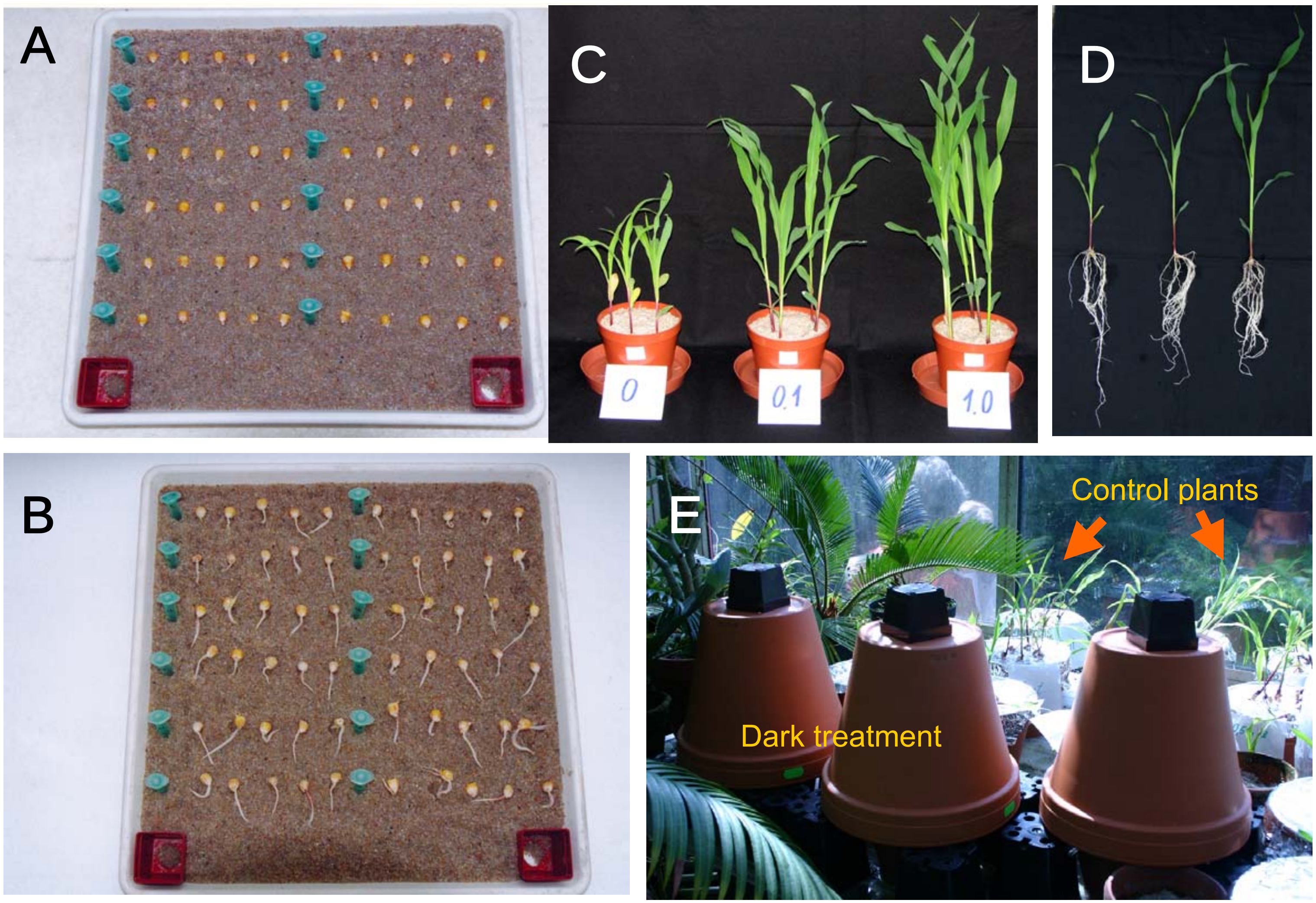
9. After two weeks of cultivations, harvest the plants. Carefully separate plants from the cultivation media (sand / pearl stone).
10. At first weight the fresh mass of whole plants and record the weight.
11. Separate the plants into the root, the rest of the grain and the shoot.
12. Weigh small pieces of aluminum foil and the wrap the plant segments individually. Carefully label.
13. Place aluminum wrapped plants in the oven at 90°C overnight.
14. Weigh the plants in their foil packets and subtract the weight of the aluminum foil to get dry mass of the plant segments.
15. To achieve dry mass of whole plant, add the individual plant segment weights.
16. Calculate the mean whole plant dry mass for each of the nutrient treatments (0.1g/l, 0.5g/l and 1.0g/l).
17. Calculate following plant characteristisc for each treatment:
    - dry weight of whole plant
    - percentage of water in whole plant
    - the biomass increment
    - root : shoot ratio

Compare the parameters across treatments.

