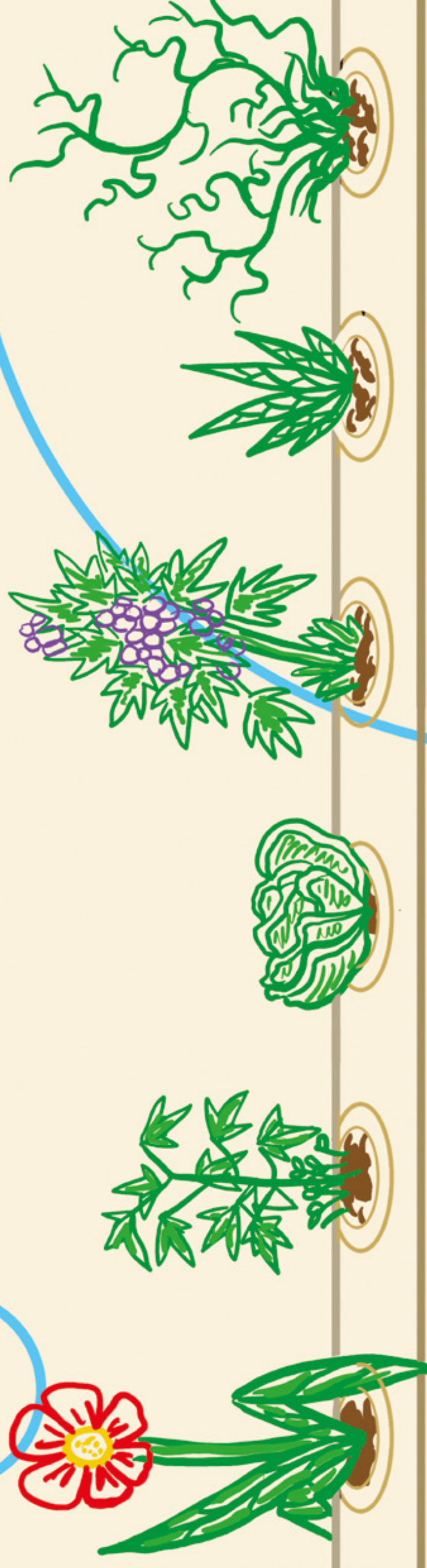
SIMPLIFIED HYDROPONIC BOOKLET



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SIMPLIFIED HYDROPONIC BOOKLET

PREFACE

This document is the result of over two decades of research on simplified hydroponics (SH), also known as simplified soilless cultivation (SSC). Our work has spanned international cooperation projects across Latin America (Peru, Brazil, El Salvador, Colombia, Dominican Republic), Africa (Burkina Faso, Kenya, Tunisia, Nigeria, Ivory Coast, Mauritania), and South-East Asia (Myanmar).

Simplified hydroponics offers numerous solutions, and the best system depends on locally available, affordable materials and site-specific environmental conditions. This manual provides detailed descriptions of various SH systems that can be used directly or adapted to new contexts. Each system includes a build-up and management guide with graphical representations for better understanding.

The manual covers key aspects of SH system management, including substrate selection, pest and disease control, irrigation management, nutrient solution preparation, and seedling establishment. Additionally, to help users tailor SH technologies to their unique environments, guidelines on designing and implementing experiments using local materials and tools are included.

I believe this information will promote the adoption of SH technologies across diverse locations and environments. I hope this document inspires current and future SH gardeners to discover new and effective solutions for SH cultivation. While no single SH solution is universally optimal, each context may reveal the perfect SH technology to implement and enhance, starting with the systems outlined here.

Prof. Francesco Orsini
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INTRODUCTION

The global population faces many challenges in terms of food production, food security, and food safety as well as environmental health issues, mainly due to climate cycles and human adverse effects.

For centuries, rural areas were the main place where the population lived, however, during the last century, due to industrialization and urbanization trends, people especially young adults moved to cities. Accordingly, today the largest part of the global population lives in urban areas. Furthermore, these migratory movements have transformed many people from producers to consumers.

World population growth, particularly in cities, together with climate change, global warming, and resource limitation implies the need for innovative and more efficient food production to overcome the challenges in the food supply chain.

Urban farming is an innovative solution for producing food in cities that is largely based on semi-protected cultivation techniques adopting soilless systems. Advanced technologies for greenhouse production of vegetable crops or those advanced technologies for automated circular hydroponic systems have been well developed and implemented in many parts of the world, particularly in developed countries. However, in many developing countries, these systems cannot be adopted due to their complex management and their high initial investments. Therefore, an urgent need for developing and disseminating simplified hydroponic technologies is emerging.

Urban farming can significantly contribute to the food supply and balanced nutrition of urban dwellers. In many parts of the World characterized by poor climatic or soil conditions, the adoption of simplified soilless systems can guarantee a constant production of fresh vegetables, ultimately reducing malnutrition. When resources like water or mineral nutrient are scarce or when environmental conditions (e.g., temperature) can be a limit to traditional agricultural systems, simplified hydroponics may support in achieving production of nutritious food .

Fresh leafy vegetables are the main crops that are produced in such systems, although other vegetable crops like fruit vegetables, root, or stem vegetables can be produced. Vegetables have a significant role in human diets, thanks to the capability to supply minerals and vitamins requirements.

More vegetable production is needed, and low-cost hydroponics systems will be proposed. This booklet will present the guidelines for the realization and technical management of some hydroponic systems.

SOILLESS SYSTEMS

Soilless cultivation systems of plants are classified as (a) Water-based Culture (Hydroponic) or (b) Nutrient-based Media and Substrate Culture. Water-based culture is practiced in different ways: cultivations carried out in the absence of natural soil, directly on the nutrient solution flowing on the substrate or with roots exposed to air and sprayed periodically with nutrient solution (Aeroponics). In the substrate based culture (also known as nutrient substrate growing media, substrate growing media, or substrate culture), natural organic nutrient substrates (peat, coir, plant waste, sawdust, bark, rice hulls, rice husk, rice straw, compost, vermicompost, meal, cake, farm yard manure, cocopeat, brick shards, biocontrol agents, biofertilizers, paper wastes, wood sawdust, peat moss, sphagnum moss, bagasse), natural inorganic nutrient substrates (sand, gravel, tuff, pumice, perlite, rockwool, vermiculite, montmorillonite), and synthetic materials (polyurethane foam or thermocoal) are used for growing crops in different containers like bags, containers, or troughs.

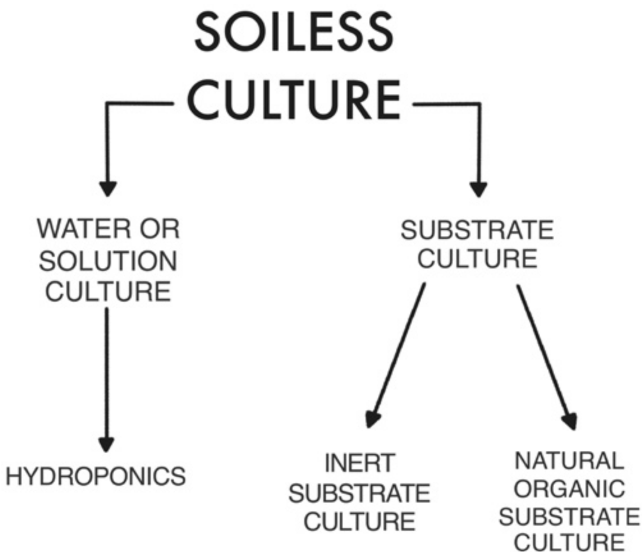


Figure 1. Soilless culture classification

The main reasons why soil-less culture is an expanding agricultural practice are: decreased presence of soil-borne diseases and pathogens because of sterile conditions; improved growing conditions that can be manipulated to meet optimal plant requirements leading to increased yields; increased water- and fertilizer-use efficiency; and the possibility to develop agriculture where suitable land is not available. In addition, with the rising demand for chemical and pesticide free produce and more sustainable agricultural practices, there has been extensive research into organic and soilless methods.

Moreover, the high productivity for the small space required makes soil-less agriculture an interesting method for food security or for the development of micro-scale farming with zero food miles.

WHAT IS HYDROPONICS?

Soilless or hydroponic cultivation is a technology for producing plants out of the soil. In hydroponic systems, plants' roots directly float in a nutrient solution or are supported by an inert substrate that can regularly be fed with a nutrient solution. Hydroponic cultivation enables easier control of plant growth in a protected greenhouse or sheltered place. This system is a major adaptive innovation for urban areas, where limited arable fertile soil is available, or in arid regions, where the soil is not fertile and cultivable. The application of soilless systems offers many advantages concerning soil cultivation. However, when this technique is combined with a protected or greenhouse system, more benefits are expected.

The main advantages of hydroponics system are:

- The closed loop of nutrient solution permits the reduction of the use of water and mineral nutrients by up to 90%
- It may use recycled materials (plastic bottles, wooden planks...)
- Avoids the contact between plant and soil, reducing soilborne pathologies
- Reduces pesticide use
- Requires limited or none energy
- Is an easy to learn technology
- Cultivation is possible even in absence of fertile soil
- Requires reduced physical effort for cultivation as compared to soil farming
- Enables to make more cropping cycles and increase planting density, and therefore, increases production along the year

OPEN LOOP AND CLOSED LOOP SYSTEMS

In a closed hydroponic system, the same nutrient solution is recirculated, and the nutrient concentrations are monitored and adjusted accordingly. In these systems, you can save lots of water, up to 90%, and nutrients, as the mineral-rich water is recirculated back to feed the pants.

Keeping the nutrient balance in such hydroponic systems is a challenge and the hydroponic nutrient solution has to be sampled and analyzed at least once a week. The nutrient solution composition has to be adjusted according to the results. If not managed properly, the nutrient solution might get out of balance.

Open loop systems are represented by the pot or any container that you use to grow a plant, where you let the water go out or get drained but do not reuse it. In open hydroponic systems, a fresh nutrient solution is introduced for each irrigation cycle. The nutrient solution is usually delivered to the plants using a drip system. In open hydroponic systems, an adequate run-off must be maintained to keep nutrient balance in the root zone.

TYPES OF HYDROPONIC SYSTEMS

NFT – NUTRIENT FILM TECHNIQUE

In this system plants are placed in holed tubes, supported by a plastic pot. Inside the tube is recirculating the nutrient solution (1-2 mm) in which the root system is partially immersed. The tubes are slightly sloped to let the solution flow better.

Recovery and reuse of the nutrient solution by a water pump or manually.

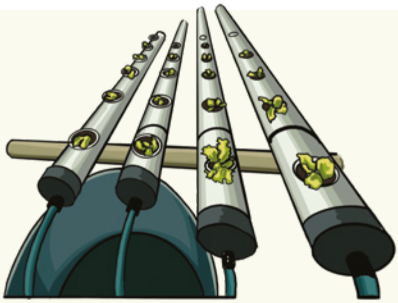


Figure 2. Simplified NFT systems

GARRAFAS PET SYSTEM

The Garrafas PET soilless system is a simplified plastic bottle system and is made of a wooden/bamboo frame and a fed-gravity irrigation system, where the nutrient solution is drained from a tank placed above or below the system. Hydraulic pipes deliver the water into the declined garden with a slope of 24-27% composed by connecting recycled plastic bottles in which substrate and plants are sited. The nutrient solution is emitted with a low flow rate by drippers in the bottom lines starting from the top. The excess nutrient solution is then directed through a drainage pipe system to the tank placed above or below by a water pump. This flux continues from sunrise until dusk.

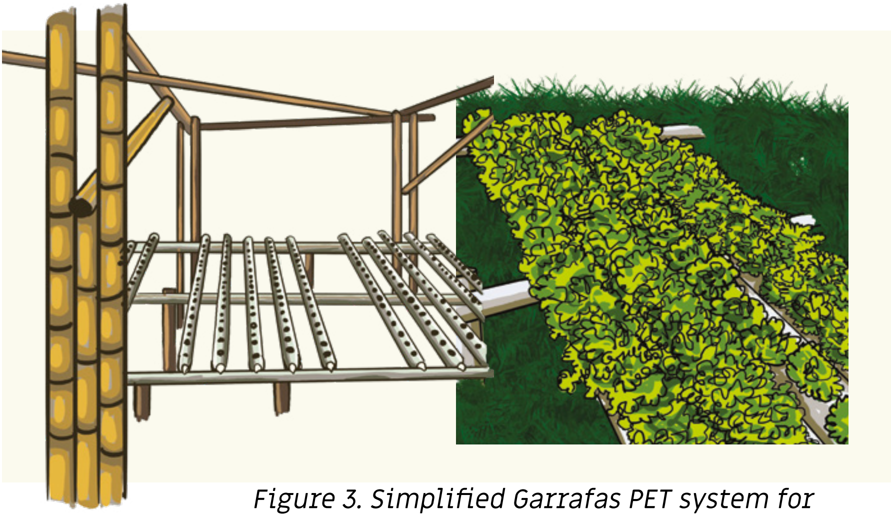


Figure 3. Simplified Garrafas PET system for lettuce cultivaton

FLOATING SYSTEM

In a floating system, plants are placed in a polystyrene tray which is floating in tanks filled with nutrient solution. An air pump can be useful for oxygenation, mainly in dry and hot seasons, while when electricity is not available, water may be manually moved to ease its oxygenation (4-8 times a day, depending on the heat, more often under warmer conditions). The system is mostly suitable for leafy crops or nursery stock.

DWC - DEEP WATER CULTURE

Deep Water Culture is one of the most simple and efficient hydroponics techniques, the plant grows in a net pot filled with a small number of clay pebbles, and the roots develop immersed in a nutrient solution constantly oxygenated by an air pump.

The air pump delivers fresh air to the growing pot through an air stone, and a high level of dissolved oxygen will be maintained inside the solution, this is necessary for the plant's health, roots development, and nutrient uptake.

Suitable for growing indoor ornamental plants with slow growth.

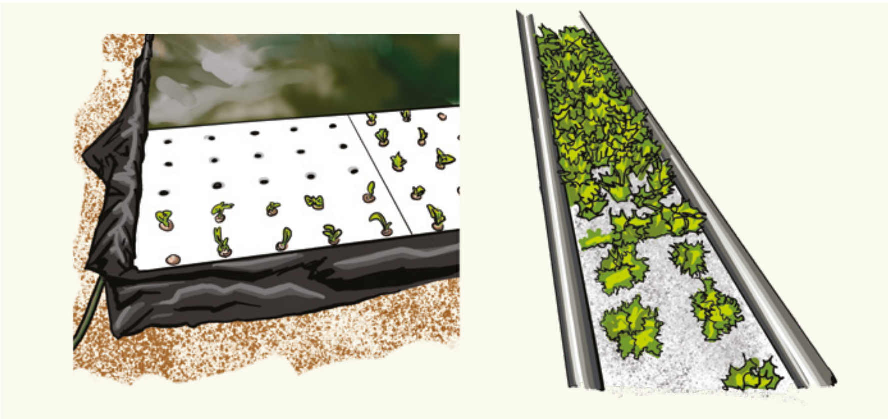


Figure 4. Example of simplified Floating Systems

Figure 5. Example of Deep Water Culture in pots

SUBSTRATE CULTIVATION

Figure 6. Bag cultivation system

The cultivation is carried out by placing the root system of plants in a substrate.

The main functions of the substrate are anchorage, support, and water and nutrition supply.

Examples.

- Raised bed on substrate
- Cultivation on rockwool
- Cultivation in bags

HINTS ON THE SYSTEM

SYSTEM 1: "KRATKY METHOD"

This method is discovered by B.A. Kratky from the University of Hawaii. In essence, Kratky can be seen as the deep-water culture, but without a pump.

The Kratky method is a simplified method that allows one to grow vegetables without particular effort. It consists of letting the vegetable grow in a recipient full of nutritive solution. Being a passive hydroponic technique, it avoids the use of electricity.

Figure 7. Illustration of a Kratky System

SYSTEM 2: "RAISED BED"

The Raised Bed technique is a type of gardening in which the substrate is raised above ground level at a specific height and enclosed in a certain manner. The structures can be made of wood, rock, concrete, or other materials, and the size could be managed based on the various needs. The system can be adapted to a "Deep Water Culture" by making the tank watertight and ensuring an adequate level of water oxygenation. The irrigation system can be more or less simplified as needed.

