Hydroponics for the Home

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Foreword

The Inter-American Institute for Cooperation on Agriculture (IICA) is highly delighted to be able to offer its English-speaking audience this book on the exciting topic of hydroponics, written by agronomist Laura Perez Echeverria, a specialist and former employee of IICA.

The book was designed as a handbook, with practical advice and useful tips for beginners in this hitherto not very well-known form of agriculture.

The author sets out to show people thinking of venturing into this field the simplest and most practical way of producing food in a small space within the home. Every member of the family, from the youngest to the oldest, can take part. Anyone, regardless of their academic, professional or even social background, can experience the satisfaction of producing and harvesting a wide variety of chemical-free vegetables and other plants.

Laura Perez's book is bound to inspire many of its readers to take the plunge and begin producing food in this way. Ms. Perez organized the First International Congress on Hydroponics, which took place in Costa Rica in March 2007, and has already begun organizing the next one, scheduled for 2009. IICA is keen to encourage as many inhabitants of our countries as possible to grow their own food.

Chelston W. D. Brathwaite
Director General of IICA

Introduction

I have the pleasure of introducing English-language readers to this book, *Hydroponics for the Home*, written with care and attention to detail by Laura Pérez Echeverría, an Agronomic Engineer who holds a Masters Degree in Economics.

The author is a respected specialist in the field of hydroponics and her school, the **"Centro Nacional de Jardinería Corazón Verde"** (Green Heart National Gardening Center) located in San José, Costa Rica, is recognized for its academic rigor and its highly qualified teaching staff.

Long years in education have taught me that simplicity and depth can go hand in hand. Sometimes we are presented with introductory technical publications that prove too awkward or complicated. Laura Pérez shows that hydroponics can be explained in an appealing and at the same time consistent way. She has made sure that everything that appears in this publication has been previously tested and measured, and its results examined. Nothing presented here is of a speculative nature. The author's main concern is to show readers what steps to take to obtain positive and encouraging results.

This eminently practical approach, which at the same time does not reject the value of solid scientific foundations, makes this an indispensable publication in the field of hydroponics. Even those who have some experience in the field will find much to interest and inspire them.

Undoubtedly, hydroponics is called upon to play a key role in the development of national and international food production.

As urban areas continue to spread, problems related to the supply of certain food items, mainly vegetables, become critical. Increased transportation costs makes the distribution of goods and services more expensive, and it is precisely the economically deprived who are most affected by these features of modernity.

This is where hydroponic techniques come to the forefront: the costs are lower and water is used in a very rational way. But hydroponics has many more advantages. For instance, the system does not require intensive labor, and can even be carried out as a recreational activity.

This publication concentrates on the simplest and easiest form of hydroponics: one that can be practiced at home, and in which everyone can participate – children, women, couples, the elderly, even friends.

The hydroponics described in Ms. Pérez's book has an additional advantage. It can be the source of magnificent income-generating opportunities for many families. Indeed, enterprising families, especially women who are heads of households, may find that hydroponics provides them with a source of income in their own communities.

The development of tourism is another argument in favor of hydroponics. Travelers and visitors are increasingly demanding fresh and healthy products. In hydroponics, we find production methods that are more environmentally-friendly and increasingly free from polluting agents. Hydroponics also has the extraordinary advantage of being a technique that can be applied at all scales - from family-based operations to large industrial production. All this is examined in the book.

I do not wish to dwell on the numerous virtues that this age-old technique offers the modern world. The book itself will generate the necessary enthusiasm. The author's intention from the moment that she decided to write this book, in which she gathers her broad experience in the field, was to relate it to the practices and studies of great specialists worldwide.

I am sure that the reader will find in Ms. Pérez's book an open door to the wonderful adventure of sowing seeds, seeing the plants grow, and finally enjoying them at the dinner table.

Fabiola Campillo
International consultant and former specialist at the FAO, Rome, and the Inter-American Institute for Cooperation on Agriculture (IICA), Costa Rica.

Chapter I
General Background

Hydroponics is an ancient technique that dates back approximately 2,600 years. The Hanging Gardens of Babylon built by King Nebuchadnezzar, one of the Seven Wonders of the World, are considered to be the first application of hydroponics in recorded history.

Some of the gardens in Egypt and China, as well as the floating gardens of the Aztecs known as **chinampas**[1], are other examples of hydroponic agriculture. The chinampas were the most efficient system of water culture known at the time.

However, it was Dr. William Frederick Gericke, of the University of California, who coined the term *hydroponics* from the Greek *hydro* (water) and *ponos* (work), or "working with water". Moreover, he was the first person to carry out large-scale commercial experiments in which he successfully grew tomatoes, lettuce and other vegetables, as well as

1 Chinampas were rafts made from bamboo-like poles and lianas that floated on the lake. They were covered with mud extracted from the shallow lake bed. The mud was rich in organic materials that provided the nutrients required by the plants. The roots went through the bottom of the raft and extracted directly the water and additional nutrients needed for their development.

roots and tubers such as beetroot, horseradish, carrots and potatoes. He later expanded into flowers, fruit, and ornamental plants.

The first commercial application of this technique occurred during World War II, between 1939 and 1945, prompted by the need to provide vegetables to the troops in places where the arid soil, excessive heat (such as in Guadalupe) or excessive cold (such as in Greenland) prevented normal cultivation using soil. After the end of the War, the American troops occupying Japan largely resolved the problem of obtaining fresh vegetables by resorting to this technique.

In the 1960s and 1970s, in response to various problems associated with soil (water supply, plant nutrition, lack of certain components that are essential for some crops, the increase in pests and diseases), horticultural research in the developed countries focused on the search for other mediums or alternatives *(substrates)* that could replace soil.

In Latin America, the possibilities of adapting this technique to meet the population's various needs are increasing day by day, and its application stimulates the creativity of people of all ages as they try to achieve greater and better results.

What is hydroponics?