Ask questions before you start! (Form your own hypotheses)

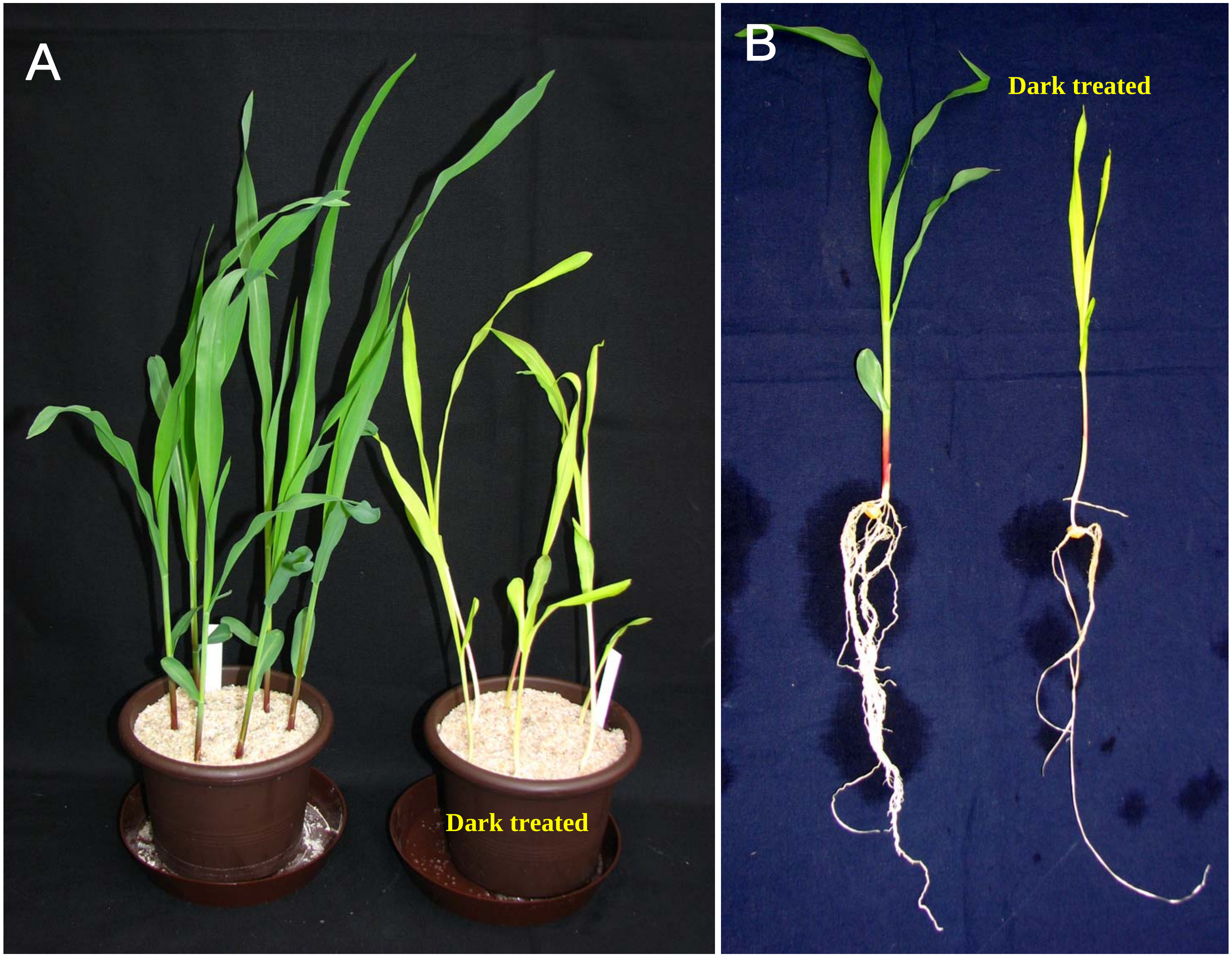
1. Are pure water and air sufficient sources for the plant growth?
2. What is the minimal amount of given nitrogen salt sufficient for plant to create 1 kg of biomass (fresh weight)?
3. Are any of the biogenous elements more important than the others?
4. Is the salt concentration in nutrient (soil) solution important for plants?

Figure Plate 1



A) Maize grains prepared for germination placed on sand saturated with water.
B) After 7 days, the root is long enough, maize is ready to plant.
C) Maize plants after 16 days of cultivation in sand, watered with different concentrations of fertilizer.
D) Single maize plants cultivated with different concentrations of fertilizer. Note extent of root and shoot in individual treatments.
E) Maize plants cultivatd in dark – covered with flower pots.

