PLANET CHANGE

Agriculture in Space: constructing a hydroponic system

Teachers manual

Co-funded by the Erasmus+ Programme of the European Union

Planet change is the short name of an EU Erasmus+ project aimed at VET teachers and their students. With small activities, the idea is to create awareness about sustainability and acquire 21st century skills. All this is done in a technical context, mostly from space technology.

www.planetchange.eu

Contents:

1. General information

Duration: 2 or 3 lessons in total, including one activity

Target group: 16-20 y.o.

European qualifications framework level: 1-4

Teacher preparation: study background information, materials listed with the activity

Topic

Themes: space hazard, construction, agriculture, climate change

Keywords: innovation, sustainability, engineering, life support systems

Activity

Goals
After this activity, students have a better understanding of the benefits hydroponic farming may offer, and its usage for extra-terrestrial farming. Students are able to construct and set up a hydroponic culture.

Summary
In these lessons, students will construct a hydroponic (soilless) culture, in which they grow crops. First, they get to learn and understand different conditions in space and the basics of hydroponic systems. With that knowledge, they can construct their own system.
Of course, conditions in space are also different, apart from the lack of nutritious soil. For students to understand this can add to the depth of their understanding, but it is not necessary to go into details here. Just a basic understanding that creating a closed ecosystem is required, will suffice.
Next, the students learn what different types of hydroponic systems exist and which variables they can change or manipulate to successfully grow crops. For this, it is necessary to understand what conditions they can vary and what challenges they have to overcome in constructing a functioning system.
The nutrients should probably be an already existing mix, in order to be able to focus on the experiment itself.
After the benefits and drawbacks are discussed, the actual experiment can be done, where they make their own hydroponic culture.
Once the system is constructed and the crops are fed, they will need some time to grow.
N.B.: if this is just a technical challenge, with constructing a closed system and making it work, there is no real need to wait for the crops to grow.
After a week (or more), the crops can be harvested. Depending on the time there is and the level of experience, you can choose to analyse the results. At least, there should be some of the crops that have grown and are ready to harvest.
Finally, there can be a discussion about the benefits and drawbacks of hydroponics.

2. Introduction

What if we want to have a spaceship in an orbit around the moon, or even Mars (which is the ultimate goal of the Artemis-mission)? How will those astronauts be able to feed themselves? It won't be possible – or at least, very inconvenient – to supply them regularly.
So, we will probably be aiming at an ecosystem inside the spaceship, or maybe even on the surface of the Moon or Mars, where they can grow and harvest vegetables.
There are already sealed ecosystems inside space stations, but how do you keep it small and efficient? This can be very complicated and might take a lot of materials that need to be sent (in)to space.
One of the solutions to diminishing the latter, is to grow crops without soil; a so-called soilless or **hydroponic culture**. This means no soil to transport, but also less space needed and even options to grow crops vertically (on Earth, that is). There are various ways to do this, and some agricultural companies are already doing this on Earth. For usage on Earth, there are also a lot of benefits; less materials are needed, less space is needed, more control over various conditions, etc.
But for space, it looks like the only sustainable way to create an ecosystem. Thus, NASA is also testing this in space (CELSS, see link below).
Obviously, we will not be able to test in space, but we can discuss what effects different variables have. And, the principles are the same; what is tried and tested on Earth, seems to work similarly in space.
Therefore, most of the research done on the subject is done on Earth and slightly adapted when put to use in space.
What we want to do here, is look at the benefits and drawbacks of hydroponic farming and construct our own system, in order to get a grasp of the technological opportunities (and challenges) there are when building a hydroponic system in a spaceship (apart from the lack of gravity).

Description of the activity

The activity itself consists of constructing a hydroponic culture. Depending on (the level of) the classes, a decision has to be made beforehand how far you want to take it; is it more about construction, more on agriculture, or are both equally important?
The (optional) schedule will thus look like this:
Lesson 1: Introduction about ecosystems in space, discussion and reflection; introduce hydroponics, including variables
Lesson 2: Decide which variables to test, construct hydroponic system, 'insert' crops
Lesson 3: Harvesting; results and discussion*

*: if you want to actually grow crops, that is

Note that the actual activity is lesson two; this means that there will be no practical part in the first lesson if you choose not to plant/start a 'control system'.
For ideas on approaching the subject more interactively, there are some triggering questions added after the first lesson.