The concept of hydroponics has evolved over time. Initially, it involved growing plants directly in water. Although this method remains common, nowadays the concept has been expanded to apply to any method of growing plants **without using soil**. Thus, the concept currently has three "layers" or levels, each of which encompasses the other:

- **Pure hydroponic culture.** This involves using a suitable "fastening" system to hold the plant in place, so that it develops its roots in a liquid medium (nutrients dissolved in water) without any type of substrate or solid support for anchoring the roots.

- **Hydroponic culture.** This term, the one most widely used, refers to growing plants using solid and porous substrates that are more or less inert (rock, gravel and other non-organic materials) through which the nutrient-laden water is made to circulate.
- **Hydroponic culture in the broadest sense.** This encompasses the other two terms, because it refers to any culture system in which plants complete their vegetative cycle without using soil. The concept is equivalent to "soil-less culture", and includes growing plants both in a substrate and in water.

We sometimes speak of **semi-hydroponic** culture. This term refers to the use of non-inert substrates, i.e. of an organic nature (such as coconut husk fiber, the bark of certain trees, or rice chaff). As these materials decompose, they supply part of the plant's nutrients.

Summary

Hydroponics is a technique for growing plants without using soil, in which the roots absorb a balanced nutrient solution dissolved in water that meets all the plants' development needs.

This technique makes it possible to cultivate rapid-growth and nutritive plants in a simple, clean, and inexpensive way that does not damage the environment. When carried out on a small scale, people can use the resources they have at hand.

For example, we all have waste materials and products that can be used to make the basic installations; we all have small or medium-sized spaces that are not being utilized; and we all have some time to spare. This is very important, because hydroponic culture requires careful attention but does not demand constant or permanent work.

Importance

Nowadays hydroponics is regarded as the agriculture of the future. It is a production system of major significance in environmental, economic and social terms, and its flexibility means that it can be applied in different conditions and for diverse uses:

- To produce food and other plants in the tropics
- To produce food in arid areas or deserts
- To produce food in temperate or cold weather
- To produce food in places where water has a high salt content
- To produce food in areas where agriculture is not possible due to poor soil
- To produce in places where the soil is highly contaminated by fungi or has high salination levels
- To grow vegetables in the city
- To produce vegetables where they are expensive and scarce
- To produce flowers and ornamental plants
- To carry out ecological research
- To save water by ensuring that plants consume only the water they need

Arguments in favor

The following are some reasons that justify the use of hydroponic techniques:

Economic and health reasons

As already noted, for certain crops hydroponics is a far more economical and profitable technique than growing them in soil.

By using hydroponics, we can obtain more products in less time than using traditional agriculture. The following are some of the advantages:

- **More product per surface unit**, in less time and of better quality. This implies greater productivity because more products are obtained in a smaller space. For example, in a square meter of soil, approximately nine lettuces can be harvested eight weeks after planting the seedling. In hydroponics, 20 - 25 lettuces can be grown in the same space. That is to say, we can obtain between 11 and 16 more lettuces. But not only do we save space. Instead of harvesting the product after eight weeks, we can do so five weeks after planting the seedlings.
- Hydroponic products are **cleaner and fresher** than traditional products. This makes it possible to obtain a better price. If our customers live nearby (in the same street or the same neighborhood) we can provide them with fresh and crisp products that have been cut just before being consumed. It is therefore important to carefully consider the best location for our garden and its proximity to our future customers. This will enable us to reduce the costs of transportation, distribution and marketing.

- ❖ A **more timely** product. We can increase production at those times of year when there is less of a supply or when there is greater demand. All this translates into a better price.
- ❖ Hydroponic products are **healthier**. Pesticides are rarely used in hydroponics, since many of the pests and diseases that affect crops come from their direct contact with the soil. Other diseases come from excess rainwater that hits the soil and soaks the leaves of the plant, encouraging the development of fungi.
- ❖ Hydroponic plants enjoy constant nutrition as they are growing, and are therefore stronger. This makes them **more resistant to diseases**.
- ❖ In addition, hydroponic growers prefer using **natural or biological control** to prevent or deal with these problems. Natural products for pest and disease control are now available on the market.

These are some of the reasons why consumption of hydroponic products increases day by day. However, as consumers often have little information about the health advantages of these products, part of your job will be to educate the public. But since this sort of PR is based on truth and ethics, it will not be difficult, and you will enjoy an increasing number of customers.

Recreational reasons

- ❖ Hydroponics can be a recreational and enjoyable pastime. Elderly people, children, stressed-out executives, individuals with various degrees of disability, and even busy housewives can find a source of permanent satisfaction in hydroponics.

- ❖ Few things are more pleasant than planting crops and seeing the results of our effort in just a few weeks. It is even more enjoyable to cook or prepare a salad using plants we have grown. From lettuce to bean sprouts and broccoli, there is much we can grow in our hydroponic garden. We can even combine two techniques, aquaculture and hydroponics, in what is known as aquaponics, that is, growing plants, such as lettuce, alongside fish.
- ❖ We can all begin with a small space at home and entrust its care to all our family members, who little by little will become real enthusiasts.

A rational use of spare time

Family hydroponics is a technique that does not require the presence of a full-time worker. Although we must pay attention to caring for the plants, the most important thing is to make sure that they are well hydrated, apply the nutrients in a timely manner, and monitor the development of the plants to detect any anomaly. But because it is not necessary to weed the soil or apply pesticides on a regular basis, caring for the plants is an easy and entertaining task.

Reasons related to Space

In any house or apartment, however small, there is always room to set up a family hydroponic garden. For instance, a well lit bed of substrate measuring one square meter can yield between 20 and 25 lettuce plants, or can be divided in four to plant some broccoli, Swiss chard, chives or radish. A garden 10 to 20 square meters in size can feed a whole family, and 30 square meters will generate a steady income throughout the year.