Figure Plate 2



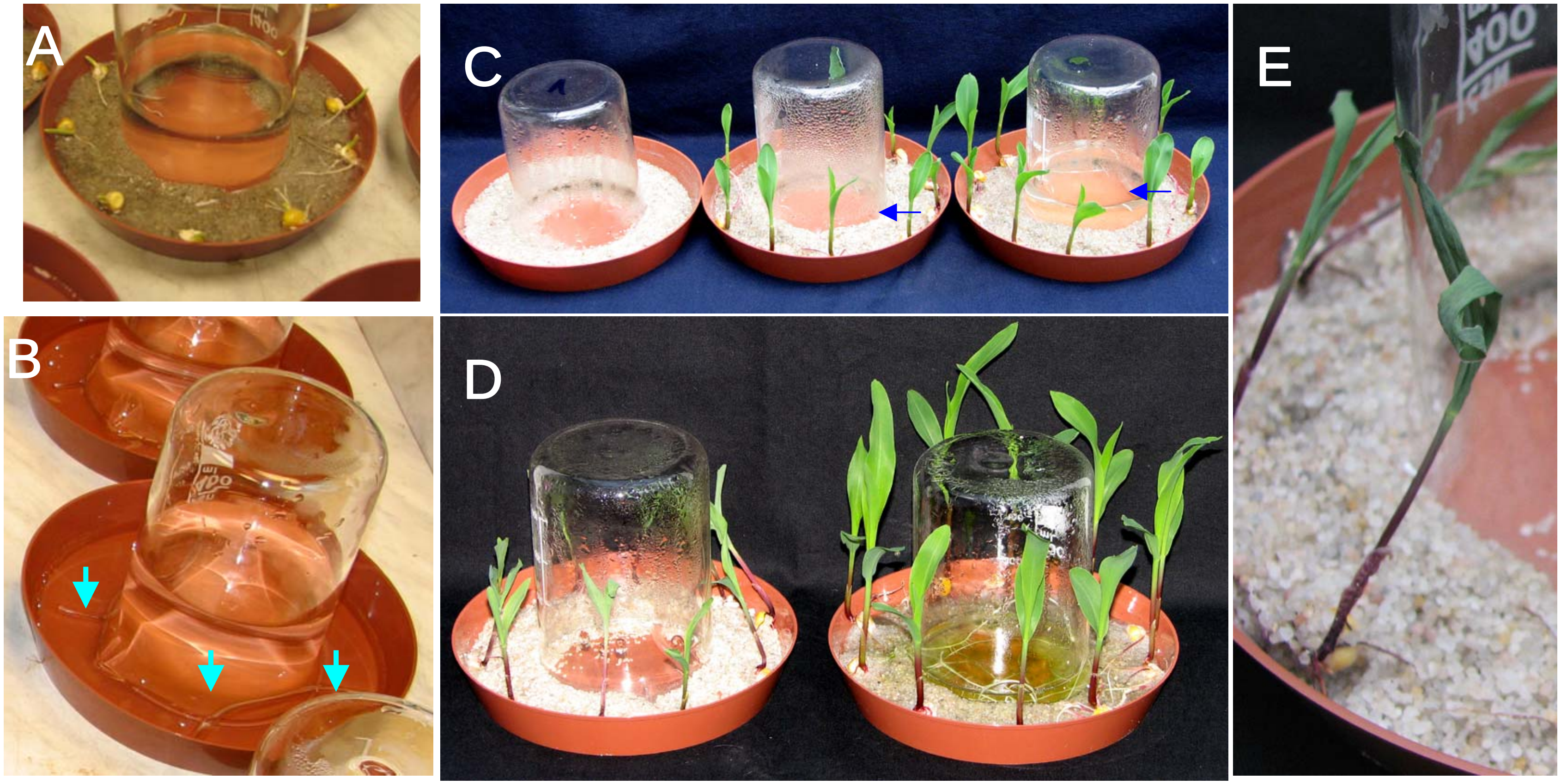
A) Maize plants cultivated for two weeks. Note the color of dark treated plants.

B) Single Maize plants cultivated for two weeks. Note the difference between plant size in both root and shoot.

Figure Plate 3

A) Maize plants cultivated in 1l plastic bottles. Note the vial with CO2 absorbent (NaOH) in left bottle.
B) Detail of vial with CO2 absorbent (NaOH). It should not contact the nutrient solution and plants!
C) Single Maize plants cultivated for two weeks. Note the difference between plant size in both root and shoot and the leaf color.

Figure Plate 4



A) Setup of the experimental system: Flat plate with a beaker filled with fertilizer solution, turned upside down.
B) Detail of experimental water setup: Blue arrows show plastic tubes which prop the beaker and let the water flow to the sand with plants.
C) From left: Cotrol (water level decrease as water evaporates). Low water and high water plant treatments. Blue arrow shows water level
D) Maize plants after 7 days of cultivation. Left: Low-water plants use the whole water volume and become dry. Right: High-water plants yet have water support and grow.
E) Detail of dry maize plant, ready to harvest.