3. Lesson 1

Introduction to agriculture in (semi-)closed ecosystems (15 min)

What is an ecosystem and why is it important to understand how it works? Why do we want to build ecosystems in space? What differences are there between growing crops on Earth and in space? How can you control ecosystems, and what factors do you have to take into account?

Optional: Start a culture (10 min)

In order to get results, it is advised to 'prepare' some crops, so the students will be able to collect results about a week after lesson 3. So, in the last part of this lesson the students will plant some seeds, under 'normal' conditions, to have crops to insert in the system. Be aware that you have to be able to 'separate' them later on. Make sure you have enough crops to be able to compare, for example 2*3=6, 3 in both systems.

Introduction to hydroponics (25 min; seen Annex II for information)

What different types of hydroponic systems are there? Which would work in space (and which wouldn't)?
Explain what kind of system they are going to construct and which drawbacks and benefits there are to that system.
Decide which variables they want to vary (possible variables: nutrient fluids, fluid volume and flow rate).
Make a rough sketch / idea of the system.

Suggestions for activating questions / considerations, both about hydroponics and about farming in space:

- Why does a seed sprout 'upwards'?
- Does (the lack of gravity) influence the firmness of the leaves?
- Does the lack of gravity mean that crops grow in random directions?
- What extra measures do you have to take when doing this in space?
- How can you make it even more sustainable / circular?

4. Lesson 2

What variables to vary, and how (20 min)

Look into the different possible variables, and decide which one to control (for instance, two small hydroponic systems, with different flow rates. Or one regular, soil-based system). This will be essential to know before constructing the hydroponic system(s) and starting it.
Explain about the nutrient solution, let the students think of a way (or several ways) to mix it.
Make sure there is a ‘control group'; the hypothesis should exist of expected differences and/or similarities between systems. One system doesn't give much data on HOW the systems function, if they do seem to produce proper crops.

Construction of a hydroponic system (25 min)

After the decision has been made on what nutrients and flow rate(s) to use, the actual construction can start.
For each individual plant, you will need a pot. Which have to be fitted into the PVC pipe. So, drill as many holes as you need to place all the pots in the tube. Be sure that: the pots are tight in the system; the roots of the plants can soak the water/nutrient solution.
Place a reservoir for the nutrient fluid, connect the pump to the system and to the reservoir.
Install the pump, make sure the system is watertight.
After you have made sure all is sealed properly and the plants are able to drink the nutrient fluid, the experiment can start. Fill your reservoir with the nutrient fluid, turn on the pump and check whether all is working properly.

5. Lesson 3

Harvesting and collecting (25 min)

If you have decided to grow crops and analyse them, now is the time to collect.
After a week (or more) of growing your crops, you can harvest them.
Be sure to remind the students of the differences between the systems and the hypothesis they had about the (possible) different outcomes that would generate.

Suggestions for ‘measuring’ / comparing the crops:

- Size of the leaves
- Sturdiness
- Colour
- Development of the roots
- Nutrients (if possible to measure)

Reflection/discussion (20 min)

What have the students learnt? Were there some surprises along the way? What was the most (and least) challenging part? What would they do differently? And what the same? Any ideas on different research?

6. Reflection

After the experiment, students can discuss the benefits and drawbacks of hydroponics, or at least of the hydroponic system they constructed. Also, there will probably be some technical challenges and (im) possibilities they ran into.
In conclusion, they should have an idea about the dos and don’ts when considering a hydroponic culture (in space).

Connections with the industry, career paths and possible excursions

As stated before, several agricultural companies already use and/or test hydroponic cultures on Earth. With a shortage of materials, a limited amount of space to grow crops and the soil getting less fertile and dryer, this is getting increasingly interesting to investigate for companies.
Therefore, a lot of research is being done and this will probably expand over the coming years.
In most EU countries, there are places to visit and experts to be consulted (or maybe invite them to explain a bit). Denmark, Italy and the Netherlands all have large facilities.
In Spain, it is particularly big in the Almeria region, in Portugal there is one near Lisbon, but also on Tenerife, in Norway in Spitsbergen and Oslo.