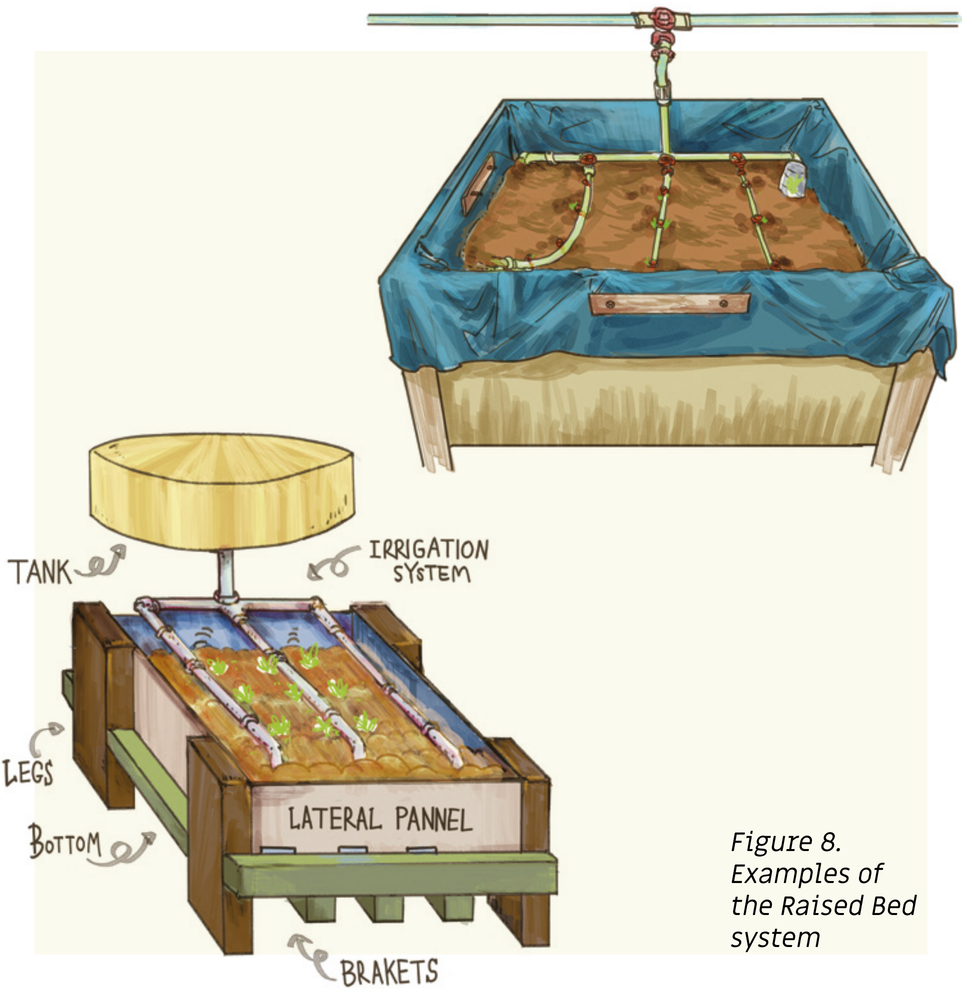


Figure 8. Examples of the Raised Bed system

SYSTEM 3: "DUTCH VASES"

This system is a bit more advanced but could be considered as well as a simplified methodology since recycled material could be used to set up the plant. Plants grown using this system have their roots immersed in a substrate primarily composed of expanded clay perlite, or a combination of both. The pot is a container, with a design to be positioned along a PVC drainage pipe. This pipe collects the nutrient solution runoff and channels it back to the main reservoir. A pump sends the nutrient solution from the tank to the vases thanks to a drip system. The excess solution then flows back to the main tank through the drainage pipe.

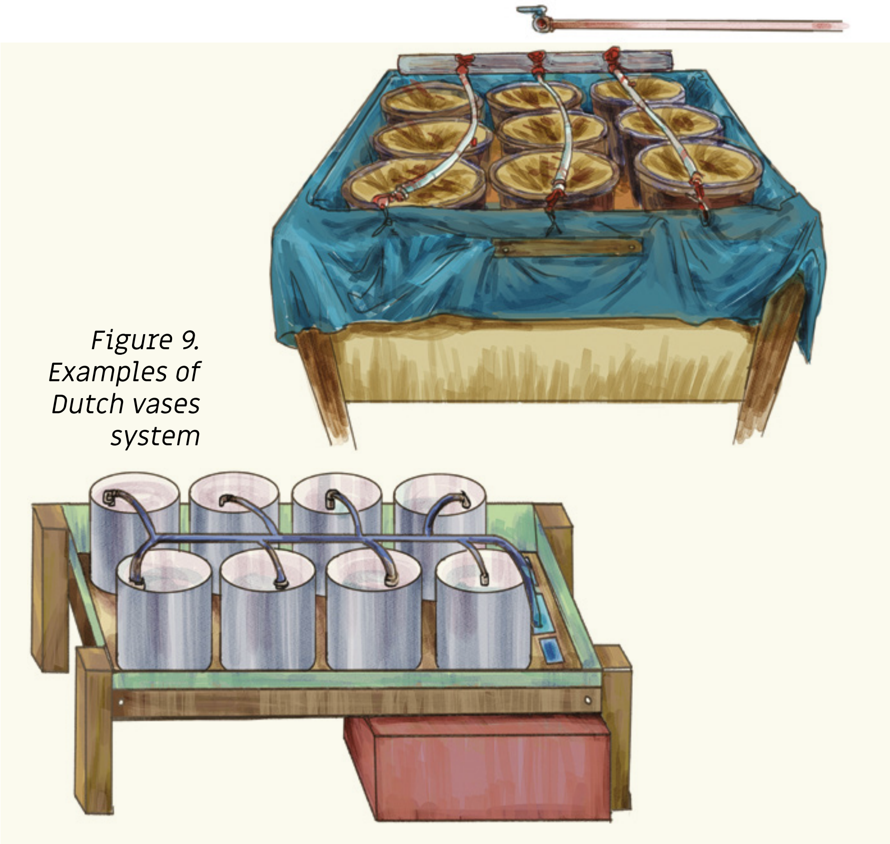


Figure 9. Examples of Dutch vases system

SITE SELECTION

The main elements to be considered when choosing an area to build a simplified soilless garden may be listed as follows:

Set the micro-garden (therefore the greenhouse) in areas that receive at least 6 hours of direct sunlight per day. It is advisable to use a space with good illumination, orienting the micro-garden longer side to the North. Avoid shaded zones, areas near houses or other buildings, as well as areas exposed to strong winds;

Choose an area with adequate and easy-to-access water supply to facilitate irrigation;

Fence the micro-garden to limit bird attacks and avoid domestic animal access (poultries, dogs, pigs, etc...). This will also deter the entry of irresponsible persons and acts of vandalism;

Keep the areas around the micro-garden free from weeds, which can host diseases and insects that may damage the vegetables.

In tropical environments, it may be necessary to adopt protective means to make the growing conditions more suitable for plants. It is important to ensure good ventilation, so usable roofs must be adequately high (at least 3.5 m). The sides can be openable, and the roof can have a ventilation opening. As for the roofing material, it must be cheap and locally available, it must allow good ventilation and protect against the impact of solar radiation (30-50% shading), and it has to protect against heavy precipitation, and withstand intense rain and wind.

GROWING SUBSTRATES

The substrate's main function is to support the plants while allowing a uniform flow of nutrient solution. The substrate does not provide a nutritional function and should be inert in this regard. Suitable substrates can be constituted by different materials, like, for instance, small stones, sand, pumice, vermiculite, carbonized or fermented rice hulls, coconut fiber, cocoa and peanut shelves,

and combinations of the above. A good substrate shall present the following characteristics:
- degradation resistance (durability);
- does not contain soluble mineral substances;
- does not contain any macro and microorganisms (to limit disease risks);
- should be dark, to allow root growth and reduce algae formation;
- has good water retention, but at the same time drains easily;
- does not maintain high surface moisture;
- is easily available in a local contest;
- is affordable, and it is light and easily transportable.

The growth media can be classified into two groups: inorganic substrates and organic substrates. The inorganic ones can be divided as natural unmodified materials as well as sand, tuff, pumice, and processed materials like stone wool, perlite, vermiculite, and expanded clay and zeolite.

The organic materials comprise synthetic substrates (like phenolic resin and polyurethane) and natural organic matter such as peat, coconut fiber, and composted organic wastes (green compost).

INORGANIC OR MINERAL SUBSTRATES

These are of natural origin but are obtained from rocks and minerals. They often undergo simple treatments to process them, without altering their qualities. They are not bio-degradable, i.e. they do not degrade over time. Examples of these are gravel, sand, and volcanic soil. It is also possible to find treated minerals, such as perlite, vermiculite, expanded clay, and rock wool. There are also industrial by-products, such as furnace slag and, coal, among others.

NATURAL

SAND

Sand is the coarse fraction of soil minerals, and its particle size and distribution are often variable as it is a natural deposit. One of the oldest known hydroponic substrates, and is not widely used today, mostly because of its low water-holding capacity and weight. Sand tends to pack tightly together, reducing the amount of air available to the roots; therefore, coarse builders' sand is best suited for hydroponic use. Alternatively, sand can be mixed with other media for a greater water-holding capacity and lighter weight.

Sand can be steam-sterilized but with thin layers, the pores may rapidly fill with water, which disturbs the steaming process. It is very durable because it is neither chemically nor biologically altered during its use as a growing medium. Sand waste can be used in infrastructure and construction; thus, it does not raise environmental pollution problems.

TUFF

Tuff is a common name for pyroclastic volcanic material, characterized by high porosity and surface area. Tuff possesses a buffering capacity and may adsorb or release nutrients, especially P, during the growth period. The chemical stability of tuffs depends on their mineralogical composition.

Tuff is a stable material, which can last for many years. Growing plants may even improve the chemical properties of tuff due to the accumulation of organic matter and low-molecular-weight fulvic acid.

PUMICE

Pumice, like tuff, is a product of volcanic activity and usually forms from silicic lavas developed in rhyolitic composition, rich in gases and volatiles.

The water-holding capacity of pumice is relatively low compared with stone wool, perlite, or organic substrates and may limit water and nutrient uptake by plants, especially in hot climates.

It is stable and can be re-used practically indefinitely. Being a natural product, it can be disposed of without causing environmental pollution.

PROCESSED MATERIALS

PERLITE

Perlite is a glassy volcanic rock with a rhyolitic composition and 2–5 percent of combined water. It is frequently used in potting soil mixtures and as a stand-alone growing medium and it is produced in various grades, the most common being 0–2 and 1.5–3.0 mm in diameter. The combined water in the perlite is converted to gas at high temperature in the oven and subsequently, the volume expands 4–20 times its original volume, resulting in a lightweight high porosity material. Perlite is neutral with a pH of 7.0–7.5, but it has no buffering capacity and contains no mineral nutrients. Perlite is a sterile product as it is produced at a very high temperature. It can last for several years; its stability is not greatly affected by acids or microorganisms. Being an inert material, recycling perlite poses no environmental problems. Steam sterilization of used perlite before planting a new crop has been recommended to safeguard against pathogen contamination.

VERMICULITE

The raw material for vermiculite is a natural clay mineral that has a layered structure with water in between the layers. The substrate, named expanded Vermiculite, is produced in a similar way to perlite by heating the grinded and sieved material to 1000 C.

Vermiculite is used as a sowing medium and as a component of potting soil mixtures. Fine grades are used mainly as a mulch in transplant production while coarse grades are frequently used in rooting media. It has a buffering capacity for pH and cations. It also adsorbs ions like phosphate due to its high surface area and some positive-charged sites on the edges of the clay.

Vermiculite is a sterile product as it is produced at very high temperatures. However, it cannot be steam sterilized as it disintegrates during heating. Therefore, it is not suitable for long periods of use. Its commonly elevate cost may also limit its application in simplified hydroponic systems.

EXPANDED CLAY GRANULES

Expanded clay is a granular product with a crystalline structure with surface and internal porosity. It is produced by forming the clay into pellets at a high temperature (1200 °C). The amount of easily available water that it maintains is very small, just 4 percent. By contrast, the material contains a large amount of air.

It has been classified as an inert material with no cation exchange or buffering capacity and it can be washed and sterilized without deleterious effect. Expanded clay granules are very stable and can last for many years. Waste material can be also used in the construction industry. Being often available and relatively cheap, is one of the most commonly used substrates in simplified hydroponic systems.

ZEOLITE

Zeolites are crystalline hydrated aluminosilicates of alkali and alkaline cations that possess infinite, three-dimensional crystal structures. They are usually formed by the metamorphism of volcanic rocks but may also be formed from non-volcanic materials in marine deposits or aqueous environments. Due to their ion exchange, adsorption, hydration–dehydration, and catalysis properties, zeolites are widely used in agriculture and numerous industries for the removal of pollutants from waste and drinking water.

Zeolites possess extremely high CEC (cations exchange capacity) values and therefore the use of zeolite as a single component growing substrate is not recommended. However, in mixed substrates, which include organic (peat and compost) or inorganic materials (sand and perlite), zeolites are used widely. It is reusable.

ROCKWOOL AND GLASS WOOL

Mineral wool is a light, artificial material, originally produced for thermal and acoustic insulation in the construction industry.

The rockwool that is used in horticulture is mainly used as slabs or blocks of bonded fibers but is also available in granulated form as a component of potting mixtures.

In general, both rockwool and glass wool (mineral wool) are sterile, easily managed, and consistent in performance. They also have little cation exchange capacity and they maintain their structure over a long period of time.

It is an effective growth medium for horticultural crops, in which the grower can easily manipulate the ratio between water and air and between each of the nutrients in the root zone. On the other hand, it is 'unforgiving' to management errors because it lacks a buffering capacity for nutrients, pH, and water, and due to the low volume of the common slabs.

Rockwool can be steamed before re-use.

Given its higher cost and limited availability, workwool slabs may be found in commercial hydroponic installations, while they are scarcely adopted in low-cost hydroponic microgardens.

ORGANIC SUBSTRATES

These are of natural origin and can be produced by biological decomposition.

RICE HULLS

Rice hulls are the outer shells of rice grains. They are a by-product of the milling process and are often used as a source of fuel or animal feed. However, they can also be a hydroponic growing medium. Rice hulls have a high porosity, which allows them to hold a large amount of water. Additionally, they are lightweight and easy to work with.

However, they deteriorate over time, thus they must be replaced regularly to avoid harming plant root systems. Because the hulls are not treated, there is also a chance they will introduce microorganisms or weed seeds into your garden.

Biochar is a carbon-rich material obtained from the thermochemical conversion of organic matter under oxygen-limited conditions and temperatures ranging from 350 to 900 °C. Namely, biochar is a by-product of biomass pyrolysis carried out industrially to produce energy as a natural gas called syngas. Pyrolysis of agricultural waste, such as plant residues, pruning waste, or other green residues from agricultural activities and food processing, is of high interest to increase the environmental sustainability of the agricultural industry.

Among other plant nutrient elements, biochar is often rich in potassium (K) to such an extent that it is considered a fertilizer product, but it may contain various types of plant nutrients in a very broad range (i.e., phosphorus (P), K, calcium (Ca), magnesium (Mg), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), sodium (Na), and zinc (Zn)). Biochar application has the potential to increase carbon content, water, and nutrient retention.

COCONUT FIBER

It is an amendment deriving from the thick mesocarp, or husk, of the coconut fruit (Cocos nucifera L.). Coir peat, as short fiber (1–3 mm) and coir dust (<1 mm), is the resulting waste material of the industrial process of long fiber production: it is often composted for about 6 months, washed, and, sometimes, treated with calcium nitrate (buffered coir) to reduce its high content in Na, chloride (Cl), and Potassium (K).

It is an environmentally friendly option that is also renewable, making it a great choice for those looking for a sustainable option. Coconut coir has good water retention properties and is also very easy to work with. Being largely available in tropical countries, and often cheap as commonly considered a waste material, it is among the most used substrates in simplified hydroponic systems.

GREEN COMPOST

As a locally produced material, compost describes organic matter (plant waste) that has undergone a long, thermophilic, aerobic decomposition as a result of the biological decomposition of organic materials conducted by various microorganism consortia. The use of composted organic wastes as soilless growing media has been increasing over the recent decades because of their high content in organic matter and nutrients (therefore allowing independence from purchasing mineral fertilizers), and because they allow the re-use of waste materials.

The typical factors limiting the inclusion of compost in growing media are high pH and high soluble salt concentration. In addition, immature compost may contain phytotoxic compounds, while its water-holding capacity and particle size might change over time. On the other hand, green compost is rich in humic substances active as plant biostimulants, meaning any substance that when applied to plants enhances nutrition efficiency, abiotic stress tolerance, and/or crop quality traits.

WOOD FIBER

Container substrates, made primarily from wood and wood-based products, have likewise been extensively investigated in recent years. Being a renewable resource, wood fiber substrate may function as a good alternative to peat. Such substrates are made from by-products of the woodworking industry: (i) pure untreated spruce wood chippings with little bark shredded by mechanical defibrillation or, sometimes, steam-assisted thermal extrusion at 80–120 °C (stabilized wood fiber), with the addition of an N-source to avoid N-immobilization.

GROWING SUBSTRATE PRODUCTION

In this chapter, the preparation, of the two most used substrates in SSC (rice hulls and coconut fiber) is presented.

RICE HULLS (CARBONIZED OR FERMENTED)

Rice hulls are left-over material of rice production to be used as a plant substrate in simplified soilless systems, rice hulls should be conditioned, either by fermentation or carbonization. This will allow the pathogen free (from viruses, fungi, and bacteria), further fermentation is avoided, as well as secondary germination of viable rice seed left in the mixture. The dark coloration of the hulls promotes root development and inhibits algae formation. Both substrates have good chemical and physical features: low decomposition index, good drainage, and high aeration. Furthermore, they are light, locally abundant, and very affordable.