The hydroponic garden is highly decorative. If placed in a hallway or balcony, it will invariably charm and surprise our guests.

Reasons related to Climate

In some countries, climate changes throughout the year severely limit agricultural activities. Taking certain precautions, hydroponics makes it possible to grow crops all year round. In family hydroponic production, you do not need sophisticated equipment or greenhouses. Greenhouses are useful for producing vegetables in places with extreme weather, since it is easier to provide the plants with good nutrition and care. Likewise, if we follow plant health standards, the greenhouse can help to keep out infections and insects. However, it is not true that in hydroponics one can only obtain good results using greenhouses. For instance, celery, lettuce, parsley, radish, tomato, turnips, Swiss chard, cilantro (coriander) and other vegetables can be grown without any protective cover, as long as the environmental conditions are appropriate.

Some crops are better suited to one climate or another. For instance, Swiss chard, string beans, tomato, cilantro, cucumber and beetroot are better adapted to a mild climate (neither very cold nor very hot). Others like strawberries, potato, or artichokes prefer colder weather. Crops that enjoy the heat include watermelon, melon, bell peppers, chili peppers, basil and squash. Some crops such as onions, lettuce, aromatic plants, and cabbage can adapt to both hot and cold climates.

ADVANTAGES OF HYDROPONICS

As an agricultural production system, hydroponics has many advantages over soil-based methods, both from the technical and economic point of view. In the preceding section, we examined the many **practical** advantages. Now it is time to summarize and focus on some of the "**technical**" advantages of the method itself. These include the following:

- Plants have an ideal balance of air, water and nutrients
- Uniform humidity
- Excellent drainage
- The possibility of growing plants more densely
- Easy and quick correction of deficiencies or excesses in the provision of nutrients
- Perfect control of pH
- Less dependence on weather conditions
- Higher yields per surface unit
- Better quality
- Earlier harvests
- Possibility of growing the same plant species repeatedly because there is no soil depletion
- Possibility of having several harvests a year
- Crop uniformity
- Lower water consumption
- Reduced production costs
- Greater productivity than in soil (see Table 1)
- Excellent conditions for starting a nursery
- Possibility of using water with a high salt content
- Greater cleanliness and hygiene
- Since there is no soil, the elimination of certain tasks such as weeding

- Simplicity and significant time saving when performing other tasks such as hilling the plant or pulling out defective plants
- Possibility of enriching food products with vitamins or minerals
- Significant reduction in environmental pollution and the risk of erosion due to a system that, if well managed, is totally environmentally friendly
- Greater control of variables
- No expenditures on agricultural machinery – no tractors, no plows or similar implements
- Prompt return on investment
- Significant reduction in labor

Table 1 Comparison between two growing methods

Crop (No. of harvest a year using hydroponics)	Yield using soil (tons per hectare at harvest time)	Yield using hydroponics (tons per hectare at harvest time)
Lettuce (10)	52	300-330
Tomato (2)	80-100	350-400
Cucumber (3)	10-30	700-800
Carrot	15-20	55-75
Beetroot	56	105
Potato	20-40	120
Pepers (3)	20-30	85-105
Cabbage (3)	20-40	180-190

Disadvantages of hydroponics

Although hydroponics has many advantages, it also has some disadvantages, including the following:

- Application on a commercial scale requires **technical knowledge** as well as a good grasp of the principles of plant physiology and organic chemistry
- On a commercial scale, the **initial investment is relatively high**, although returns are also high in the medium and long term
- Great care and attention to detail is required, particularly in the preparation of formulas and **plant health control**
- It is necessary to be familiar with and **know how to manage the species** that is being grown
- A **constant supply of water** is required
- Depending on the substrate used, at the end of the plants' productive cycle, if the material is not reused, it generates **waste that is hard to recycle**, which has an impact on the landscape and the environment

All these disadvantages can be corrected or resolved, however we should be aware of the details of our productive efforts and take them into account.

Plants and the environment

The environment is a system within the biosphere with several dimensions, as well as complex and ever-changing interrelations.

In that environment the plant is born, grows, ripens and dies. The factors that influence its growth are **light, water, nutrients, air, temperature and a medium in which it can germinate and grow its roots.** When soil is used for growing plants, it generally provides nearly everything that the plant requires. The plant also absorbs part of its nutrients from atmospheric gases.

Light

Light is a vital factor for plant growth. However, not all species require the same amount of light and some crops, such as certain varieties of edible mushrooms, can only tolerate minimal amounts of light. Nevertheless, in general it is advisable for the crop to receive as much light as possible, particularly in colder weather. During such periods it is recommended that the plants be placed near windows or doors in rooms with very good light and pale colors. It is also recommended that the plants receive at least six hours of light, though they should not be exposed to the sun all day.

Air

Air is one of the most important factors, but it is often undervalued. When there is too much heat, the environment must be moistened by placing containers with water in the area or wetting the substrate. It is also advisable to spray the leaves, but not excessively, otherwise the plants may suffer from diseases caused by fungi or bacteria.

Temperature

The optimal temperature for plants in hydroponics is between 15 and 35 degrees Celsius. A plant's degree of adaptation to changing temperatures will vary according to the species.

Watering

The watering systems used in hydroponics range from the simple methods, such as a watering can, to sophisticated systems involving automatic controllers to determine the dosage of nutrients and pH, as well as automatic watering devices. Home watering systems need not be so complicated. Experience recommends the use of a dark-colored storage tank for the material used as substrate (the dark color helps to prevent algae from developing), as well as clean containers for storing the solutions and, if possible, a pump that can feed the plants.

Medium or substrate

The medium or substrate in which the plants sprout or develop can be solid or liquid. Needless to say, **no soil or earth may be used.**

Which types of plants to grow with hydroponics, and how?