7. Annex I: Materials

PVC pipe (not too slim)
Pump (a simple pump for a garden pond should be fine)
Reservoir for the nutrient fluid
Post to put the plants in (n.b.: these must fit IN the PVC pipe)
Nutrient solution for a NFT system (this is commercially available)

8. Annex II: Background information / tutorials / examples

Hydroponics

What is a Hydroponic Farming System?
The Latin word hydroponics means "working water". Hydroponic farming is the method of cultivating plants without using soil.
In this farming technique, water replaces soil, such that water delivers nutrients to the plants.
So, instead of exerting energy on looking for nutrients in the soil, the crop's roots can focus on their growth because the nutrients are easily accessible.
As a result, plants can grow quicker and healthier.
In traditional farming, plants need soil to provide water and nutrients, but it is unnecessary during the photosynthesis process.
So, as long as there's water and nutrients, plants can sustain themselves and survive.

This is mostly done by using water-based mineral solutions:

- Water culture (soilless culture); just water and nutrients to feed plants (or with peat-based, rockwool, coir, perlite, …)

Types of water cultures: Nutrient film technique (NFT), deep water culture (DWC), aeroponics (a.o.)

Terrestrial or aquatic plants may grow with their roots exposed to the nutritious liquid or in addition, the roots may be mechanically supported by an inert medium such as perlite, gravel, or other substrates. Because there is an inert medium, these are called soilless cultures.

Types of soilless cultures: ebb and flow, wick systems, Dutch bucket, bag culture (a.o.)

Different types of hydroponic systems

1. Deep Water Culture System
A deep water culture system or DWC system is the easiest method in hydroponic farming because it lets water aerate the plants. This system is currently the most popular method in the market.
In this system, the netted pots holding the plants are directly in deep water. This submerges plant roots and help the plant's access to nutrients.
2. Wick System
The Wick system is where you need to use a growing tray to hold the plants. Then, you need to place the tray on top of a nutrient solution container.
Instead of a pump, you simply connect a wick from the growing tray to the reservoir.

With the help of capillary action, the wick will absorb water and nutrients from the container. Then, it transfers the nutrients to your plants.

This system is especially suitable for novices since the wick constantly waters your plants, even if you are away.

3. Nutrient Film Technique System

In this system, netted pots are placed within channels in which water is continuously allows to flow over the roots of the plants.

The channels are tilted to allow the water to flow easily. And it needs an aerated such as air stone and water pump to let the water travel upward back to the channel.

Unlike the deepwater system, the nutrient solution of the NFT system flows over plant roots.

However, you will need to change the water and nutrients every week. This is to ensure that your plant receives enough nutrients, to keep the water clean and avoid the build-up of algae.

This system would likely fit large-scale farming or commercial scale because it can be easily expanded.

4. Ebb and Flow System

The unique thing about an ebb and flow system is its timer. A water pump starts filling the grow bed with the nutrient solution from the container below.

When the timer stops, the water slowly drains back to the reservoir underneath.

To control the water, the grow bed is equipped with an overflow tube. This prevents the stem and fruits from getting wet.

This method suits any vegetation because it imitates or even perfects the natural periodical cycle of rain and drying and makes faster plant growth possible.

5. Drip System

This system is also one of the most popular methods among commercial growers. It allows the nutrients to pump to slowly drip into the tube of individual plants, which keeps them well-nourished.

The drip system comes in two different configurations.

Firstly, there is the recovery system, which is popular among amateur home growers. It circulates water to the plants and drains it back to a reservoir.

The other configurations are so called non-recovery systems, which are famous amongst commercial growers. After the plants have absorbed the nutrients, the remaining water drains off through a tube and becomes waste. Therefore, it is convenient to plant large crops like melons, onions, pumpkins, and zucchinis.

6. Aeroponics

Aeroponics is also a unique way of doing hydroponic farming. With aeroponics, farming can be done vertically (i.e., like a tower) or horizontally (like a cube).

It allows the plant to suspend in the air and expose its roots to nutrient solutions.

Nutrients are pumped from a reservoir where a nozzle delivers the solution in a fine mist to the plants.

The mist is usually sprayed from the top and cascades down to the chamber for a vertical type.