RICE HULLS CARBONIZATION PROCESS

The carbonization process has been successfully adopted in several experiences of SSC (Brazil, Mauritania, Ivory Coast, Myanmar).

It is performed in the following steps:

- few fires are started;
- once the fire is running, every fireplace is covered with rice hulls and left until the hulls on the surface starts becoming black. Once this occurs, new rice hulls are placed above the dark spots;
- the process should continue until the required amount of hulls is turned black;
- at this stage, the fire is extinguished with water, and once hulls have cooled down, they can be transferred to the soilless system and transplanting can take place.

Beware that fire can easily spread over rice hulls. Never leave fire unattended and always keep fresh water at hand.

The carbonization process should be conducted on a large amount of hulls (10-15 bags, minimum) in order not to repeat it frequently. It is quite a smoky practice and no matter the amount of hulls to be burned, by increasing the number of fires it will take the same time to prepare one bag or twenty bags. A possible option for burning is the process of “toasting” the hulls. In this case, a metal barrel is placed on a structure that allows it to rotate it, over a burning fire. Hulls are placed in the barrel and left there until toasting is completed.

RICE HULLS FERMENTATION PROCESS

A possible alternative to carbonization is rice hulls fermentation process. The substrate is submerged in water and left to ferment for 15 to 20 days. Afterward, it is washed with fresh water, disinfected with a solution of bleach (1% in water) for 24 hours, and then washed again. The substrate is then left to dry under the sun and collected and stored in bags in a cool and dry place, in order to use it when needed.

COCONUT FIBER (WASHED)

Coconut fiber is a substrate deriving from the shell of a coconut, after grinding, pressing, and selecting. By grinding, the substrate is reduced into small pieces that can easily host plant growth. By pressing, the substrate volume is reduced, and the selection eliminates the biggest not ground pieces. The physical characteristics of the processed substrate are optimal for soilless cultivation and coconut fiber is amongst the most used substrates also in high tech hydroponics. A common problem that may be experienced when using coconut fiber in soilless cultivation is due to salinity. Coconut palms are usually cultivated along coastal areas and the salt spray from the sea winds may cause salt deposition on coconuts. The problem may be easily overtaken by washing the substrate. The substrate is submerged in water for two to three days, and then water is left to drain freely or recollected for use as a pest repellent. The washing process may allow for the reduction of the substrate salinity from initial values of 3.0 dS m-1 down to 0.3 dS m-1.

CROP MANAGEMENT

Crop management involves meeting the diverse needs of plants to ensure optimal growth and productivity. This includes providing specific nutrient solution tailored for the crop variety, maintaining proper environmental conditions, implementing pest and disease control measures, and practicing effective cultivation techniques. Understanding and addressing these factors are crucial for successful agricultural production.

PLANT REQUIREMENTS

Basic plant requirements are described below.

Nutrients: there are two main types of nutrients needed by plants: macronutrients and micronutrients. While both are vital for plant growth, they are required in different quantities. Macronutrients, which consist of nitrogen, phosphorus, potassium, calcium, magnesium, and sulfur, are necessary in larger amounts compared to micronutrients, which are only needed in trace amounts. Understanding the role of each nutrient is essential to grasp their impact on plant growth. When deficiencies occur, it's important to identify the lacking element and adjust the system accordingly by adding supplementary fertilizer. See the related chapter (Nutrient management) for more information.

pH: it directly affects their ability to access essential nutrients. Typically, most plants thrive within a pH range of 5.5 to 7.5, with a preference for mildly acidic conditions. When the pH strays from this range, plants may experience nutrient lockout, meaning that even though nutrients are present in the water, plants cannot effectively absorb them. This is particularly problematic for key nutrients like iron, calcium, and magnesium. Sometimes, what appears to be nutrient deficiencies in plants may be caused by a pH level outside the optimal range.

Temperature: different varieties of vegetables have specific temperature requirements to grow optimally. Winter vegetables thrive in temperatures between 8 and 20°C, while summer vegetables prefer temperatures ranging from 17 to 30°C. Leafy green vegetables, such as lettuce, prefer cooler temperatures, typically between 14 and 20°C, especially during nighttime. Temperatures exceeding 26°C can cause leafy greens to bolt, resulting in bitterness and making them unsuitable for sale. Water temperature has as well great influence in plant growth. Seasonal planting also considers photoperiodism, where certain plants require specific daylight conditions to flower and fruit. Short-day plants require less than 12 hours of light before flowering, signaling the onset of winter and prompting the plant to prioritize reproduction. Conversely, long-day plants flower after a specific day length, though this is less relevant for vegetables and more so for ornamental plants. It's crucial to adhere to local seasonal planting practices for each vegetable or choose varieties unaffected by photoperiodism. These temperature ranges represent optimal conditions, but plants can still grow well outside of them. However, it's important to recognize that different plant varieties have varying needs.

Light: it plays a pivotal role for plants. It is responsible for fueling the process of photosynthesis, providing them with energy needed for their development. In addition, it regulates a series of physiological processes, such as seed germination, flowering, and pigment production. In indoor environments, artificial lighting can be used to ensure plants receive the right amount of light.

CROP SELECTION

Various herbs and vegetables can be successfully cultivated in hydroponic systems, suitable for research, domestic, and commercial purposes. Leafy greens and fruiting vegetables such as tomatoes, cucumbers, and peppers thrive particularly well in most of the systems. Some root crops may not be suited that much for hydroponic set up since they require special attention and are typically grown in deep growing beds.

The choice of plants is influenced by the typology of hydroponic systems. Media bed units often support a polyculture of leafy greens, herbs, and fruiting vegetables simultaneously. On the other hand, commercial Nutrient Film Technique (NFT) and Deep-Water Culture (DWC) units typically favor monoculture practices due to space limitations. Fruit-bearing plants require enough water and space, while large bulbs and root crops are better suited for media beds.

Staggered harvesting and replanting cycles are recommended to ensure consistent production.

MAIN CROPS

LETTUCE

The plant has a short taproot with numerous lateral roots. The stem is very short. The number, shape, size, and color of the leaves vary depending on cultivars.
Plant growth can be divided into 3-4 stages:
- seed germination-seedling stage;
- rosette stage;
- head formation (only for cultivars that form it);
- reproductive stage.

Lettuce thrives in hydroponic systems and different varieties are commonly grown. It is a winter crop and optimal growing conditions include night temperatures of 3–12°C and day temperatures of 17–28°C. Water temperatures exceeding 26°C may also lead to bolting and bitter leaves. For lettuce, pH levels of 5.8–6.2 are ideal, though it can tolerate up to pH 7, with potential iron deficiencies.

Seedlings are transplanted into hydroponic systems when plants have 2–3 true leaves. During warm weather, provide cover to prevent water stress. In media beds, plant new lettuce where they are partially shaded. Harvesting can begin when heads or leaves reach edible size. For market sale, harvest full plants at 250–400g.

PH: 6.0-7.0

PLANT SPACING: 18-30 CM (20-25 HEADS/M^2)

GERMINATION: 3-7 DAYS AT 13-21°C

GROWTH TIME:

24-32 DAYS (LONGER FOR SOME VARIETIES)

TEMPERATURE: 15-22 °C (FLOWERING OVER 24 °C)

LIGHT EXPOSURE: FULL SUN (SHADING IN WARM TEMPERATURES)

HYDROPONIC METHOD: MEDIA BED, NFT AND DWC

Figure 10. Lettuce main needs

BASIL

Basil stands out as a prime candidate for hydroponic cultivation. Optimal germination of basil seeds necessitates a consistent temperature range of 20–25°C. In post-transplantation, basil thrives in warm to very warm environments with full sun exposure, although shading may enhance leaf quality. During periods of intense solar radiation, accompanied by temperatures exceeding 27°C, it is advisable to employ ventilation or shading nets to mitigate the risk of tip burn.

During the transplanting process into hydroponic systems, seedlings should possess 4–5 true leaves. Basil is vulnerable to fungal infections such as Fusarium wilt, grey mould, and black spot, particularly in conditions of suboptimal temperatures and high humidity. Implementing adequate air circulation and maintaining water temperatures above 21°C, both during the day and night, serves to alleviate plant stress and minimize the incidence of diseases.

The harvesting of basil leaves is recommended upon reaching a plant height of 15 cm, continuing for a duration of 30–50 days. Careful handling of leaves during harvesting is imperative to prevent bruising and discoloration. Pruning flowering tips throughout plant development helps deter leaf bitterness and fosters lateral branching. Nevertheless, maintaining a portion of flowering plants can attract pollinators and beneficial insects, ensuring a steady supply of basil seeds.

Figure 11. Basil main needs

PH: 5.5-6.5

PLANT SPACING: 15-25 CM (8-40 PLANTS/M^2)

GERMINATION: 6-7 DAYS AT 20-25 °C

GROWTH TIME: 35-42 DAYS (START HARVESTING WHEN PLANT IS 15CM)

TEMPERATURE: 18-30°C,OPTIMAL 20-25 °C

LIGHT EXPOSURE: SUNNY OR SLIGHTLY SHELTERED

HYDROPONIC METHOD: MEDIA BEDS, NFT AND DWC

REMOVE FLOWERING TIPS TO AVOID BITTER TASTES IN LEAVES AND ENCOURAGE BRANCHING.

PARSLEY

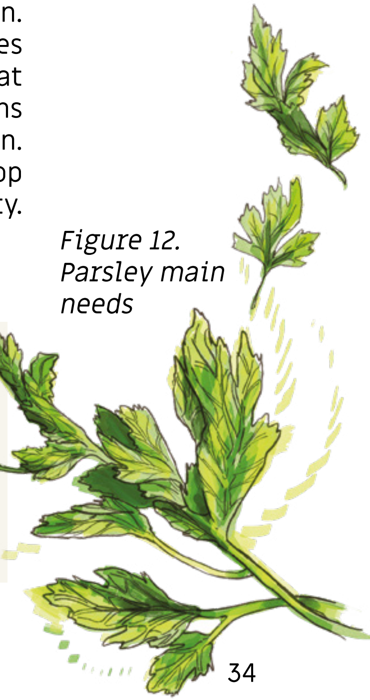
In terms of cultivation conditions, parsley, typically regarded as an annual despite its biennial nature, flourishes over a two-year period in regions with mild winters and limited frost. While parsley can withstand temperatures as low as 0°C, it thrives best in temperatures above 8°C for optimal growth. During its initial year, parsley predominantly focuses on foliage production, transitioning to seed production with the emergence of flower stalks in its second year. Adequate sunlight exposure, preferably up to eight hours daily, is beneficial, although partial shading becomes important when temperatures exceed 25°C.

In terms of cultivation practices, the primary challenge lies in the germination phase, which can extend from 2 to 5 weeks depending on seed quality. To expedite germination, seeds can undergo pre-soaking in warm water (20–23°C) for 24 to 48 hours before being sown into propagation trays. Emerging seedlings exhibit a grass-like appearance, characterized by two slender seed leaves opposite each other. The transplant into the hydroponic system is typically recommended after 5 to 6 weeks, ideally during the early spring season.

As for harvesting, it typically commences when individual plant stalks attain a length of at least 15 cm. Initiating the harvest with outer stems promotes ongoing growth throughout the season. Selective harvesting, particularly focusing on top leaves, is advised to ensure continued productivity.

Figure 12. Parsley main needs

PH: 6.0-7.0
PLANT SPACING: 15-30 CM(10-15 PLANTS/M²)
GERMINATION: 8-10 DAYS AT 20-25°C
GROWTH TIME: 20-30 DAYS AFTER TRANSPLANT
TEMPERATURE: 15-25°C
LIGHT EXPOSURE: FULL SUN; PARTIAL SHADE AT >25°C
HYDROPONIC METHOD: MEDIA BEDS. NFT AND DWC



CABBAGE

Cabbage thrives during the winter months. Due to its big size at the end of the cycle, media beds are preferred over rafts or grow pipes to adequately support the plant's growth.

Optimal conditions for cabbage cultivation entail a winter climate with temperatures ranging between 15–20°C. To ensure optimal head development, it's advisable to harvest cabbage before daytime temperatures exceed 23–25°C.

Transplanting cabbage seedlings with four to six leaves and a height of 15cm is recommended. Careful consideration of planting density based on the selected cabbage variety is essential for maximizing growth potential. In cases where daytime temperatures exceed 25°C, utilizing a shading net help prevent premature

PH: 6.0-7.2
PLANT SPACING: 60-80 CM(4-8 PLANTS/M^2)
GERMINATION: 4-7 DAYS AT 8-29°C
GROWTH TIME: 45-70 DAYS FROM TRANSPLANTING
TEMPERATURE: 15-20°C (GROWTH STOPS AT >25°)
LIGHT EXPOSURE: FULL SUN
HYDROPONIC METHOD: MEDIA BEDS
HARVEST AT 10-15 CM SIZE (DEPENDING ON VARIETY).

Figure 13. Cabbage main needs

bolting, where the plant shifts focus towards seed production rather than head growth. Given cabbage's susceptibility to pests like cabbage worms, aphids, root maggots, and cabbage loopers, vigilant monitoring and the use of organic pesticides safe for hydroponic systems are vital for effective pest management.

Harvesting cabbage should begin when the heads are firm and reach a diameter of approximately 10–15 cm, depending on the specific variety. Using a sharp knife, carefully cut the head from the stem, ensuring to discard outer leaves into the compost bin. Over-ripeness, indicated by cabbage heads prone to breaking, emphasizes the importance of timely harvesting to maintain optimal quality.

TOMATO

Different considerations must be made to cultivate tomatoes in hydroponic to ensure optimal growth and yield.

Ideal growing conditions for tomatoes involve warm temperatures and abundant sunlight exposure. Temperatures below 8–10°C impede growth, while night temperatures of 13–14°C are conducive to fruit setting. However, temperatures exceeding 40°C can lead to floral abortion and poor fruit development. Understanding the two major types of tomato plants, determinate and indeterminate, is essential for proper management. Determinate varieties require pruning to encourage fruiting, while indeterminate varieties necessitate support structures for continuous floral production.

Tomatoes exhibit moderate salinity tolerance, making them suitable for regions with limited freshwater availability. Higher salinity levels during the fruiting stage can enhance product quality. When transplanting seedlings into hydroponic units, precautions must be taken to avoid root damage and waterlogged conditions around the plant collar. Pruning is essential to establish the desired growing method, whether bush or single stem, and to promote airflow and reduce fungal incidence. Moreover, remotion of auxiliary suckers diverts nutrients to fruits.

Harvesting tomatoes at the peak of ripeness ensures optimal flavor and quality. Firm, fully colored fruits are indicative of readiness for harvest. Tomatoes can continue ripening indoors if half-ripe, with storage possible for up to 2–4 weeks under specific temperature and humidity conditions.

Figure 14. Tomatoes main needs

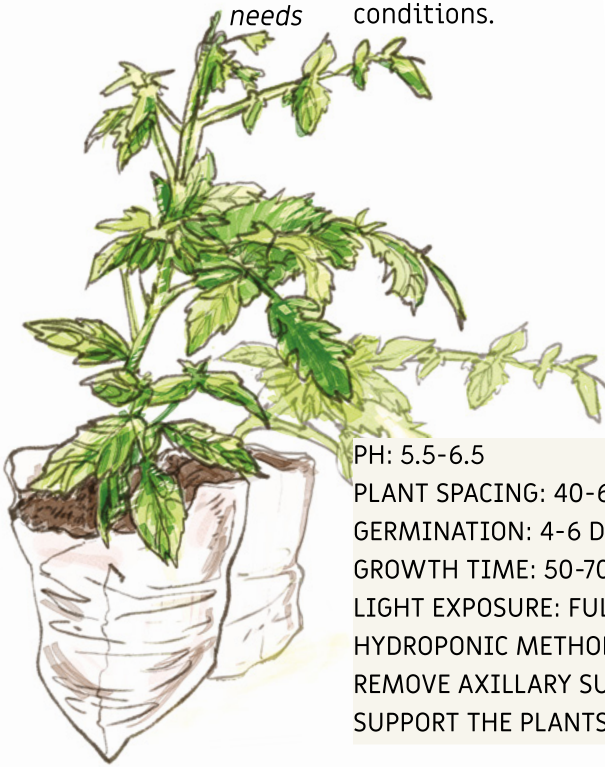
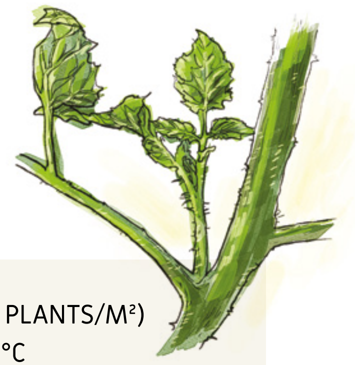


Figure 15. Tomato axiliary sucker



PH: 5.5-6.5

PLANT SPACING: 40-60 CM (3-5 PLANTS/M²)

GERMINATION: 4-6 DAYS; 20-30°C

GROWTH TIME: 50-70 DAYS TILL FIRST HARVEST:

LIGHT EXPOSURE: FULL SUN

HYDROPONIC METHOD: MEDIA BEDS

REMOVE AXILLARY SUCKERS.