Hydroponics makes it possible to grow vegetables, flowers, and culinary, medicinal, and other plants using **water, substrates and chemical fertilizers** to feed the plants. As noted previously, the system does not require or use soil. It was developed to ensure controlled and balanced conditions so that plants could develop better, since the nutrients provided are optimal and are applied in ideal conditions of humidity, air and light, regardless of the size of our facilities. As mentioned earlier, for the plants to grow well they need **water, light, air, mineral salts and a good support or substrate.**

In hydroponics, plants absorb carbon dioxide from the air, and obtain other nutrients needed for development from water. The salts are transformed with help from the light (energy). Given that the substrate is generally inert[2], it is necessary to keep it moist and supplied with a nutritive solution or the plant will die. As mentioned earlier, hydroponics can be used to grow any type of plant: flowers, aromatic and medicinal plants, certain fruit, and many varieties of peppers and vegetables. The latter are the ones that are best suited to family hydroponics.

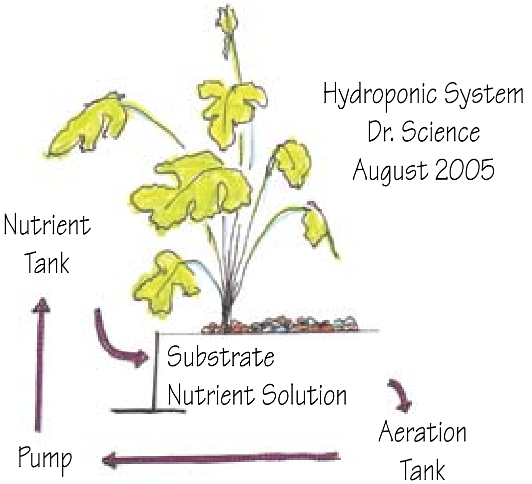
Although a large number of plant species can be grown, it is always important to consider the **agro-climatic conditions**, such as the quality of the water, the microclimate, the season, and the marketing channels. These are the factors that determine what to grow.

The vegetables that are most frequently grown using hydroponics are different varieties of lettuce, celery, cilantro, tomato, cucumber, bell pepper, chili pepper, watercress, chives, basil, mustard and other leafy vegetables.

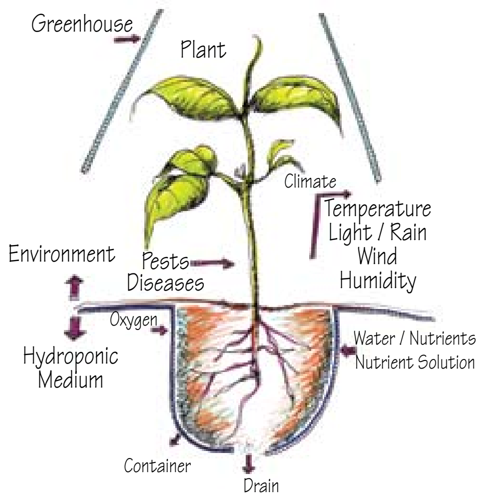
Each crop requires different forms of **care, environmental** and nutritional conditions, although the same nutrient formula can be applied to most crops. If we are thinking of going into business, however, we should **tailor the nutrition to the crop that has been chosen.** This will give us the best results. Similarly, we should take into account the agro-climatic conditions that may interfere with the development of the crop.

2 Inert: inactive. It means that it does not contribute anything to the plant, either chemically or biologically.

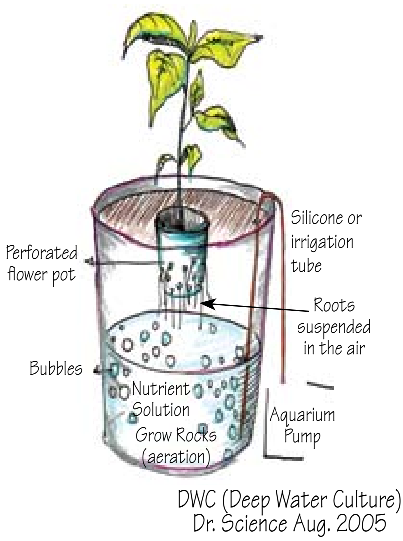
Home hydroponics takes up little space and is an activity the entire family can participate in and enjoy.



Planting in solid substrate.



Planting in containers.



Planting in liquid substrate.

Where to place the hydroponic garden

The main points to consider when choosing a site for our hydroponic garden are the following:

- The site must receive a minimum of **six hours of sunlight a day**
- It must be near a **water supply** and near the place where the nutrients are prepared and stored
- The area must not be exposed to **rain, strong winds or** excessive **shade** caused by trees or buildings
- It must be **protected** from access by pets and small children who can damage the plants
- It **must not be close to drains, latrines, garbage containers**, or anything else that could contaminate the system

Space is not a limiting factor in hydroponics- you can plant in columnar pots using the vertical hydroponics method, which only requires 40 cm, or in spaces as large as greenhouses. The pots that are set up in columns must be resistant and light. The substrate must also be light. You can use a mixture of coconut husk fiber and pumice stone, or rice chaff, or charcoal.

Chapter II
Production Systems

Hydroponic systems are divided into two large groups: closed and open.

In the case of **closed systems**, the **nutrient solution is recirculated**, continuously providing the nutrients that the plant requires. Closed systems include:

- Floating Root
- Nutrient Film Technique (NFT)
- PVC or bamboo channels (generally tubes), placed either flat or in stair-like fashion
- Plastic or polystyrene pots set up in columns

Open systems are those where the solution is discarded after use instead of recycling.

Within these two groups, there are as many types of systems as there are designs for the growing variables involved:

- Growing beds
- Columns made out of tubular plastic bags ("sleeves") or vertical and horizontal PVC pipes
- Individual containers such as pots, plastic sacks, and old tires

Some crops respond better to one system or another. For example, lettuce crops can be grown in nearly all systems, but develop faster when root floating and NFT systems are used. Other crops, such as tomato, cucumber, and bell peppers grow better in horizontal sleeves or in individual containers such as sacks or pots.