Because of its vertical setup, this system consumes 95% less water than traditional methods and is very suitable in situations where there is limited ground area.

Benefits of hydroponics

When it comes to growing hydroponically, these systems offer a variety of benefits over other plant production practices. Such benefits associated with hydroponic systems include higher rates of production, improved crop quality, lower water usage, reduced area required for production, and the potential for year-round production at just about any location. Thus, these systems can be quite profitable, making them desirable for both hobbyist and commercial growers alike!

… key benefits compared to soil culture including the fact that the roots of the plant have constant access to oxygen and that the plants have access to as much or as little water and nutrients as they need. This is important as one of the most common errors when cultivating plants is over- and underwatering. Hydroponics prevents this from occurring as large amounts of water, which may drown root systems in soil, can be made available to the plant in hydroponics, and any water not used, drained away, recirculated, or actively aerated, eliminating anoxic conditions in the root area. In soil, a grower needs to be very experienced to know exactly how much water is needed to feed the plant. Too much water, and the plant will be unable to access oxygen, which can lead to root rot; too little water causes the plant to undergo water stress or lose the ability to absorb nutrients, which are typically moved into the roots while dissolved, leading to nutrient deficiency symptoms such as chlorosis.

Why grow without soil?

- Grow anywhere
- Fewer resources
- 'Easy troubleshooting' (less variables)

Benefits of hydroponic culture:

- Conserves water
- Maximizes space
- Facilitates micro-climates
- Grows crops faster
- Nutrient control
- Produces higher yields
- Produces fresh and high-quality food
- Time saving, cost effective
- Easy harvesting
- And… no soil needed

Drawbacks of hydroponics

Drawbacks:

- Expensive setup
- Dependence on electricity
- Needs constant monitoring and maintenance
- Risks of waterborne diseases
- Problems affect plants quicker

Common problems:

- System clogging
- Infestation (algae, pest)
- Seedling problems (wilting, dead roots)
- Nutrient deficiency (tip burns)

Nutrients

What fertilizer do I need for hydroponics?

The typical 3-part fertilizers used in general hydroponics are NPK (Nitrogen, Phosphorus, Potassium) fertilizer mix, $CaNO_3$(Calcium Nitrate), and $MgSO_4$(Magnesium sulphate).

While commercial farmers mainly use powdered fertilizers, home growers mostly prefer liquid fertilizers because they are easier to dose.

Can you use regular fertilizer for hydroponics?

Yes, you can use regular fertilizer for hydroponics.

However, regular fertilizers lack some nutrients needed by hydroponic plants, which can cause problems at different growth stages.

Therefore, it is best to use products purposely made and tailored for hydroponic farming.

Macronutrients

Nitrogen

This nutrient is an essential amino acid element responsible for your plants' faster growth and development.

Phosphorus (P)

It is the nutrients responsible for photosynthesis, growth, and fruiting for plants that bears fruits.

Potassium (K)

This nutrient is essential, especially for fruiting plants, because it helps grow stems, roots, and flowers, maintains pressure, releases waste gases and vapor, and prevents wilting.

The other macronutrients like Calcium (Ca), Magnesium (Mg), and Sulphur (S) also help plants grow and photosynthesize.

Micronutrients

Nutrients like Boron (B), Zinc (Zn), Manganese (Mn), Iron (Fe), Copper (Cu), Molybdenum (Mo), and Chlorine (Cl) are also essential for nurturing and development of plants.

These things are all critical for your plant's growth. So, what fertilizers are best with the complete nutrients your plant needs?

You can choose between these three types:

Powdered Fertilizers

This type is a dry fertilizer usually used on a commercial scale. You can easily use it by following the instructions and dissolving it with water.

It comes in different Nitrogen, Phosphorus, and Potassium ratios, or what we usually call NPK.

However, the ratio depends on what plant you're planting. For example, the proportion of NPK for lettuce is different from tomatoes.

The disadvantage of this type is that it is pricey, especially the premium ones.

Liquid Fertilizers

This type of fertilizer is the easiest way to deal with because it only needs a little preparation. It dissolves faster than the powder.

However, if you buy it in distant places, the shipping will be costly because it's liquid. And it is more expensive than the solid type.

Organic Fertilizers

Organic fertilizers or homemade fertilizers are one of the most budget-friendly options.