SUPPORT THE PLANTS DURING THE GROWTH.

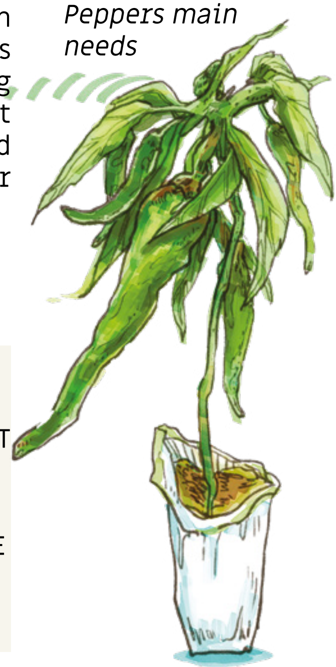
PEPPERS

Peppers come in various types, ranging from sweet bell peppers to hot chili peppers. They can all be cultivated using hydroponic systems. While peppers generally prefer media bed systems, they can also thrive in NFT pipes with extra support.

The optimal conditions for growing peppers include warm temperatures and full sunlight. Seeds require high germination temperatures between 22–34°C, with temperatures below 15°C hindering their growth. Daytime temperatures of 22–28°C and nighttime temperatures of 14–16°C create the best conditions for fruiting, with humidity levels around 60–65%. Root temperatures of 15–20°C are ideal, while temperatures below 10–12°C can stunt growth and deform fruit. Conversely, temperatures exceeding 30–35°C can lead to floral abortion.

It is recommended to transplant seedlings with 6–8 true leaves into hydroponic units. For red sweet peppers, allowing green fruits to ripen on the plant enhances flavor and vitamin C levels. Thinning out excess flowers encourages proper fruit growth. Harvesting should start when peppers reach a marketable size, with ripe peppers showing a change in color. Continual harvesting throughout the season promotes flowering, fruit setting, and growth. Fresh peppers can be stored for up to 10 days at 10°C with 90–95% humidity or dehydrated for long-term storage.

Figure 16. Peppers main needs



PH: 5.5-6.5

PLANT SPACING: 30-60CM(3-4 PLANTS/M^2)

GERMINATION: 8-12 AT 22-30°C (SEEDS WILL NOT GERMINATE BELOW 13°C)

GROWTH TIME: 60-95 DAYS

TEMPERATURE: 14-16°C NIGHTTIME, 22-30°C DAYTIME

LIGHT EXPOSURE: FULL SUN

HYDROPONIC METHOD: MEDIA BEDS

EGGPLANT

Growing eggplants in hydroponic systems offers several benefits, especially in media beds, where their extensive root system allows the plant to grow properly. Each plant can yield between 10 to 15 fruits.

Daily temperatures ranging from 22 to 26°C and relative humidity of 60 to 70% are conducive to optimal fruit set, while temperatures below 9 to 10 °C or above 30 to 32 °C are limiting factors.

For successful growth, seeds typically germinate within 8 to 10 days under warm temperatures (26 to 30 °C), with transplanting recommended at the 4 to 5 leaf stage. Springtime temperature increases signal the ideal time for transplantation. Towards the end of summer, pinching off new blossoms encourages existing fruit to ripen. Pruning plants to 20 to 30cm at the end of the season interrupts the crop cycle without removing plants entirely, allowing for production to resume later. While pruning is optional, it can aid in managing branches in confined spaces or greenhouses, often facilitated by stakes or vertical strings.

Harvesting should begin when eggplants reach 10 to 15cm in length, with shiny skin indicating ripeness. Dull or yellow skin suggests overripeness, rendering the fruit unmarketable due to internal seed development. Employing a sharp knife, cut eggplants from the plant, leaving at least 3 centimeters of the stem attached to the fruit for optimal preservation.

PH: 5.5-5.7
PLANT SPACING: 40-60CM(3-5 PLANTS/M^2)
GERMINATION: 8-10 DAYS AT 25-30°C
GROWTH TIME: 90-120 DAYS
TEMPERATURE: 15-18°CNIGHT,22-26°C DAY
LIGHT EXPOSURE: FULL SUN
HYDROPONIC METHOD: MEDIA BEDS

Figure 17. Eggplant main needs

PLANTS HEALTH

Plant health encompasses more than just the absence of diseases; it represents the overall well-being of a plant, allowing it to reach its full potential in productivity. While managing pathogens and pests is essential, optimal nutrition, smart planting methods, and proper environmental control also play significant roles in maintaining plant health. Additionally, having knowledge about the specific plants being grown is essential for addressing various production challenges.

Insects can transmit diseases to plants, which can subsequently suffer from stunted growth due to the extraction of liquids by pests as they bore into plant tissues. Greenhouses, being enclosed spaces, create favorable conditions for pests, making pest management more challenging compared to outdoor cultivation. Pest prevalence is heavily influenced by climate and environment, with tropical regions facing greater difficulties due to higher insect incidence and competition.

Various harmful insect pests, such as whiteflies, thrips, aphids, leaf miners, cabbage moths, and spider mites, feed on and damage plants. While chemical pesticides are commonly used in soil vegetable production, alternative methods like physical, environmental, and cultural controls are effective in reducing pest threats. Integrated Production and Pest Management (IPPM) combines different strategies to grow healthy plants and minimize pesticide use, including physical, mechanical, and cultural controls.

Physical measures like netting/screens and physical barriers help prevent pest damage, while regular monitoring and hand inspection enable early pest detection and removal. Trapping methods and environmental management, such as maintaining optimal light, temperature, and humidity, also contribute to pest control. Plant selection, indicator plants, and sacrificial/catch crops are additional cultural controls that can help manage pest infestations.

Companion planting, a form of cultural control, utilizes plant relationships to deter pests or enhance plant growth. By strategically planting certain crops together, growers can release natural chemicals that repel pests or attract beneficial insects. Companion planting tables can aid in selecting compatible plant combinations. Fertilization, spacing, crop rotation, and sanitation further contribute to effective pest management.

Chemical control is considered a last resort and should be used sparingly, with biological controls preferred due to their safety and ecological benefits. Microbial extracts like *Bacillus thuringiensis* and *Beauveria bassiana*, along with beneficial insects like lacewings, can help suppress pest populations. However, it's important to note that biological control methods do not completely eradicate pests but rather maintain a balance between pests and their predators

CROP	COMPANIONS	INCOMPATIBLE
TOMATO	Onion family, nasturtium, marigold, asparagus, carrot, parsley, cucumber, basil, oregano	Potato, fennel, cabbage family
EGGPLANT	Beans, marigold, petunia	
PARSLEY	Tomato, beans	Lettuce, carrots, mint
LETTUCE	Carrot, radish, strawberry, cucumber, onion, cilantro	Cabbage, kale
ONION	Beets, carrot, lettuce, cabbage family, summer savoury	Beans, English pea
BEANS	Irish potato, cucumber, corn, strawberry, celery, summer savoury	Onion
CUCUMBER	Beans, corn, English pea, sunflowers, radish	Irish potato, aromatic herbs

Table 1. Companion plants

NAME	INGREDIENTS	PREPARATION	FUNCTION
NEEM	Green leaves: 2kg; Water: 9L; Vegetal soap: 100ml.	Grind the leaves or the fruit using a mortar and some water. Add some more water and leave to rest for three nights. Filter and dilute up to a final amount of 9L. Then this solution shall be sprayed upon the plant.	White fly, aphids, caterpillars, nematodes.
ASH	Wood ash: 0.5 cups; Water: 4L; Kerosene: 6 soup spoons.	Mix the ash with water and leave the solution to rest for 24 hours. Add 6 spoons of Kerosene. Mix strongly and spray on the plants.	Aphids, other sucking insects and leafminer.
GARLIC	85g of chopped garlic; 50ml of mineral oil (kerosene of vegetable oil); 10ml of soap; 950ml of water.	Add garlic to vegetable oil. Allow mixture to stand for 24 hours. Add water and stir in the soap. Store in bottle container. Dilute 50ml of emulsion to 950ml of water. Shake well before spraying. Spray thoroughly on the infested plant, preferably early in the morning.	Phytofagous insects, nematodes and fungi.

Table 2. Organic product recipes and target

NAME	INGREDIENTS	PREPARATION	FUNCTION
MEXICAN MARIGOLD	Leaf and stems of marigold: 1kg; Water: 10L.	Mix leaves and stem with water and boil for thirty minutes and then rest to rest for two days. Filter and spray the solution on the plants.	Aphids, acars, and some caterpillars.
CHILI PEPPER	chili pepper: 500g; Water: 4L; Coconut soap: 5 soup spoon.	In a pot, boil ripe pods or chili seeds in water for 15 - 20 minutes. Take the pot from the fire and add 4 litres of water. Cool and strain. Add soap. Stir well. Then, spray on infested plant.	Ants, aphids, caterpillars, flies and mealybugs.
BLACK PEPPER	Grinded black pepper: 100g; Coconut soap: 60g; Alcohol: 1L; Water: 1L.	Leave pepper to soak in alcohol for 7 days. Dissolve the soap in boiling water, then remove it from the fire and mix with the pepper-added alcohol. Filter the solution and store it. For use, dilute a glass of the preparation onto 10L of water and spray on the plants in three events with a three days interval between them.	Aphids, mites, and scale insects.

INTEGRATES DISEASE MANAGEMENT

Effective disease management is essential for successful plant production, focusing on environmental conditions, pest control, plant care, and the use of organic remedies to prevent or treat diseases. Similar to Integrated Production and Pest Management (IPPM), integrated disease management prioritizes prevention, plant selection, and regular monitoring to combat diseases, with targeted treatment applied when necessary.

Environmental controls play a vital role in disease management, with temperature and humidity being key factors. Diseases tend to thrive in areas and seasons where conditions favor pathogen growth over plant health. Moisture, particularly surface water, facilitates fungal spore germination, highlighting the importance of controlling relative humidity and moisture to reduce disease risks.

Dynamic or forced ventilation, achieved through windows and fans, helps maintain optimal temperature and humidity levels, preventing condensation on plant surfaces. Covering water surfaces in DWC canals and selecting appropriate media bed systems also contribute to disease prevention by minimizing moisture accumulation. Controlling water temperature is crucial to prevent fungal outbreaks such as root rot caused by *Pythium spp.*, which thrive in warm, moist environments.

Plant selection is another critical aspect of disease management, as different plant varieties exhibit varying levels of resistance to pathogens. Using resistant cultivars adapted to specific environments or more tolerant to certain diseases can promote healthy plant growth. Additionally, purchasing seeds or seedlings from reputable nurseries and avoiding plant injuries help prevent disease introduction.

Nutrition significantly impacts a plant's susceptibility to disease, with a balanced nutrient profile enhancing plant resistance. Regular monitoring for early signs of infection or pest presence enables timely intervention, such as removing infected plant parts to prevent disease spread. Exclusion measures, like insect-proof structures and soil contamination avoidance, further minimize disease risks.

Treatment options include inorganic or chemical treatments for controlling disease outbreaks under unfavorable environmental conditions. Biological control agents, such as *Thricoderma spp.* and *Bacillus subtilis*, offer organic alternatives for combating specific diseases. Proper product selection and application methods ensure effective disease management without harming beneficial organisms.

In planting design, maximizing space through careful layout planning and staggered planting helps maintain a balanced nutrient profile and continuous harvest. Encouraging plant diversity and utilizing vertical space optimally contribute to a healthier growing environment. Climbing vegetables can be trained to grow away from beds, creating more space, while hydroponic systems allow for easy plant relocation to manage space effectively.

NURSERY AND SEEDLING DEVELOPMENT

Plants can be sown directly into the soil-less system or transplanted when they have developed some true leaves. In general, it is preferred to transplant the new crop immediately after the previous harvest, to reduce downtime and accelerate production. For example, leafy vegetables (such as lettuce and spinach) and medium-sized fruit crops (such as tomatoes and peppers) are sown in the nursery and then transplanted into the cultivation system. Direct sowing is preferable for vegetables such as carrots, turnips, peas, and beans to preserve the root structure. In contexts where nursery plants are not available or too expensive, a small nursery can be built in a well-lit and well-ventilated area to avoid moisture buildup. Sowing should be done in plastic or polystyrene trays. Where not available, small pots can be created with newspaper (paper pots). A good substrate for seedlings is composed of 50% carbonized rice hulls and the other 50% mature goat or cattle manure, or another mixture of inert/organic substrates depending on local availability.

When the trays are ready, sow one or two seeds per cell and cover with a thin layer of substrate (the depth depends on the species). The trays should be shaded in a protected area and kept wet. After germination, the trays could be moved to the nursery, where they must still be protected from intense and direct radiation. Shading nets should be used to reduce the incidence of sunlight. At this stage, the seedlings should be watered with nutrient solution until transplanting, which takes place when they have 3-5 true leaves.

The first phases are the most delicate and require constant care, therefore some good practices need to be considered, namely:

Wash the trays with bleach (1% sodium hypochlorite) before sowing, rinse them, and dry them in the sun;

Use shading net

Monitor frequently the presence of fungal diseases or dangerous insects in the nursery and be ready to intervene promptly;

Schedule irrigations adequately and avoid water stagnation;

If possible, use a nebulization system to reduce temperatures in the hottest hours of the day, during the most critical periods and months;

Avoid watering the trays from above, to avoid damaging the young seedlings, and use sub-irrigation;

During the rainy season, replace water with a solution of nutrient solution with foliar fertigation and delay the first daily irrigation

Always keep the interior and exterior areas of the nursery clean of wild plants

Reduce planting density immediately after germination to avoid competition between seedlings.

The transplant is a very delicate phase. Root damage must be kept to a minimum. Wetting the trays before transplant will help to remove seedlings from the substrate, and maintain the plantlets turgid, thus reducing transplant shock. Transplants should be done during the coolest hours of the day (at sunrise or sunset) to avoid the hottest hours of the day (particularly critical during warm months). The seedlings need to be transplanted to a good depth, and the substrate must be pressed gently around the root system. Different species or cultivars have different cycle lengths to harvest.

Table 3. Plant growth stages and operations related

SPECIES	Period between... ... planting and germination (days)	... germination and transplant (days)	... transplant and harvest (days)
LETTUCE	5	15 - 18	25 - 30
TOMATO	6	18 - 22	65
CUCUMBER	5	15 - 18	40
EGGPLANT	10	20 -25	75
ONION	10	30 - 35	80
CHIVES	10	30 - 35	55
PEPPER	12	30 - 35	80
CABBAGE	7	30 - 35	90
CAULIFLOWER	7	20 - 25	75
OKRA	3	15	35
CORIANDER	7	20 - 25	40

NUTRIENT MANAGEMENT

Plants require various nutrients for optimal growth. In particular carbon, oxygen, and hydrogen are obtained primarily from the air and water rather than directly from the roots. Carbon dioxide (CO2) from the air is absorbed through small pores called stomata on the leaves. Inside the leaf, carbon dioxide is used in photosynthesis to produce glucose and oxygen. The oxygen produced as by-product during photosynthesis is released back into the air. Instead, water (H2O) is absorbed through the plant's roots from the soil. During photosynthesis, water molecules are split into oxygen and hydrogen atoms, with the oxygen being released into the air and the hydrogen being used in the synthesis of glucose. All the other essential nutrients for plant growth are obtained from the nutrient solution and categorized into macronutrients (such as nitrogen, phosphorus, potassium), mesonutrients (like calcium, magnesium, and sulphur), and micronutrients (like iron, manganese, boron, copper, zinc, molybdenum, and chlorine). Micronutrients are required in smaller quantities but are equally crucial contributing to functions like chlorophyll synthesis, nutrient uptake and many others, and deficiencies can have significant impacts on plant growth and productivity. In traditional soil cultivation, micronutrients are often naturally present in sufficient quantities. However, in hydroponic systems where plants grow in a soilless medium, these essential micronutrients must also be supplied through the nutrient solution.

Each nutrient plays a specific role in plant development:

Nitrogen (N): Essential for chlorophyll formation, stimulating growth, and enhancing protein content. Deficiency leads to yellowing leaves and stunted growth.

Phosphorus (P): Vital for root and flower development, fruit maturation, and overall plant vigor. Lack of phosphorus results in purple discoloration and reduced fruit production.

Potassium (K): Boosts disease resistance, seed size, and fruit quality. Deficiency causes leaf scorching.

Calcium (Ca): Stimulates root growth, overall vigor, and seed production. Deficiency manifests as leaf margin scorch and fruit rot.

Magnesium (Mg): Key component of chlorophyll and sugar synthesis. Deficiency leads to pale green leaves and excessive root branching.

Sulphur (S): Maintains green color, promotes seed production, and vigorous growth. Deficiency causes weak growth and yellowing.

Copper: Essential for chlorophyll formation and plays a role in photosynthesis. It also aids in enzyme activation and electron transport within plants.