Worldwide, closed systems are the most common, but in many of our countries the **open system in beds with substrate and manual or drip irrigation** (generally with a little hose per plant), without recirculation of the nutrient solution, tends to predominate, given the general quality of irrigation water and the technical knowledge required to set up closed systems.

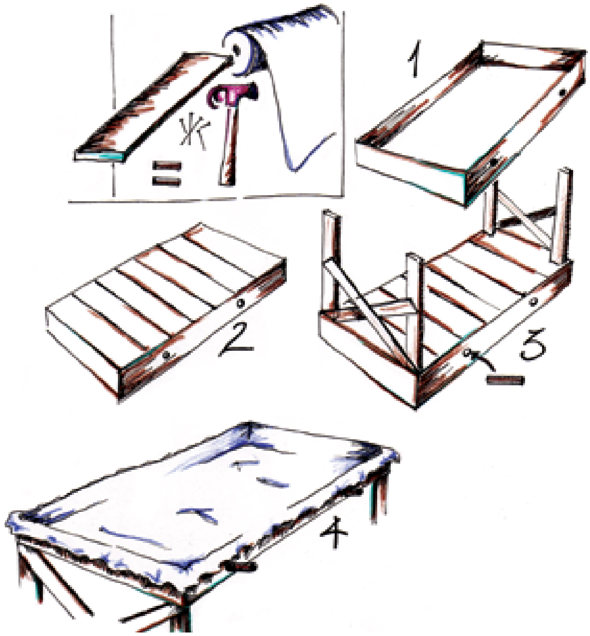
Another classification is based on whether the system uses a **solid or liquid medium.**

Solid substrates

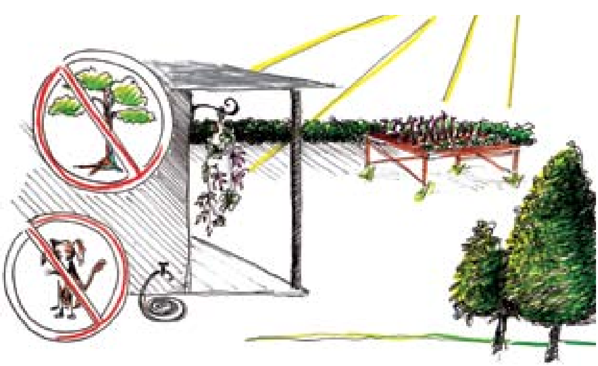
Bed system

This is one of the systems preferred by people who have a hydroponic garden in their homes, since the bed, which is made from discarded pallets or out of semi-hard wood, is an inexpensive system that is easy to set up.If the bed is exposed to the environment, it has a useful life of five years, provided that it has been painted.

The wood must be at least two centimeters thick. Its parts must be well adjusted and sealed to prevent leaks. The bed can be placed at a height of between 80 and 90 cm, an ideal height for an adult, as it will not necessary to bend down and one can work with little physical effort. The height may vary depending on the needs of each person, such as children, disabled people, or those who are very tall or very short.



Bed system. *The recommended size for the bed is one square meter. It should measure no more than two meters in length, and be from 1.0 to 1.2 meters wide. Line the floor and interior walls of the bed with construction-grade plastic sheeting (preferably black), fill it with substrate and then moisten the substrate. Make two holes in the sides of the bed for drainage via a small hose. Make a small hole in the substrate, insert the plantlet and tamp down the substrate just enough for it to stand on its own.*



Hydroponic plants require at least six hours of sunlight per day and should not be exposed to strong winds or heavy rain or kept in the shade for long periods of time. They should be kept out of the reach of children and household pets, and away from drains, toilets or garbage cans, which are sources of contamination for the plants.

Vertical hanging bag system. *The substrate must be moistened before it is placed in the bag. Once the bag is full, small incisions are made along the length of the bag to insert the plantlets.*

At the top, near the loop used to hang the bag, two small incisions are made on opposite sides of the bag. Two funnels made from empty soft drink bottles are inserted into the incisions to feed the plants.

Stacked flower pot system. *Pots are stacked on top of one another up to 2 meters high. Each pot has four or six corners in which plantlets are placed. This system can be mechanized using a pump and a nutrient tank where water is re-circulated.*

The bed or container is easy to make. If a pallet is used, the size of the bed will be determined by the size of the pallet. However, the recommended size is one square meter. The length should not exceed two meters, and the usual width is between 1 and 1.2 meters. The depth of the bed must be between 7 and 10 cm, unless we want to grow carrots, which require greater depth, 20-25 cm, depending on the variety you wish to grow.

For the legs, inexpensive timber can be used, but preferably not conifers such as pine or cypress. Instead, semi-hard woods should be used, such as botarrama *(Vochysia ferruginea)*, laurel, or gmelina. The legs of the bed must be very firm.

Use a spirit level to obtain an inclination of 1 per cent. This will help drain off excess nutrients.

The inside of the bed must be lined with **construction plastic (preferably black)**, which ensures that it is totally waterproof. On top of the plastic, place the chosen substrate and moisten it. Next, drill a small hole on the side of the bed that is slightly lower and fit into it a small (half-inch) hose, about 10 cm long, for drainage. Seal it with silicone. Now you are ready to plant the seedlings. Make sure that the seedlings are spaced 15 to 20 cm apart, depending on what we have chosen to grow.

Planting is easy. Make a little hole in the substrate (a finger will do), place the seedling in it, and then tamp down the substrate around it to keep the seedling in place. This must be done gently, so as not to damage the plant. After that, fill the bed with the nutrient solution.

Hanging vertical sleeve system

This system makes the best use of vertical space, that is to say, there is greater production per surface unit. However, it has two drawbacks. Firstly, the upper plants may cast shade on the ones below, affecting their development due to insufficient light. Therefore, it is advisable not to make the sleeve too long. Secondly, irrigation is also affected if the sleeve is very long.