It is from natural resources. However, preparing the different ingredients is challenging to make the nutrient solution needed.
All nutrients should be from a partially decomposed material.
In using organic fertilizer, expect that more water consumption is needed because you need to change the solution frequently to avoid odour formation.
It would be best if you control the amount of nutrients solution. And compared to processed fertilizers, it slows the growth of plants.

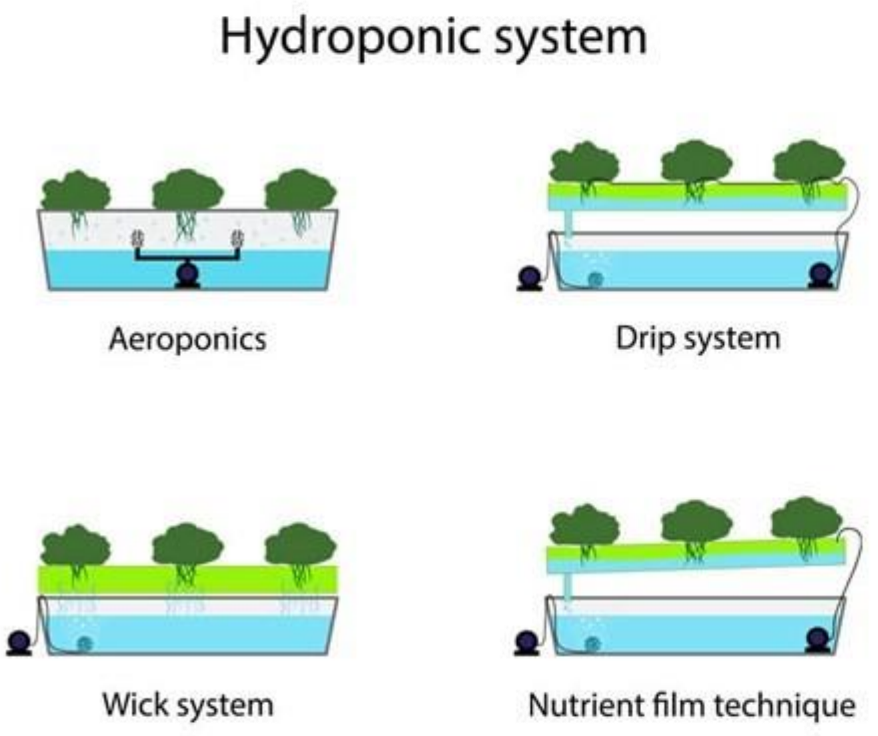
Further information / background:

https://www.nal.usda.gov/farms-and-agricultural-production-systems/hydroponics
https://en.wikipedia.org/wiki/Controlled_ecological_life-support_system (on NASA research)
https://en.wikipedia.org/wiki/Hydroponics

Building instructions:

how-to-build-hydroponics-unit-pvc-pipes-cheap-veggies-soilless-farming
https://www.instructables.com/PVC-Hydroponics-Unit/

9. Annex III: visualisation of hydroponic systems




WHAT IS
HYDROPONIC
FARMING?
BEGINNER'S GUIDE
WHAT IS HYDROPONIC FARMING SYSTEM?
Hydroponic farming is the method of cultivating plants without using soil
Types of Hydroponic Farming System
Deep Water Culture System
Wick System
Nutrient Film Technique
Ebb and Flow System
Drip System
Aeroponics
WHAT IS VERTICAL HYDROPONIC FARMING?
It is a way of stacking up several layers of farm space on top of one another in a vertical direction
How does vertical hydroponics work?
With the help of high-powered pumps
This compact design is space-saving and efficient
CROPS THAT YOU CAN GROW IN A VERTICAL HYDROPONIC TOWER
ADVANTAGES AND DOWNSIDES OF HYDROPONICS
BENEFITS
Conserves water
Maximizes space
Facilitates micro-climate
Grows crops faster
Nutrient control
Produces higher yields
Does not require soil
Produces fresh and high-quality food
It doesn't need pesticides
Time-saving and cost-effective
Easy harvesting
DISADVANTAGES
Expensive setup
Dependence on electricity
Needs constant monitoring and maintenance
Risks of waterborne diseases
Problems affect the plants quicker