Boron: Promotes cell wall formation, pollen germination, and seed and fruit development. Boron also regulates various physiological processes, including sugar transport and hormone regulation.

Iron: Crucial for chlorophyll synthesis, electron transport in photosynthesis, and nitrogen fixation.

Iron is involved in various enzyme reactions and plays a role in DNA synthesis and respiration.

Manganese: Facilitates photosynthesis by splitting water molecules, which is essential for generating oxygen and electrons. Manganese also activates enzymes involved in nitrogen metabolism and antioxidant defense systems.

Zinc: Necessary for chlorophyll synthesis, enzyme activation, and protein synthesis. Zinc plays a crucial role in DNA and RNA metabolism, hormone regulation, and stress response mechanisms.

Molybdenum: Facilitates nitrogen metabolism by aiding in the conversion of nitrates into amino acids. Molybdenum is essential for nitrogen fixation in legumes and plays a role in enzyme systems involved in sulfur metabolism.

Chlorine: While not traditionally considered a micronutrient, chlorine is involved in osmotic regulation and photosynthesis. It also plays a role in stomatal regulation and chloride ion uptake, contributing to plant water balance and nutrient transport.

Both nutrient deficiency and excess can be harmful to plants. Deficiencies interfere with growth and development, while excesses can cause toxicity, disrupting metabolic processes and leading to plant damage or death.

THE NUTRIENT SOLUTION

When substances like sugar, salt, or fertilizers dissolve in water, the resulting liquid is called a solution. Specifically, if fertilizers are dissolved in the water, it is referred to as a nutrient solution.

NUTRIENT SOLUTION DEFINITION

A nutrient solution is a carefully proportioned blend of water and minerals. Its purpose is to deliver water, oxygen, and vital mineral elements derived from soluble salts to the plant roots. It is composed of three main ingredients which are water, soluble salts and oxygen.

NUTRIENT SOLUTION INGREDIENTS

Water
Acid / Base
Mineral fertilizers
Precision balance / pipette / graduated cylinder
Pumps
pHmeter
ECmeter

IONS AND THEIR ROLE IN NUTRIENT SOLUTION

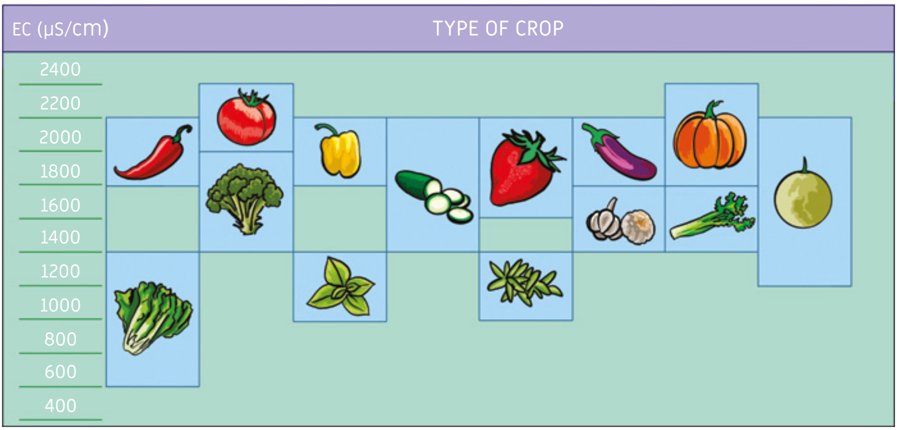
Ions are charged particles formed when atoms gain or lose electrons and we distinguish anions which are atoms negatively charged that gained an electron from cations which are positively charged atoms that lost an electron. These ions come from dissolved mineral salts in the water and are essential for plant growth. Each ion plays a specific role: for example, nitrate ions (NO3-) provide nitrogen, phosphate ions (PO43-) supply phosphorus, and potassium ions (K+) offer potassium. Ions absorbed by plant roots and used in various metabolic processes, including photosynthesis and nutrient transport, crucial for healthy growth and development.

ELECTRICAL CONDUCTIVITY (EC)

Electrical conductivity (EC) is the measure of how well a solution can conduct electricity. It reflects the concentration of dissolved ions, including nutrients and minerals, in the solution. Higher EC values indicate a higher concentration of dissolved salts, while lower values suggest a lower concentration. EC is measured in units such as deciSiemens per meter (dS/m), part per million (ppm) or microSiemens per centimeter (μS/cm). Monitoring EC helps ensure the nutrient solution's salinity remains within optimal ranges for plant growth. Too high EC levels can lead to nutrient imbalances or toxicity, while too low levels may indicate nutrient deficiencies scenarios. Adjusting nutrient concentrations based on EC measurements allows growers to optimize nutrient solutions for healthy plant growth. Overall, EC serves as a valuable tool in managing nutrient solutions and promoting plant health.

Units of measurement conversion,
1 g/L, =, 1000 ppm
1 dS/m, =, 1 mS/cm
1mS/cm, =, 1000 μS/cm

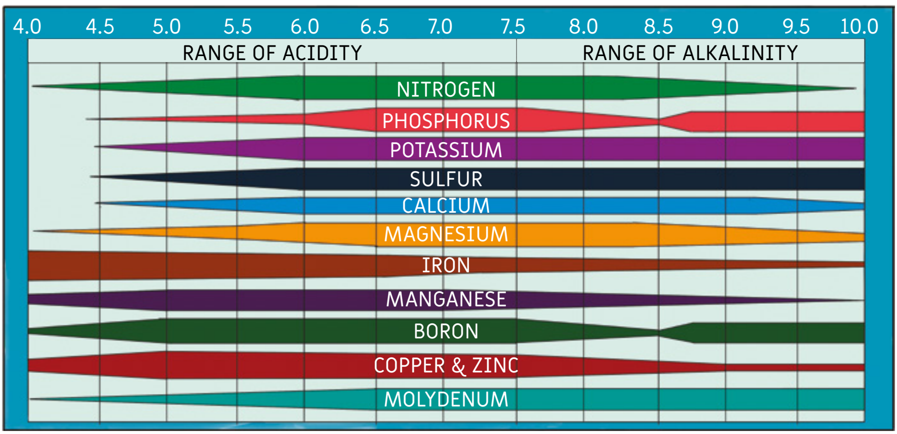
Table 4. Optimal electrical conductivity (EC) range for different crops



pH

pH is a measure of nutrient availability, it measures the acidity or alkalinity of a solution, which affects plant uptake. pH is a logarithmic scale ranging from 0 to 14, where pH 7 is neutral, below 7 is acidic, and above 7 is alkaline. Different plant species have specific pH preferences for optimal nutrient uptake and growth. For most plants, the ideal pH range is slightly acidic to neutral, typically between 5.5 and 6.5. Outside this range, nutrient availability can be limited, leading to deficiencies or toxicities. Adjusting pH using acids (like phosphoric or nitric acid) or bases (like potassium hydroxide) ensures the nutrient solution remains within the optimal pH range for healthy plant growth.

Table 5. Nutrient availability across different pH ranges



WATER SALINITY

Water salinity is the amount of salts dissolved in the water. It is mainly determined by high level of Sodium, an element that is not absorbed by plants. High salinity in water will cause the impossibility to plants to absorb water and nutrients! Thus, highly saline water has to be avoided. Water with an EC of up to 1000 µS/cm is suitable for hydroponic cultivation (checked with an electroconductivimeter).

TAP WATER	RAIN WATER
High pH	Slightly acid pH
High EC	Low EC
Correction of pH, and dilution with rain water are the first steps	Integration of calcium and magnesium

PREPARING THE NUTRIENT SOLUTION

To prepare the nutrient solution, fertilizers are added to freshwater until the desired EC is achieved. The amounts of fertilizers depend on the water quality and its own nutrient content. Specialized fertilizers containing NPK and micronutrients are recommended, with adjustments made to achieve the optimal EC and pH levels.

DETERMINING THE QUANTITY OF ACID REQUIRED TO ACHIEVE THE CORRECT pH

1. Set the volume of nutrient solution to be prepared (N in the formula).
2. Collect a 1-liter water sample precisely.
3. Check the pH of the water.
4. If the pH is >6.5, apply a small quantity of acid to bring it within the optimal range. Conduct multiple trials to identify the optimal acid dose

for correcting one liter of water (d in the formula), starting from a minimal dose of 0.1 gram. Utilize a precision scale for best accuracy.

5.Reassess the pH and repeat "Step 4" if the pH remains >7.

6.Once the dose per liter of acid (d) is determined, multiply it by the quantity of nutrient solution to be generated (N).

Acid (grams) **= d** (grams/liters) **x N** (litres)

By monitoring both EC and pH levels in the nutrient solution, growers can maintain optimal conditions for nutrient uptake, ensuring plants receive the necessary nutrients in the right amounts and pH conditions for robust growth and development.

MANAGEMENT OF THE NUTRIENT SOLUTION

If the EC increases it means that plants are absorbing more water than nutrients, in this case it must be added some water to the nutrient solution to restore the optimal EC and if this continues to happen it means that the optimal EC is at lower value than the one that is set. This situation occurs very often in hot climates conditions where plants need to transpire a lot. It must be also kept in mind that EC values are related to the temperature of the nutrient solution (with the optimum between 18°C and 28°C).

Temp(°C)	EC (mS cm^{-1})
15	1.62
20	1.80
25	2.00
30	2.20

Accumulation of unused nutrients in the solution should be avoided. Thus, if it is used a recirculating system, it's important to finish the nutrient solution in the tank before refilling with new fresh nutrient solution and the same is suggested for the depletion of some nutrients

Protons and carboxylates excreted by roots can accumulate in the nutrient solution.

It is very important to remember also that there is a synergy and an antagonism between some nutrients (see figure below).

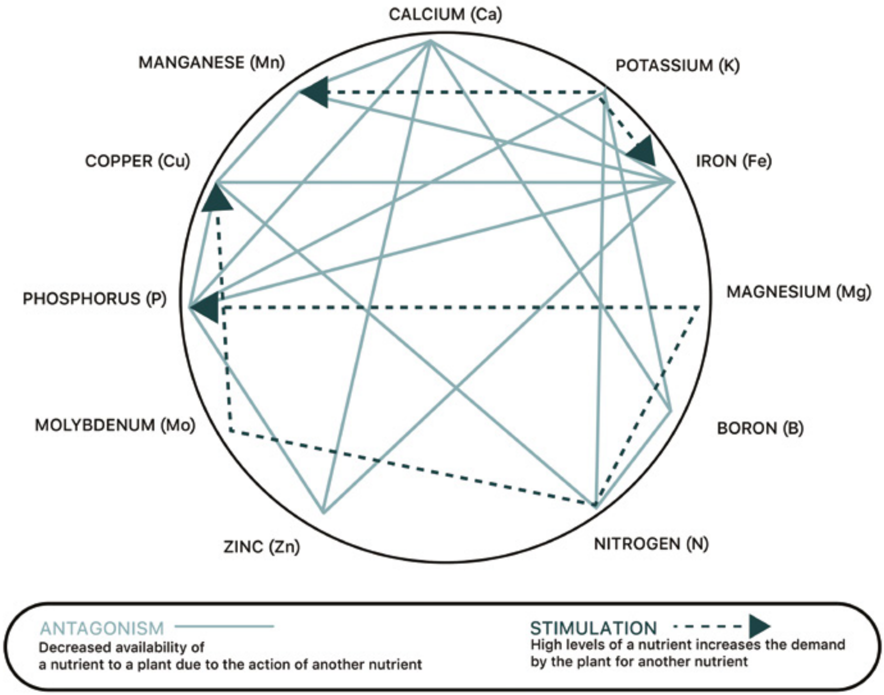


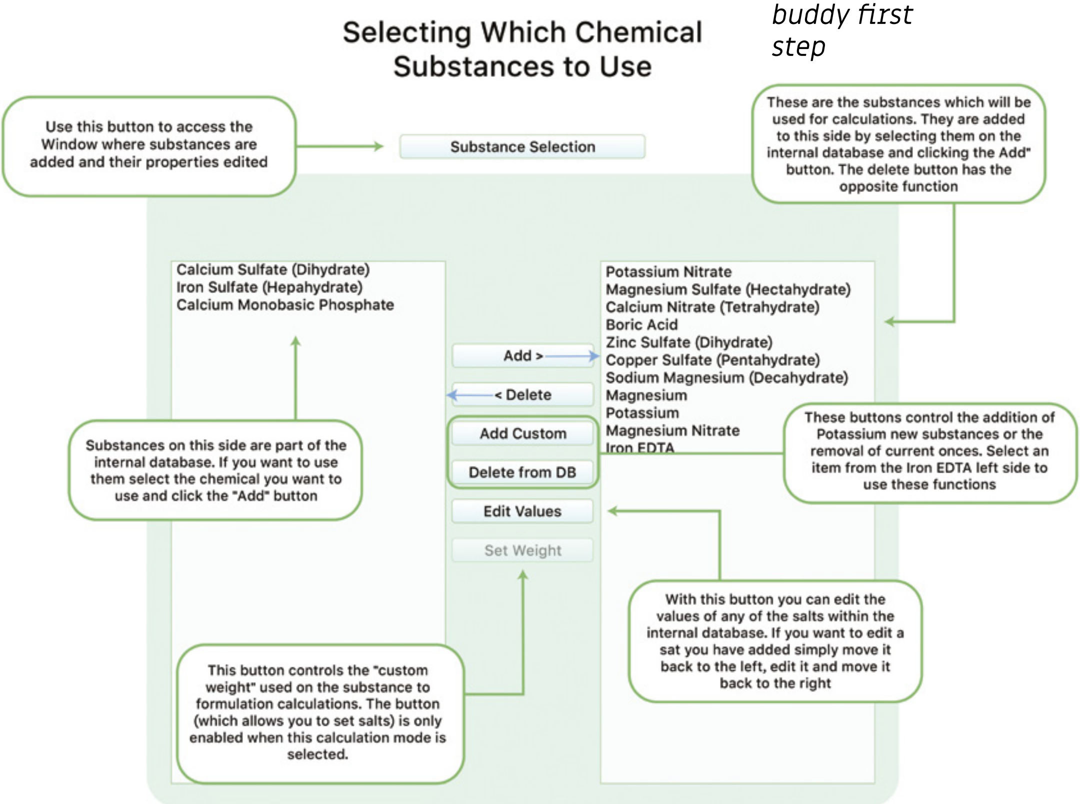
Figure 18. Mulder's chart: a graphical representation used in plant nutrition to illustrate the interactions between essential nutrients. It shows how the presence or deficiency of one nutrient can positively (synergistic) or negatively (antagonistic) affect the uptake and utilization of others

OPEN SOFTWARES FOR NUTRIENT SOLUTION PREPARATION

HYDRO-BUDDY

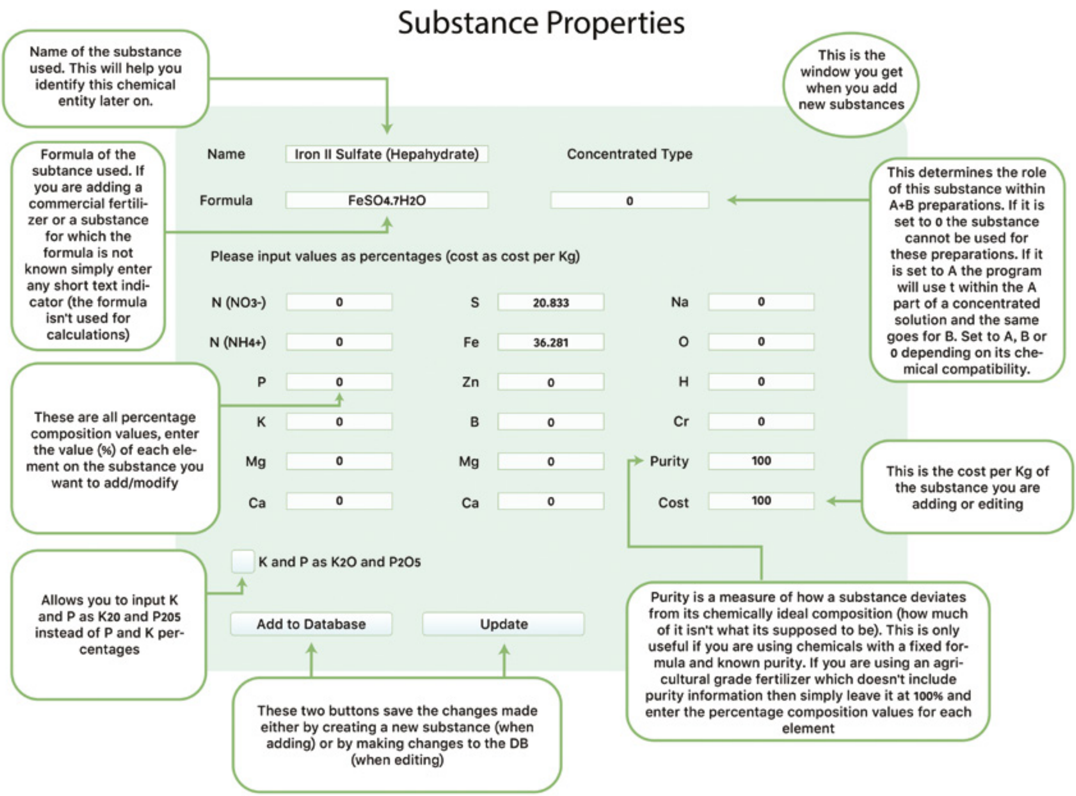
Hydro-Buddy, a software conceived by Daniel Fernandez, serves as an open-source tool to calculate nutrient solutions in hydroponic setups and general agricultural contexts. It empowers users to select from a range of chemical fertilizers based on their accessibility, while also granting the option to tailor formulations or introduce novel substances to suit specific needs.