A sleeve is a kind of elongated plastic bag closed both underneath and on top, similar to a sausage, which is filled with the chosen substrate and affixed to a beam.

The growing medium may be coconut husk fiber, rice chaff, charcoal or an inert material that does not weigh too much. If it did, it would be almost impossible to move the sleeves from one place to another. For instance, if rock were used, not only would it be very heavy and unmanageable, but it could easily tear the plastic or fall. The materials used for the substrate may be mixed. Each gardener must judge the proportions to use, since there are no precise rules. **Experience** will guide you on the best mixture to use, taking into account the climate where you live, the availability of the substrate, its characteristics and its cost. However, a mixture of coconut husk fiber, charcoal and chippings often works well in this system.

The plastic used to make the sleeve must be 7 micra thick. (A micron is equal to one millionth of a meter.) It is available in three colors: black, silver and white. The black one is recommended for cold climates, because it retains the heat better. The white one is recommended in hot climates, and the silver in temperate areas.

The optimal and most manageable size for the sleeve is between 1 m and 1.5 m, with a circumference of about 70 cm. In general, this tubular plastic is available on the market in the form of rolls, with a double width of approximately 35 cm on each side, which makes it very simple to cut it to the desired length and fill it with substrate.

The substrate must be moistened before filling the sleeve. In the process of filling it, the substrate must be tamped down, so that it is evenly distributed and without air pockets.

Once the sleeve has been filled, make small incisions to plant the seedlings (see diagram). For example, in a sleeve that is 1m long, mark a circumference every 15 cm, leaving the first one 20 cm from the top. As you move down, you would be drawing a circumference 35 cm below the top, another one 50 cm below, another 65 cm below, and the final one 80 cm from the top of the sleeve. In each circumference we can plant four seedlings, each positioned 90 degrees from the next. Do not make the incisions so that the lower holes are directly above those in the next circumference, or the higher plants would block the light required by the lower ones. If you wish, you may draw an equilateral triangle so that the base is at the lower circumference and the apex touches the next circumference above, so that the lower plants and those next above are about 30 cm. away from each other. The distance between plants along the circumference should be 15 to 20 cm. Make the holes in the shape of a triangle, with sides measuring 4 cm (see diagram). Many people prefer to mark the position of the holes and make them, before filling the sleeve. If you want to do this, you will find it easier if you insert a piece of cardboard inside the plastic. If you prefer, the markings and holes can also be made when the sleeve is full.

In the upper part of the sleeve, close to where it is attached by a rope to the beam, make two more small incisions, a good distance apart from each other. Insert two small funnels there, which will be used to feed the plants. You can make your own funnels, as shown in the picture, by cutting small plastic soft-drink bottles that have been discarded. Near the bottom, make another small incision and insert a little tube that will serve to drain away the excess water and old nutrients.

Once the sleeves have been prepared, they are hung vertically from a beam using rope or a hook. The sleeves must be placed with **1 m between columns and 1.2 m between rows.** This ensures that light reaches the sleeves as uniformly as possible.

In this system, plants are positioned in a triangle or crow's foot pattern (zigzag pattern), as shown in the diagram. This is done so that the roots of the plants may develop fully. Moreover, on the vertical sides of the sleeve it is usual to plant upward-growing crops such as chives, celery and basil in order to take better advantage of the space.

People often ask whether several plant species can be grown in the same sleeve. The answer is a partial yes. Several factors must be considered, such as the characteristics of each crop, so that they do not compete for the sleeve's limited space. The different crops planted should also have the same cropping or development cycle so that they can be harvested at the same time.

The plants that are best suited to sleeves are **lettuce, mustard, basil, several culinary herbs such as climbing oregano, spearmint, tarragon, celery, strawberries, chives, leek, fitweed** *(Eryngium foetidum)*, **and flowers such as busy lizzies (impatiens) and carnations.** Tomatoes may also be grown this way, but the sleeves must be adapted so that they have a longer life. This involves adding a small PVC pipe to each hole, so that the sleeve can bear the weight of the tomatoes and can be used again.

Once the harvest is over, the roots are removed and the substrate is submerged in chlorine water (of the ordinary kind used at home), at a ratio of 40 ml of chlorine per liter of water, for several hours, after which the chlorine water is thrown out and the substrate is rinsed with plain water.

Horizontal sleeve system

This system uses the same substrates and polyethylene tubes used in vertical sleeves, but this time they are placed horizontally. These can be used to grow **tomatoes, cucumber, bell pepper, strawberries, eggplant, squash, mini-vegetables, flowers** and many other plants. Several of these plants will need propping up to support their growth. These sleeves are easier to handle if you make them between 1 m and 2 m long, as in the case of the vertical ones.

You can also use bamboo, or four inch PVC pipes. These can be laid on the ground and attached to a wall in rows.

Pot column system

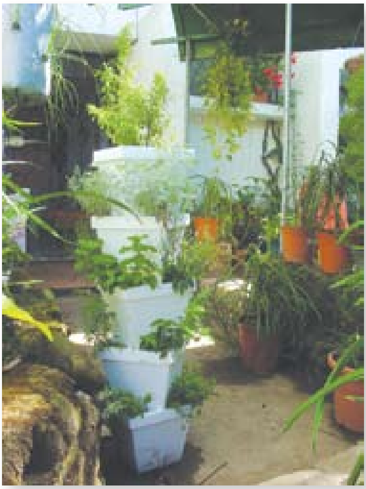
This involves placing plastic or Styrofoam pots in columns as high as 2 m. Each pot has four or six corners when the seedlings are planted. Plants that do well with this system include strawberries, parsley, thyme, chives, spearmint, and climbing oregano. The system can be automated using a pump and a tank of nutrients to re-circulate the water.

Individual container system

This system is used to plant tomato, peppers, eggplant, cucumber, melon, and watermelon. Before setting it up you should lay some plastic covering and fine gravel on the ground to prevent the roots from coming into contact with the ground.