Figure 19. How to use Hydro-buddy first step



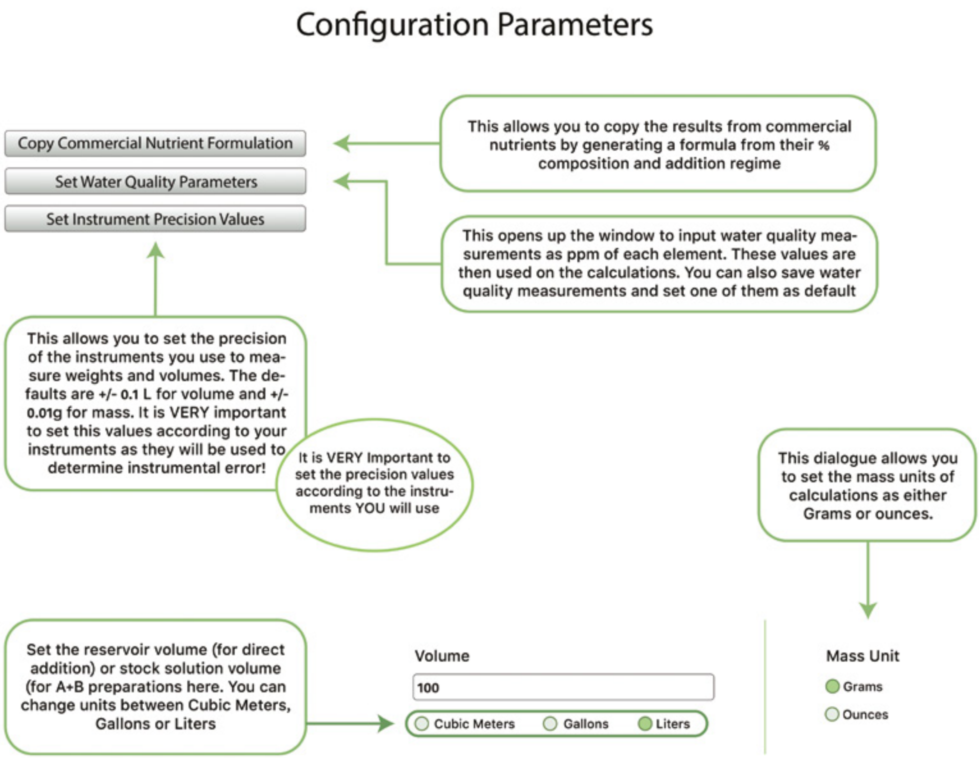
The software enables users to define specific nutrient formulations and adjust quality parameters, which is crucial given the variability in plant types and water sources. Additionally, it offers customization options for mass, volume units, and precision values, ensuring flexibility and accuracy in nutrient solution preparation.

Figure 20. How to use Hydrobuddy second step



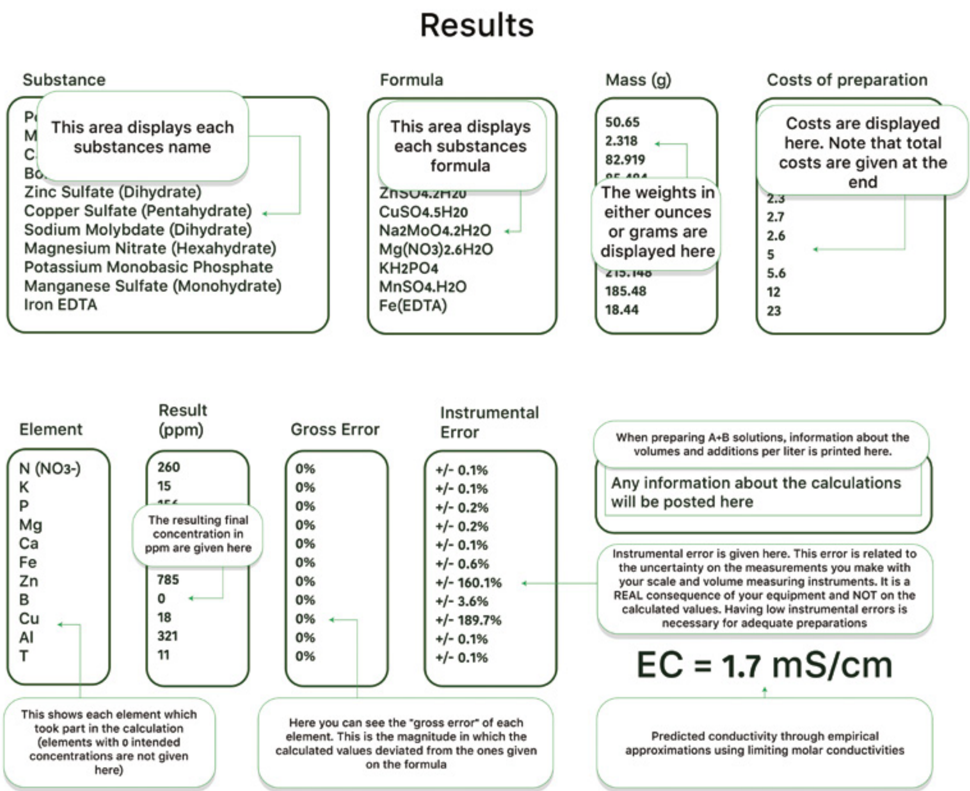
After calculations, Hydro-Buddy provides a detailed breakdown of the substances used, their weights, concentrations, and predicts the solution's electrical conductivity (EC). Additionally, it calculates associated costs, making it a comprehensive tool for efficient solution preparation.

Figure 21. How to use Hydro-buddy third step



You can download for free Hydro-Buddy from the following website:

Figure 22. How to use Hydro-buddy fourth step



FRESH

Fresh is an open-source Excel sheet designed from the University of Bologna to aid in the preparation of nutrient solutions for hydroponic systems and various agricultural applications. The tool allows users to select from a broad range of chemical fertilizers, ensuring flexibility based on local availability and specific crop requirements. It also enables the customization of nutrient solutions, allowing adjustments to better suit the particular needs of different crops.

You can download for free Fresh from the following link:

Location

Tank capacity (l)
100

NUTRIENT	Blu	NitroK	solfato ammonico	nitrato di calcio
	%	%	%	%
N	21,00	13,00	20,00	15,50
P_2O_5	5,00			
K_2O	10,00	46,00		
S	15,00		26,00	
SO_3	37,46	0,00	64,32	0,00
MgO	3,00			
Mg	1,80	0,00	0,00	0,00
CaO				15,50
Ca	0,00	0,00	0,00	10,85
Fe EDTA				
Cu				
Zn				
B				
Mn				
Mo				
Amount of fertilizer for 1000 liters of NS (g)	800	400		300
Amount of fertilizer per tank (g)	80	40	0	30
Fertilizer price per kg				
Fertilizer price per tank	0	0	0	0
Total cost of filling a tank	0			

Figure 23. How to use Fresh step-by-step

Indicate the location (optional)

Indicate the reservoir capacity (in liters)

Indicate the names of the available fertilizers

For each fertilizer, enter the concentration (%) for each mineral element as stated in the fertilizer label. For example in B9 include the N% of first fertilizer, in B10 the P2O5 % of the first fertilizer and so on.

Enter the quantity of fertilizer (in grams) that you plan to dissolve in 1000 liters of water, and verify that the concentration of each element (M9-M23) falls within the range identified by the columns min-max (N9-N23 and O9-O23).

If the concentration of certain elements (M9-M23) falls far outside the threshold min-max (N9-N23 and O9-O23), it is required to adjust the quantity of the fertilizers (B25-K25) and re-check

When all limit min-max are met, in line 26 the quantity of each fertilizer (in grams) to be added to the reservoir filled with water is indicated.

Enter in line 27 the cost per kg of each fertilizer (optional)

In line 28 the cost of each fertilizer in the reservoir is indicated.

In cell B29 the total cost of fertilizers per each reservoir is indicated.

MANAGEMENT OF THE IRRIGATION SYSTEM

MONITORING AND MANAGEMENT OF THE IRRIGATION SYSTEM

Microorganisms: Microorganisms, including bacteria and fungi, can form biofilms in irrigation tanks and pipes, potentially causing clogs and affecting plant health. To prevent this, it's essential to thoroughly disinfect all components at the end of each grow cycle. This includes tanks, pipes, and any other surfaces that come into contact with the nutrient solution.

Oxygen: Proper oxygenation is crucial for the health of plant roots in hydroponic systems. Regularly check that pumps are functioning correctly to ensure proper circulation and oxygenation of the nutrient solution. Otherwise, if pumps are not used, it is fundamental to manually mix the nutrient solution periodically to further oxygenate it and prevent stagnation.

Algae in the tank: The presence of algae in the nutrient solution tank indicates that light is entering the tank, which can promote algae growth. To prevent this, ensure that the nutrient solution tank is completely opaque and shielded from light. This will help inhibit algae growth and maintain water quality.

Molds and Algae: In hydroponic systems, substrate moisture levels must be carefully managed to prevent the growth of molds and algae. Ensure that the top layers of the substrate are allowed to dry out between watering cycles. This helps prevent excess moisture buildup, which can promote mold and algae growth on the substrate surface.

Salt deposits: Over time, mineral salts can accumulate in hydroponic systems. This happens particularly in recirculating systems, where water evaporates and leaves behind dissolved minerals. At the end of each growing cycle, it's important to flush the system with a mild acid solution to dissolve and remove salt deposits. This helps prevent nutrient imbalances and maintain system health.

FILTRATION

Filtration is a crucial process in irrigation systems aimed at removing solid particles, sediments, and debris from water before it reaches the irrigation components such as drippers, sprinklers, or micro-sprayers. This process ensures the longevity and efficiency of the irrigation system by preventing clogging, reducing maintenance, and optimizing water distribution.

AIMS

Functions of filtering may be summarized as follows:

Prevention of clogging: filtration prevents the accumulation of particles that could clog irrigation components, ensuring uniform water distribution.

Protection of equipment: by removing debris, filtration protects pumps, valves, and other irrigation equipment from damage caused by abrasive particles.

Improved water quality: filtration enhances water quality by removing contaminants, sediments, and organic matter, promoting healthier plant growth.

Water conservation: Cleaner water reduces the need for system flushing and maintenance, conserving water and reducing operational costs.

TYPES OF FILTERS:

Here are listed some of the most common filters used:

Screen filters: these filters use a mesh or screen to physically trap particles of a certain size. They are commonly used in irrigation systems and come in various mesh sizes to accommodate different water sources and particle sizes.

Sand media filters: these filters utilize layers of sand to trap particles as water passes through. They are effective for removing finer particles and organic matter.

Disc filters: disc filters use a stack of grooved discs to trap particles. They are efficient and suitable for high-flow applications.

Hydrocyclone filters: these filters use centrifugal force to separate particles from water. They are effective in removing heavier particles and are often used as pre-filters.

DIY HOMEMADE FILTER:

Figure 24. DIY homemade filter

Materials Needed:
- Plastic bottle (2-liter works well)
- Gravel
- Fine pebbles
- Fine sand
- Activated charcoal
- Cotton or filter fabric

Steps:
- Rinse the plastic bottle thoroughly to remove any residues.
- Make a big hole in the cap.
- Place a piece of cotton or filter fabric on top of the bottle and screw the cap
- Cut the bottom of the plastic bottle and place the bottle upside down.

Layer the materials in the following order:
  - Activated charcoal
  - Fine sand
  - Fine pebbles
  - Gravel

TESTING THE FILTER

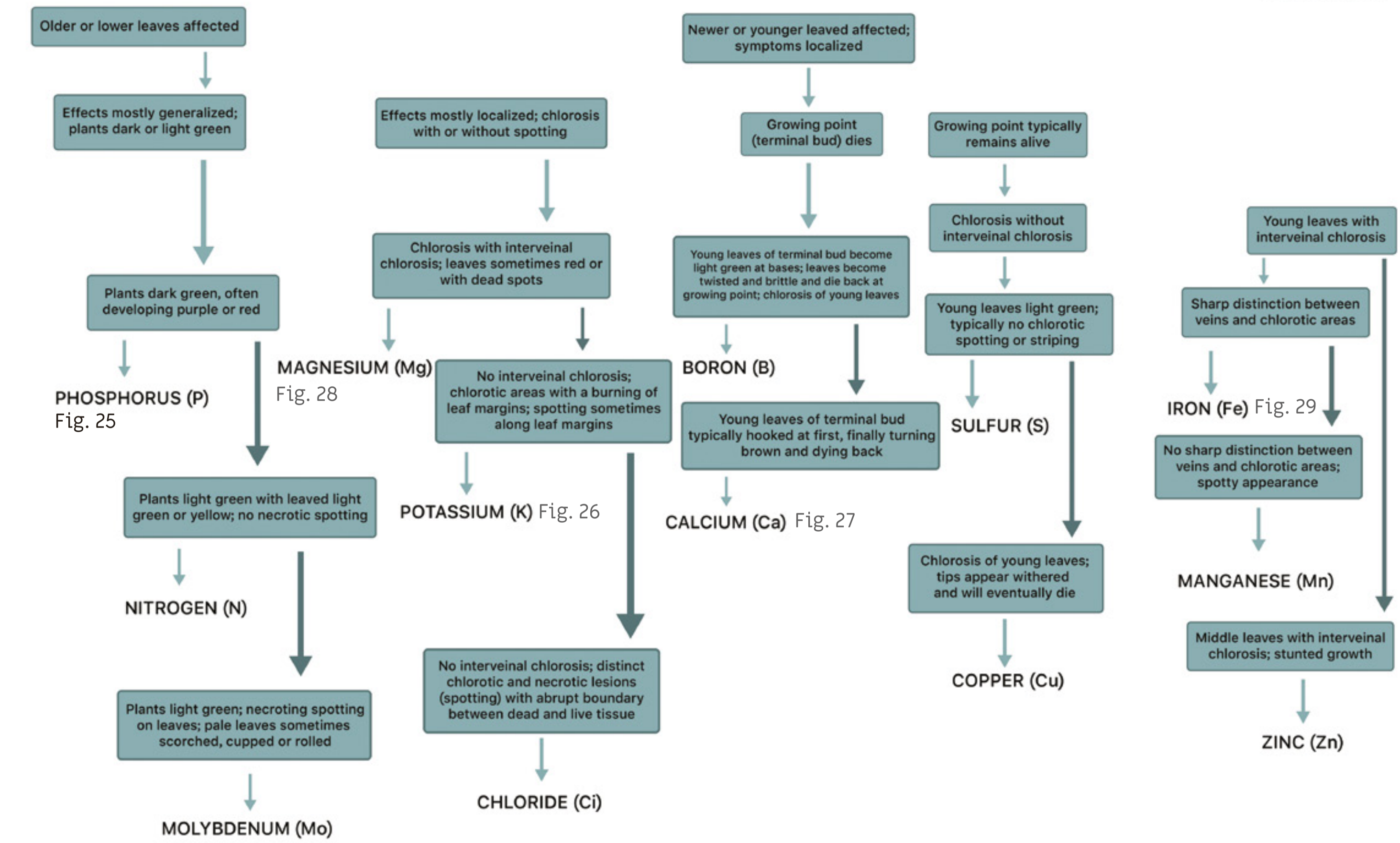
Pour dirty water through the top of the filter and observe the clarity of the filtered water. Then, adjust the layers or replace the cotton/filter fabric as needed to improve filtration efficiency.

This homemade filter can be used for small-scale applications where a commercial filter is not available or practical. However, it may not be as efficient or durable as professionally manufactured filters, so regular maintenance and monitoring are essential.

HOW TO CLEAN A CLOGGED IRRIGATION SYSTEM

To clean a clogged irrigation system, begin by preparing an acid solution with a pH below 2. Empty the existing nutrient solution from the tank and the irrigation system. Replace the nutrient solution with the prepared acid solution, ensuring it reaches all parts of the system. Activate the pump and allow it to circulate the acid solution throughout the system for at least one hour. The acidic solution will help dissolve any mineral deposits or organic matter causing clogs. After the allotted time, drain the acid solution from the system thoroughly. Rinse the system with clean water to remove any remaining acid residue. Refill the tank with fresh nutrient solution and resume regular irrigation operations. Regular maintenance and periodic cleaning can help prevent future clogs and ensure optimal system performance

IMMOBILE NUTRIENTS



- If symptoms don't meet any of the key descriptions, either go back through the key another time or refer to text for more specific symptom descriptions.

Figure 24. Nitrogen deficiency symptoms on pepper (top) and tomato plant (bottom)

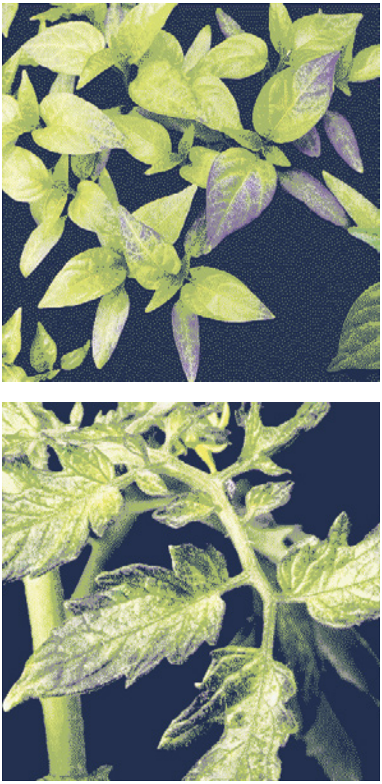
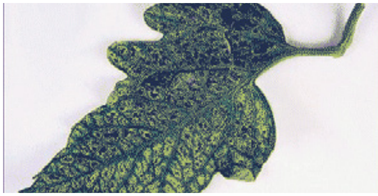


Figure 25. phosphorus deficiency symptoms on tomato (top) and pepper plant (bottom)

Figure 26. Potassium deficiency symptoms on pepper (top) and tomato plant (bottom)

Figure 28. Magnesium deficiency symptoms on tomato (top) and pepper plant (bottom)



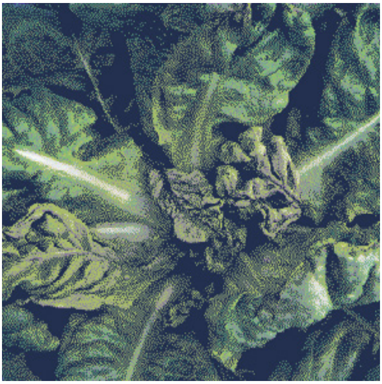
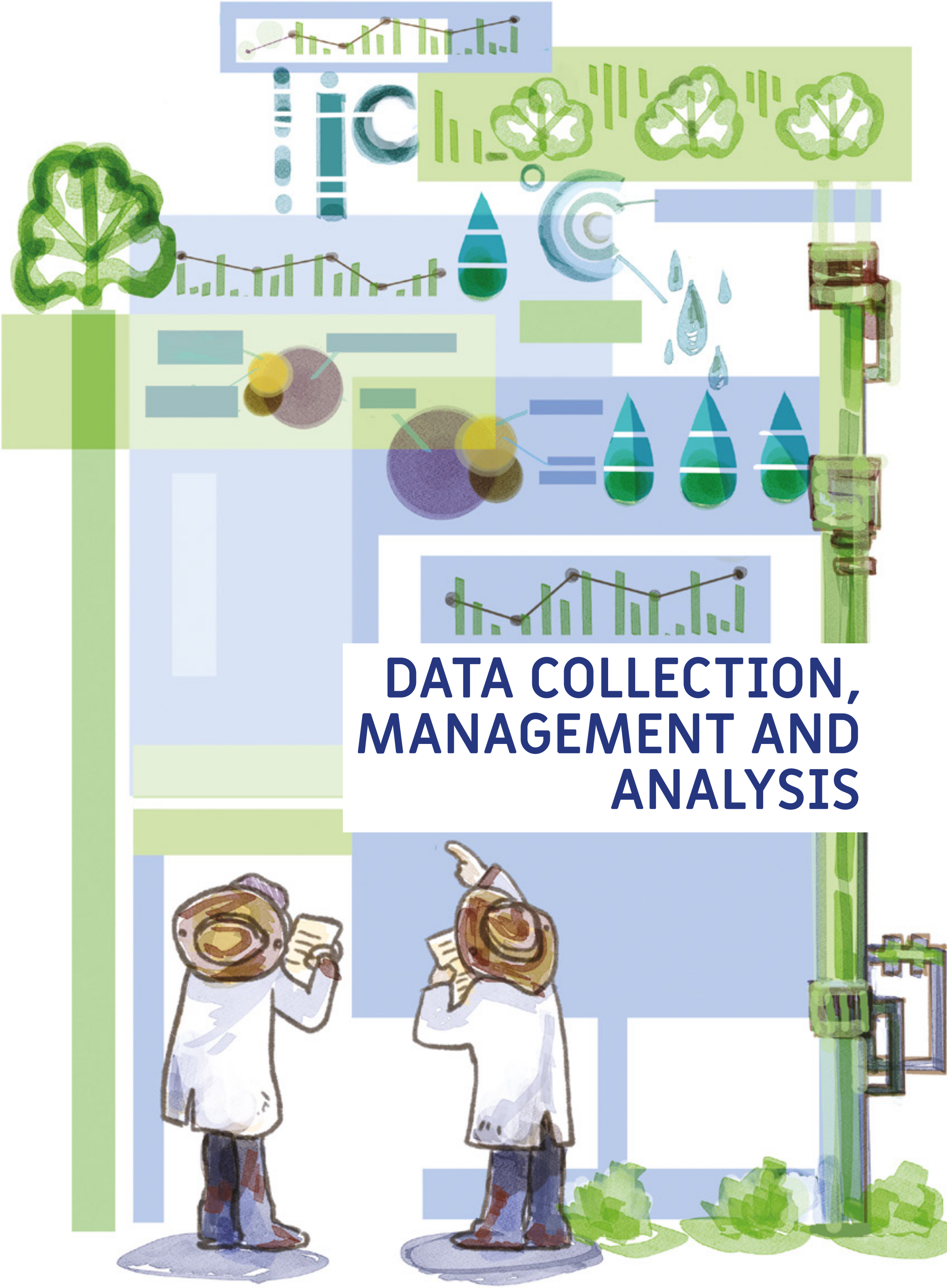


Figure 27. Calcium deficiency symptoms on tomato fruit (bottom) and lettuce plant (top)

Figure 29. Iron deficiency symptoms on tomato (top) and eggplant (bottom)

DATA COLLECTION, MANAGEMENT AND ANALYSIS



Often, when setting up a new simplified hydroponic farm or garden, the system components require require adaption to the local environmental conditions, available materials, and crops to be grown. Accordingly, it is advisable to set up experimental trials that specifically address (in a scientifically sound way) the validation of system improvements. This chapter aims at guiding farmers and gardeners in defining experimental designs and implementing them through appropriate data collection and analysis.

THE SCIENTIFIC METHOD

Inductive reasoning empowers scientists to generate broad theories about the world by drawing upon specific observations of its behavior. However, a drawback of this approach is the potential for inaccuracies in these theories. The "scientific method" serves as a structured framework to aid scientists in maximizing the utility of their observations. This method typically comprises four steps, as outlined by Little and Hills (1978):

Formulation of the hypothesis: This involves proposing a tentative explanation based on initial observations and the knowledge acquired through the literature on the topic.

Planning the experiment: Constructing an experiment that objectively tests the hypothesis is crucial, and this is the central focus of our course.

Careful observation and data collection: Conducting thorough observations and meticulously gathering data.

Interpretation of results: Analyzing the experiment's findings may either confirm, modify, or refute the initial hypothesis.

There are four fundamental components of experimental design to consider:

- Error control;
- Replication;
- Randomization;
- Local Control.

ERROR CONTROL

Controlling errors, or similarly, conducting a controlled experiment essentially means two things:

Implementing measures to avoid sources of error, keeping them at the lowest possible level (high precision);

Acting to isolate the effect under study (accuracy), preventing it from being confused with random or other effects. For example, if we need to compare two substrates, we must ensure that the subjects included in the experiment differ only in the substrate used and not for other reasons.

REPLICATION

Replication involves repeating an experiment under identical conditions, but in the context of experimental designs, it refers to having multiple distinct experimental units receiving the same treatment. Replication, in conjunction with randomization, allows for estimating error variance accurately. Without randomization, increasing replication may not lead to a true estimate of error.

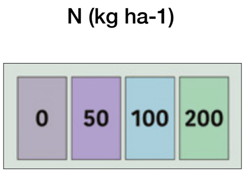
Generally, the greater the number of replications, the higher the precision of the experiment. The minimum statistical number of samples is three, but increasing the number of replicates allows for a more solid analysis. The decision on the number of replications depends on factors such as the homogeneity of experimental material, the number of treatments, and the desired level of precision. As a general guideline, the number of replications should provide at least 10 to 15 degrees of freedom for computing the experimental error variance.

By replicating, researchers can derive a reliable estimate of experimental error. This estimation is crucial for making statistical inferences, such as conducting significance tests or determining confidence intervals. Moreover, increasing the size of the experiment through replication enhances the precision of estimating the differences between treatment effects. This improvement occurs because a larger experiment size reduces experimental error.

RANDOMISATION

The process of assigning treatments or factors to be tested to the experimental units based on specific laws or probability is technically termed randomization. In its strict technical sense, randomization ensures the elimination of systematic error. It also guarantees that any remaining error component in the observations is purely random. This forms the basis for accurately estimating random fluctuations, which is crucial in testing the significance of genuine differences.

Through randomization, each experimental unit has an equal chance of receiving any treatment. For example, if there are five eucalyptus clones to be tested in 25 plots, randomization ensures that no particular clone is favored or disadvantaged by external sources of variation beyond the experimenter's control. Random allocation can be done using various methods, such as drawing lots or selecting numbers from a page of random numbers. The process is further illustrated in subsequent sections discussing different forms of experimental designs.



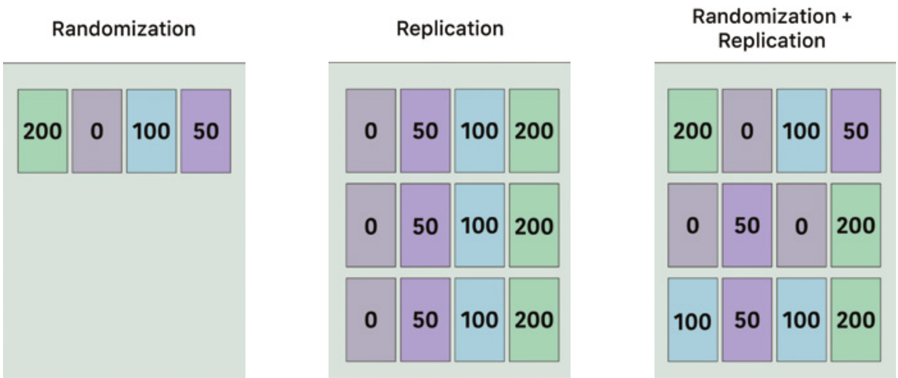


Figure 30. What is the optimal dose of nitrogen to maximize tomato yield? The above figures illustrate various nitrogen levels applied to the soil (0, 50, 100, and 200 units). Within each replication, different treatments are displayed, while the randomization demonstrates their distribution. Finally, it shows how these treatments are combined.

LOCAL CONTROL

Local control involves managing all factors except those under investigation. Similar to replication, local control aims to reduce or manage variation due to external factors and enhance experiment precision. For instance, if an experimental field exhibits heterogeneity in soil fertility, dividing the field into smaller blocks can create more homogeneous plots within each block. This homogeneity ensures an unbiased comparison of treatment means, as it becomes challenging to attribute mean differences solely to treatment variations when plot differences persist. Implementing local control to achieve homogeneity of experimental units not only enhances experiment accuracy but also facilitates drawing valid conclusions.

In summary, while randomization eliminates systematic error in allocation, leaving only random error, replication and local control aim to minimize this random error. All three components are essential for accurately estimating error variance and conducting valid significance tests.

PRACTICAL EXAMPLE

Determine which of the three substrates (rice hulls, coconut fiber, volcanic lapillus) is most effective for lettuce growth in a hydroponic Garrafas PET system.

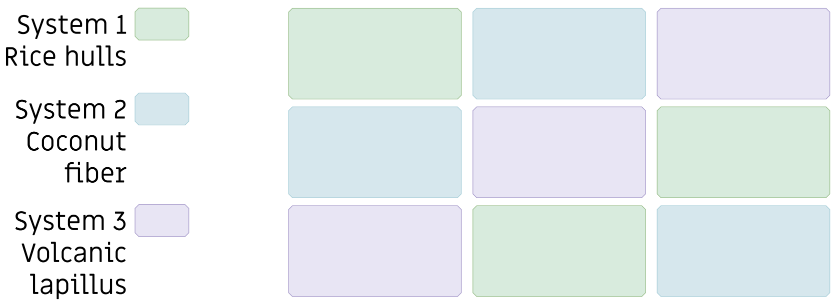
Experiment Structure:

- Substrates Tested: Rice hulls, Coconut fiber, Volcanic lapillus.
- Number of Systems: 9 Garrafas PET systems.
- Number of Bottles per System: 28 PET bottles per system (7 rows of 4 bottles each).
- Total Number of Plants: 252 plants (9 systems x 28 bottles per system).

Fundamental Components of Experimental Design:

1. Error Control:
   - Keep all other conditions constant (light, temperature, nutrient solution, etc.) for all systems.

2. Replication:
   - Have multiple systems with the same substrate
   - Use systems for each substrate, for a total of 9 systems.
   - Replicates: With 3 systems per substrate and 28 plants per system, each substrate will have 84 plants (3 systems x 28 bottles).
3. Randomization:
   - The reason randomization is important is that the positioning of treatments within the block may affect their performance: Randomization is crucial to eliminate the risk of observed differences in results being influenced by uncontrolled systemic or environmental variables. Without randomization, pre-existing differences between systems could potentially affect outcomes, such as variations in light, temperature, or other environmental factors.
   - Randomize the assignment of substrates to the hydroponic Garrafas PET systems.
4. Local Control: rice hulls substrate, the substrate currently employed



WHAT IS AN EXPERIMENT?

An experiment is a data collection method where you, as a researcher change some variables and observe their effect on other variables.

An experiment is typically planned by the researcher: the experimental design encompasses the organization of the experiment. Often, the researcher sets the conditions, applying different treatments to selected subjects/individuals, aiming for as much uniformity as possible initially. The treatments are frequently juxtaposed with a reference or control treatment (no treatment, placebo, standard practice).

PLAN OF THE EXPERIMENTAL SCHEDULE

For conducting an experiment accurately, it is crucial to establish a timeline to adhere to and ensure an adequate number of plants are available for observation.

1. Schedule in advance, specifying the number of observations and the sampling frequency.
2. Edge Effect: Ensure sampling plants within the interior of the experimental area, avoiding edge locations susceptible to non-representative environmental conditions such as increased light exposure and airflow.
3. Randomization: Employ a rigorous randomization process in plant selection to mitigate bias and ensure the statistical robustness of the experiment.
4. Establish the measurement protocol with precise parameters and methodologies.

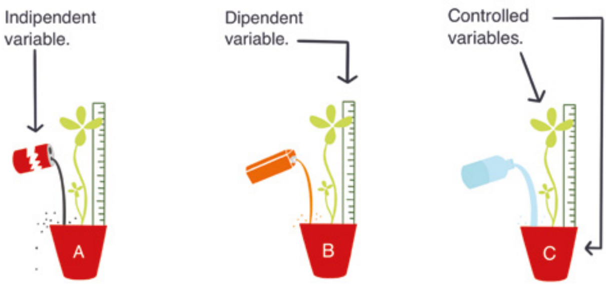
TYPES OF VARIABLES

The variables that you manipulate are referred to as (1) independent while the variables that change as a result of manipulation are (2) dependent variables. The standard experimental conditions are named (3) controlled variables (Fig. XX).

Controlled variables are conditions that must be kept under control and constant throughout the experiment, so as not to interfere with the dependent variable. When the experiment is repeated, the controlled variables must remain the same. Controlled variables are important because they reduce the impact of confounding results, improving the internal validity of a study. By doing this, you can prevent research bias and demonstrate a correlational or causal relationship between your variables of interest. Confounding is often referred to as a “mixing of effects” wherein the effects of the exposure under study on a given outcome are mixed in with the effects of an additional factor (or set of factors) resulting in a distortion of the true relationship.

TYPES OF VARIABLES

INDIPENDENT	DEPENDENT	CONTROLLED
The one thing you change. Limit to only one in an experiment.	The change that happens because of the independent variable.	Everything you want to remain constant and unchanging.
Example: The liquid used to water each plant.	**Example:** The height or health of the plant.	**Example:** Type of plant used, pot size, amount of liquid, soil type, etc.



TYPE OF DEPENDENT VARIABLES IN AGRONOMIC EXPERIMENTS

- VEGETATIVE/QUANTITATIVE/MORPHOLOGICAL: e.g., Yield, plant height, leaf area, number of flowers
- PHYSIOLOGICAL: e.g., chlorophyll content, stomatal conductance, net photosynthesis
- BIOCHEMICAL: e.g., carotenoids content, antioxidant capacity, total phenols content
- QUALITATIVE: e.g., maturation degree, soluble solids content, titratable acidity

HOW TO MEASURE DEPENDENT VARIABLES?