System using PVC pipe or bamboo

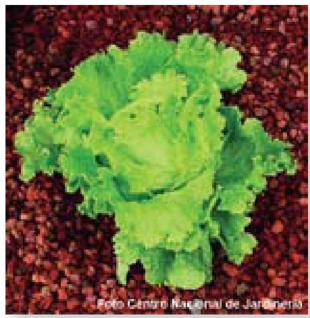
Nutrient film technique



Stacked plastic or polystyrene flower pots

Floating garden system

Lettuce can be grown using almost all systems. Some plants, depending on their characteristics, adapt better to one system better than to others.



Within each system, there are a number of methods: beds, columns or sleeves made from tubular plastic bags (vertical and horizontal), and containers such as flower pots, bags, plastic boxes and tires.

A large variety of plastic containers may be used – from garbage bags to empty paint pots, gallon containers, pots and sacks. A four-gallon container is large enough to grow peppers and tomatoes. All containers must have drainage so that the spent nutrient solution can drain away.

A mixture of substrates similar to those used in the sleeves must be used. They must be light, with particle sizes no larger than 3 mm, with good moisture retention, capillarity and aeration. A mixture of 50 per cent charcoal and coconut husk fiber or pumice stone works well. Plant two seedlings per container, and place these in double rows. The space between containers in a row should be 40-50 cm from the center of each container to the next, while the space between rows should be between 1.0 and 1.5. This gives us four to five plants per square meter.

LIQUID SYSTEMS

Root floating system

Producing vegetables using this technique is less expensive and faster. It also requires less work and uses water more efficiently. The vegetables that are best suited to this system are lettuce, celery, basil and watercress.

In this system, the roots are permanently submerged in the nutrient solution – without any substrate – and are held in place by holes in a polystyrene board, which should on average be one inch thick. In the case of celery, one-and-a-half-inch boards are used, since celery plants require greater support.

The root floating system consists of two stages:

- When the seedlings are ready, they are transplanted to a small root floating system, which can be made from a discarded box for grapes or other fruit. Circular holes 2 cm in diameter should be bored into the 1-1.5 inch[3] polystyrene board. These holes are where the seedlings will be planted, held in place by a little piece of polyurethane foam. The distance between the holes will depend on the type of crop. For instance, in the case of lettuce, the holes are placed between 15 cm and 20 cm apart. Beetroot requires less space: between 10 cm and 15 cm will do. Here the seedlings will grow over a period of 15 days.

- After this, the young plants are transplanted to their final position. The chosen box or container, as well as the bed, are lined with black plastic, since the roots need to be in the dark.

The first transplanting increases costs when there is a large volume, and also increases the risk of contaminating the water by manipulation. Many growers skip this step by planting the seedlings in their permanent container.

In this system there are no restrictions regarding size, but it is important to bear in mind the sizes in which polystyrene sheets come and use these to the best advantage.

The polystyrene sheet of the cover must not float, and must be about 2 cm above the water level, which helps to aerate the roots. This will also extend the useful life of the sheet. In order to ensure this, the sheet must be tightly fitted to the box. Cut two of the corners off the sheet so that they are rounded. This will make it easier for you to manipulate the sheet when you want to see how the roots are developing or when you need to add more nutrient solution.

3 The thickness of the board depends on the crop chosen. For example, in the case of lettuce and beetroot, a 1.0 inch board should be used, while for celery one that is 1.5 inches is preferable.

To prevent the plants from sinking into the water, cut a 2 cm x 3 cm x 5 cm rectangle of polyurethane foam and wrap it around the beginning of the stem of the seedling. In this way, the plant is firmly secured and the foam absorbs the nutrient solution (see diagram).

The optimal temperature of the water containing the solution is **between 15°C and 20°C.**

In the case of the root floating system or NFT, the first thing you must do is estimate the volume of water in the container. One way to do this is to measure the length, width, and height of the container. Then multiply the length by the width and by the height (how high the water reaches). If you carry out this calculation in cm, you must divide the result by a thousand. That tells us, in liters, the volume of water in the bed.

Example

A container is 1.20 m long by 1.00 m wide by 0.07 m high.

1.2 x 1 x 0.07 = 0.084 m^3

Since 1 m^3 is equal to 1,000 liters, we can apply the rule of three: *1 m^3...........1000*

0.084...........x, in other words, 84 liters

Now, for each liter of water in the container, apply 5 cc of Concentrated Solution A, 2.5 cc of Concentrated Solution B, and 5cc[4] of Concentrated Solution C. In the previous example, you would need to add 420 cc of Concentrated Solution A, 210 cc of Concentrated Solution B, and 420 cc of Concentrated Solution C to the water of the 84 liter container. Then stir well using a plastic or wooden stick so that the three solutions are mixed homogeneously in the water.

4 1 cc is equivalent to ml.

Aeration

The importance of this aspect has been underestimated, even though it is one of the most essential in hydroponics.

Plants absorb nutrients when the water molecules transpire on the leaves. If ventilation (exchange of air) increases, the levels of transpiration will improve. This correlates to the level of nutrients absorbed. If there is no air (oxygen) in the area of the roots, they will stop absorbing nutrients and water and eventually the plant will die.

Even if that does not occur, when the nutrient solution is not stirred as frequently as it should be, algae will start forming and it will that alter the development of the crop and make it look less appealing.

It is therefore essential to stir the nutrient solution at least twice a day with a little wooden or plastic stick, or even with your well-washed hand, until bubbles form. You may even move the box around gently, if it is not too heavy. Another option is to raise and lower the sheet rapidly for about 15 seconds. This helps the roots do a better job of absorbing the water and the nutrients.