Data collection instruments are the tools used to gather and record information for research. We can distinguish:

1. ANALOGIC INSTRUMENTS: equipped with a scale with a sliding index.
2. DIGITAL INSTRUMENTS: the measurement is expressed numerically.

It's important to consider the risk of error, analogic instruments are more likely to determine observational errors and to define a specific method for data collection (better if performed always by the same person).

Measurements are divided into two main types, the destructive and non-destructive. We must also consider the number of replicas; indeed, the minimum statistical number of samples is 3.

DESTRUCTUVE AND NON-DESTRUCTIVE ANALYSIS

NOT DESTRUCTIVE: plant height, number of flowers, number of fruits, leaf length, leaf width (once per week)

DESTRUCTIVE: leaf area, yield, leaf fresh weight, steam fresh weight, leaf dry weight, stem dry weight (beginning and end of experiment).

The number of samples collected, and several measurements can vary according to cases.

COLLECTING DATA

A useful data collection system is Excel. It is very important that data gathering is carried out in an orderly manner, adding a column for the independent variable, sample number, replicate, and dependent variable.

- Collect the data in an orderly manner.
- Add a column for:
    - the independent variable,
    - the sample number,
    - replicate,
    - dependent variables.

Figure 26. Example of Data Collection database on Excel file

INDIPENDENT VARIABLE — SAMPLE NUMBER — REPLICATE — DEPENDENT VARIABLE

E15 fx

	A	B	C	D	E
1	TREATMENT	N° SAMPLE	REPLICATE	PLANT HEIGHT	LEAF AREA
2	Peat	1	1		
3	Peat	2	1		
4	Peat	3	1		
5	Peat	1	2		
6	Peat	2	2		
7	Peat	3	2		
8	Coconut Fiber	1	1		
9	Coconut Fiber	2	1		
10	Coconut Fiber	3	1		
11	ECT...				

TYPES OF MEASUREMENTS

WATER USE EFFICIENCY

Hydroponic cultivation represents a valid opportunity for the agricultural production sector, especially in areas characterized by limited water availability. The evaluation of production sustainability necessitates the delineation of resource utilization within implemented hydroponic systems. Proficiency in methodologies for quantifying water and nutrient utilization efficiency is essential. Given the array of hydroponic systems in operation, scrutinizing water usage efficiency can yield significant insights and streamline comparisons of production methodologies.

WUE = Biomass produced (kg) **/ Water used** (kg)

To calculate the Water Use Efficiency (WUE), it is necessary to ascertain the quantity of water utilized. Therefore, by starting from the known volume of water present within the tank and being aware of the daily quantity of water added, after the cycle, you will be able to compute the total amount of water used and the water use efficiency.

NUTRIENT USE EFFICIENCY

To calculate Nutrient Use Efficiency (NUE), you typically follow these steps:

1. Determine the amount of nutrient applied: This is the total quantity of the nutrient applied to the plants over a specific period, usually expressed in kilograms (kg) or grams (g).
2. Measure the yield of the crop: This is the total amount of crop harvested or produced, usually in kilograms or another appropriate unit.
3. Calculate NUE using the formula: NUE is calculated using the following formula:

$$\text{NUE} = \text{YIELD}\,NUE = \frac{\textbf{Yield}\ (\text{Kg})}{\textbf{Nutrient Applied}\ (\text{Kg})}$$

By calculating NUE, it is possible to assess the effectiveness of nutrient application strategies and make informed decisions to improve crop productivity and sustainability.

EVALUATE THE ECONOMIC VIABILITY

Another important measure that can be carried out through data collection is the evaluation of economic sustainability. By collecting data on costs, yields, and market prices, it becomes possible to calculate key financial metrics such as Capital Expenditure (Capex), Operational Expenditure (Opex), and Amortization. Understanding these metrics is essential for determining how long it will take to recoup the initial investment and to understand the viability of the system.

Capital Expenditure (Capex): Capex refers to the initial investment costs required to set up a project or system. This includes expenses for purchasing equipment, materials, infrastructure, and other assets that will be used over a long period. For hydroponic systems, Capex covers the costs of setting up the entire growing system.

Operational Expenditure (Opex): Opex includes the ongoing expenses required to operate and maintain a system. These are recurring costs such as labor, utilities (water, electricity), maintenance, and consumable supplies. In hydroponic systems, Opex would cover costs like nutrient solutions, energy for lighting and pumps, and regular upkeep.

Amortization: Amortization is the process of spreading out the cost of an initial investment (Capex) over its useful life. This financial metric helps in understanding how much of the initial investment is “used up” each month or year. For hydroponic systems, it allows us to calculate the monthly cost of the initial setup by dividing the total Capex by the expected lifespan of the materials or equipment.

To illustrate these concepts, an example of a material comparison conducted in Nigeria for a raised bed hydroponic system is presented. This comparison reveals important insights into the financial implications of using high-grade versus low-grade materials:

1. Costs and Amortization:

High Grade Materials:	Low Grade Materials
Total Cost: 166,700 Naira	Total Cost: 134,700 Naira
Cost per square meter: 83,350 Naira	Cost per square meter: 67,350 Naira

Amortization Price Calculation: Amortization price is calculated as the cost per square meter divided by the durability in months of the materials.

High Grade Material:	Low Grade Material:
Amortization Price = 83,350 Naira / 36 months = 2,315 Naira per month	Amortization Price = 67,350 Naira / 12 months = 5,612 Naira per month

2. Estimating Required Production for Amortization
To determine how much must be produced to amortize the material costs, calculate the revenue generated per square meter by the hydroponic system.

Revenue per Square Meter:
- Lettuce Market Price in Nigeria: 3,873 Naira per kg
- Average Yield per Cycle: 3.2 kg/m² (based on plant density and yield per plant)
- Lettuce Cycle Length: 35 days

Revenue Calculation:
Revenue per m² = Market Price * Yield per m² per cycle
Revenue per m² = 3,873 Naira/kg * 3.2 kg/m² = 12,393 Naira/m²

3. Calculating Required Production Cycles
Number of Cycles Needed to Repay Investment:
Cycles Needed = Total Cost per m² / Revenue per m²

For High Grade Material:
- Total Cost per m² = 83,350 Naira
- Revenue per m² = 12,393 Naira/m²
- Number of Cycles = 83,350 Naira / 12,393 Naira/m² ≈ 6.73 cycles

Since you cannot perform a fraction of a cycle, round up to the nearest whole number:
Number of Cycles = 7 cycles

For Low Grade Material:
- Total Cost per m² = 67,350 Naira
- Revenue per m² = 12,393 Naira/m²
- Number of Cycles = 67,350 Naira / 12,393 Naira/m² ≈ 5.44 cycles

Round up:
Number of Cycles = 6 cycles

SOME EXAMPLES OF APPLIED RESEARCH

1. CONTRIBUTION TO SIMPLIFIED HYDROPONICS TO IMPROVING FOOD SECURITY

By the will of the European Commission, the EFSA Panel on Nutrition, Novel Foods, and Food Allergens (NDA) was commissioned to offer scientific guidance concerning the nutritional profile for the establishment of standardized mandatory front-of-pack nutrition labeling and the formulation of nutritional profiles to regulate nutrition and health claims on food products. From these studies, it was found that the recommended daily intake of leafy green vegetables is 80g. Therefore, when implementing projects of simplified hydroponics for increased food security, it may be wise to determine the quantity of leafy greens that can be produced to meet such nutritional objectives.

To determine how many cultivable square meters are needed, the following data will be needed:

- Plant density
- Growing cycle length
- Yield

By knowing the yield per plant, the density per square meter, and the cycle length, it is possible to determine how much can be produced (on average values) in a square meter in a day, and consequently, how many square meters of cropped surface are needed to reach such goal. To this end, the control treatment may be represented by plots of traditional on-soil cultivation of the same crop. A draft experimental design is included in Fig. 27.

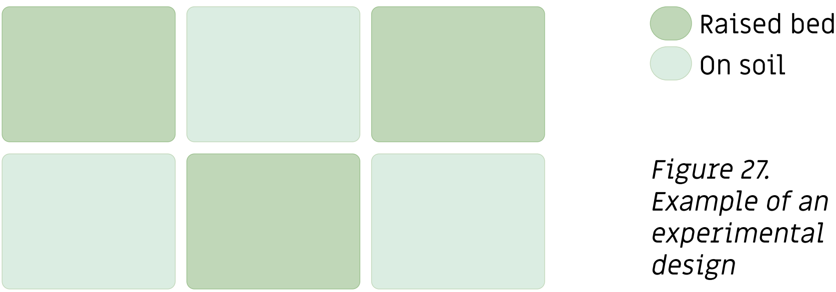


Figure 27. Example of an experimental design

2. SELECTION OF CULTIVATION SUBSTRATE FOR TOMATO CULTIVATION IN SIMPLIFIED HYDROPONICS

Independent variables: coconut fiber, rice hulls, peat

Controlled variables: temperature, nutrient solution (amount and quality), shading nets, pots

Dependent variables: number of flowers, number of fruits, measurement of the leaf length, measurement of the leaf width, leaf area, yield, leaf fresh weight, stem fresh weight, leaf dry weight, stem dry weight

Instruments: digital scale, tape meter, oven, pH meter, EC meter, thermometer, easy leaf APP (Fig 28.)

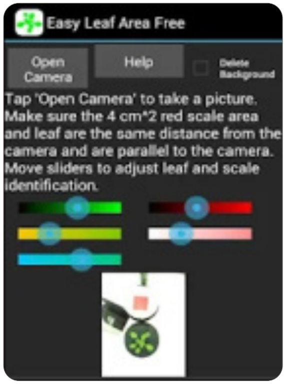
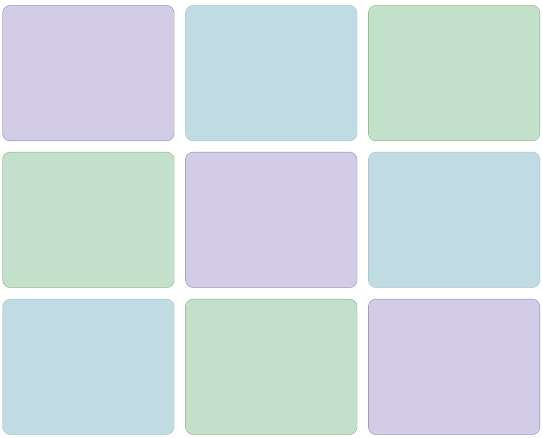
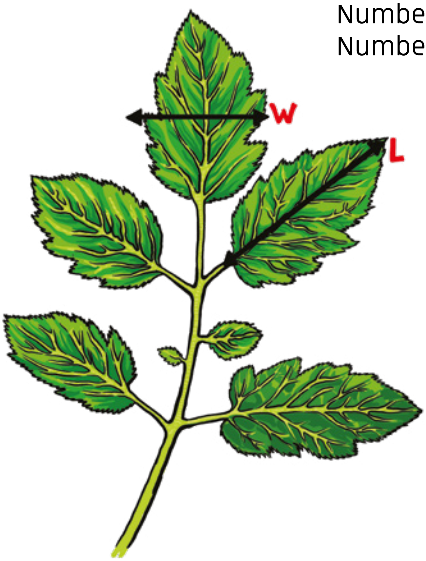


Figure 28. Screenshot of Easy Leaf Area App

Substrate 1
Substrate 2
Substrate 3

Experimental design:





Number of flowers
Number of fruits

ONCE A WEEK - NON-DESTRUCTIVE:

NOT DESTRUCTIVE:
- Measurement of the leaf length
- Measurement of leaf weight
- Number of flowers
- Number of fruits

DESTRUCTIVE:
- Leaf area
- Yield
- Leaf fresh weight
- Stem fresh weight
- Leaf dry weight
- Stem dry weight

INTERMEDIATE MEASUREMENT (USEFUL FOR GROWTH ANALYSIS):

Treatment	Number of sample	Replicate	Number of leaves	Number of fruits	Number of flowers	Leaf length	Stem width
1							
2							
3							
1							
2							

Table 7. Example of data collaction dabatase for intermediate measurements of replicates

END OF THE EXPERIMENT

DESTRUCTIVE:
- Leaf area
- Yield
- Leaf fresh weight
- Stem fresh weight
- Leaf dry weight
- Stem dry weight

Treatment	Number of sample	Replicate	Leaf area	Leaf fresh weight	Stem fresh weight	Leaf dry weight	Stem dry weight
1							
2							
3							
1							
2							

Table 8. Example of data collection dabatase for final measurements of replicates

CONCLUSION

The adoption of simplified hydroponic systems presents a transformative opportunity for enhancing food security in the developing economies. These techniques offer a sustainable and efficient method for crop cultivation, addressing critical issues such as limited arable land, poor soil quality, and unpredictable climate conditions. By embracing hydroponics, continuous crop production can be achieved throughout the year, irrespective of seasonal changes. This continuous production ensures a steady supply of fresh produce, significantly improving food availability and nutritional outcomes.

Moreover, hydroponic systems are adaptable to a variety of environments, making them suitable for urban and rural settings alike. The ability to grow crops in limited spaces, such as rooftops or small backyard areas, empowers even the most resource-constrained communities to cultivate their own food. This adaptability reduces reliance on external food sources, fostering greater self-sufficiency and resilience within the community. Furthermore, the efficiency of hydroponics in using water and nutrients means that these systems require fewer resources compared to traditional soil-based agriculture. This is particularly advantageous in regions facing water scarcity or limited access to agricultural inputs.

The controlled environment of hydroponic systems also offers significant advantages in terms of stability and predictability of food supply. By minimizing the impact of pests, diseases, and adverse weather conditions, hydroponics ensures more reliable and consistent crop yields. This stability contributes to the overall resilience of food systems, making communities less vulnerable to the shocks and stresses that often disrupt traditional farming practices. In addition to these practical benefits, the implementation of hydroponic techniques provides valuable opportunities for education and skill development. Training local farmers and community members in these innovative methods fosters knowledge transfer and capacity building, creating a foundation for ongoing agricultural advancement.

Ultimately, the widespread adoption of simplified hydroponics can transform agricultural practices in developing regions, paving the way for a more sustainable and secure future. By working together to implement these systems, communities can be empowered to achieve greater food sovereignty, improve health outcomes, and build resilience against environmental and economic challenges. Your commitment to this initiative is crucial, and with collective effort, we can harness the potential of hydroponics to create lasting positive change for generations to come.

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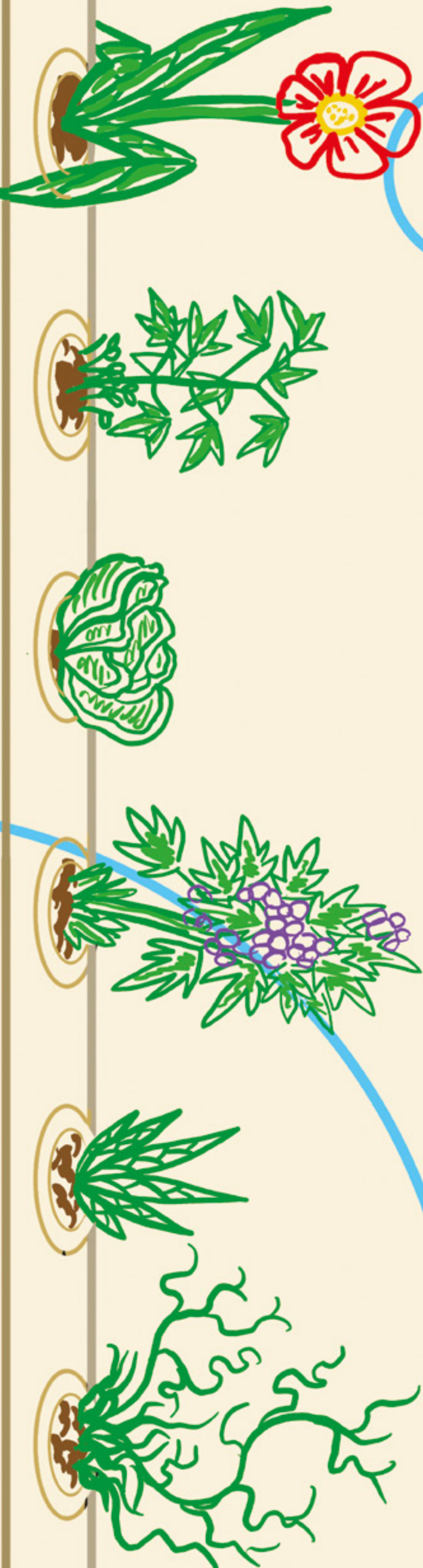

This manual is designed to guide readers in implementing small to medium-scale simplified hydroponic systems for vegetable crop production. Simplified hydroponics takes the principles of commercial high-tech systems and adapts them to use low-cost, locally available materials, making them accessible to smallholders in diverse contexts across the Global South. The manual covers everything from system design and management to adaptation to local conditions. It includes technical instructions for building a simplified hydroponic garden. Since no single solution is universally perfect, each context may uncover the most suitable technology to implement and improve upon, beginning with the systems detailed in this manual.