Electrical conductivity

Electrical conductivity indicates the quantity of nutrients dissolved in the solution. This should be measured regularly, since plants absorb the water more quickly than the nutrients. It is therefore important to maintain the volume of the nutrient solution constant. There are devices to measure conductivity. The greater the quantity of salt, the greater the conductivity will be; which is measured in miliSiemens/cm (mS/cm). A medium level of conductivity would be **1.5-2.4 mS/cm.**

pH

This is a measure of the acidity or alkalinity of the solution. The scale for measuring pH goes from 1 to 14. Accordingly, 7 is neutral. Anything below that is acid, reaching its highest point at 1. Above 7 the same is true regarding alkalinity, reaching its highest level at 14. If we take into account that plants absorb nutrients best within a range of **5.5 to 6.5**, it is necessary to monitor the pH in order to prevent abrupt rises or falls. If you need to lower the pH, you can use citric acid. If you wish to increase it, you can use sodium hydroxide or potassium hydroxide. The pH is measured with pH paper or a pH meter.

Maintaining the water level in the containers and other considerations

Whenever the water level in the container drops appreciably, it must be filled only with water. Every third time it is refilled, you must add with the water half the nutrient concentration per liter. For instance, if the third time you refill the container you need 5 liters of water to reach the initial volume, then you must apply 12.5 cc of Concentrated Solution A and C and 6.25 cc of Concentrated Solution B.

Three points to remember in this system:

1. **Aerate** the nutrient solution manually every day with a clean plastic utensil or by moving the container with your hands, if it is not too heavy. Do this at least twice a day to redistribute the nutrients evenly in the solution and oxygenate it. Otherwise, the roots begin to darken and limit the absorption of nutrients and water.

Aeration can also be done by shaking the sheet up and down for 15 seconds, or by lifting the sheet and using your hand or a small stick to stir up the water and form bubbles.

When the containers are larger than one square meter, the sheets must be cut to the right size. The sheets bear a lot of weight, especially around harvest time when each plant can weigh more than 300 grams. If the sheets are not cut correctly, they may tear.

2. **Prevent the formation of algae**. When the nutrient solution is not moved often enough and when the surface of the water is exposed to direct light, it fills with green algae (if they are healthy) or black algae (when they decompose). This can be prevented by covering those parts with white plastic. Although algae do not compete with the crop for the nutrients, they could affect the harvest if they should rot massively due to bacteria or viruses. If this very unusual event should occur, you can apply a chemical algaecide, but do so very sparingly.

3. **Monitor the level of the nutrient solution**, so that the roots are always in contact with it. If part of the solution evaporates, top it up again with a little water. If a large amount has evaporated add some more nutrient solution.

Recirculation system or NFT

In this system, a pump (of the type used in aquaria) recirculates the nutrient solution through the roots of the plants. The water containing the nutrients is collected and stored in a tank, from which it flows back to the opposite end of the system pushed by the pump.

In NFT (Nutrient Film Technique), plants are normally grown on PVC tubes, or even hollow bamboo stems, with a diameter of between 4 and 6 inches. The tubes lie horizontally, with a slight inclination to help the solution circulate. Holes are perforated into the tubes and spaced 20 cm apart from each other. This is where the plants are placed, supported by small plastic cups[5] or polyurethane foam.

If a PVC gutter is used instead of a tube, it should be covered with a polystyrene board, with perforations where the plants will be, supported by polyurethane foam. The tubes or gutters can be supported by a table or a frame (diagram).

Containers

If you wish to get started with hydroponics, you can use all sorts of containers – old tires, bamboo, plastic pots, plastic cups, 1-gallon containers, plastic bottles with the tops cut off, flower vases, old tubs, plastic gutters, plastic disposable containers, pallets, polystyrene boxes (like the ones in which grapes are imported), and plastic fruit baskets, among others.

The most suitable containers are made out of plastic, brick or concrete. Metal containers must be painted or varnished and lined with plastic. Wooden containers must also be lined with black plastic or waterproof material. You can also work with the plastic that is used for construction; if this is not available, try using large black garbage bags of the kind used to collect fallen leaves and other waste in gardens. You must use two of these (one inside the other), as the double thickness makes it less likely that they will tear. Wood works well, but make sure that it is of good quality (semi-hard) and

5 Special cups or baskets for hydroponics can now be purchased, as shown in the picture.

of the required thickness, depending on the size of the bed you wish to assemble.

Containers of any size may be used, but they must have a height of between 10 cm and 25 cm, so that the roots have enough room to develop. However, there are some exceptions: in the case of violets, the container may be just 5 cm high, but in the case of carrots the height of the container can vary from 25 cm to as much as 30 cm. Size depends on individual needs and space, but the maximum length of a bed or tube should not exceed 6 meters, while the width should not exceed 1.2 m. A very common size for beds is 1.20 m long by 1 m wide. This is because they are made from discarded pallets that come in that size and that are generally sold very cheaply or even given away.

Characteristics

Containers should have the following **characteristics**:

- They should be preferably **dark and opaque**, since algae[6] develop better in clear containers.
- They must be **waterproof** to prevent loss of the nutrient-rich water.
- They must be made from **chemically inert material** to prevent reactions or changes to the nutrient solution.
- Containers used with a solid substrate must have **holes** in them to drain the water to facilitate the plants' aeration.

6 Algae contain chlorophyll (green pigment) and carry out photosynthesis in the presence of light. This process releases oxygen into the solution during the day, but consumes it at night. The presence of algae in the solution, together with light, may enrich the solution as long as the algae are kept in check. The reason for preventing light from reaching the water is to limit their growth.

However, it must also be possible to plug the holes whenever conditions require this, e.g. during the summer months when the nutrient solution should be left for a longer time in the containers.

- Containers must have an **inclination** of between 1 and 5 per cent, depending on the substrate used, to ensure good drainage.
- They must be **durable**.

Costs are a key factor when choosing which culture system to use. Regardless of the method employed, the **quality** of our product will be determined by the correct use of good nutrients. It is advisable to only buy guaranteed nutrients from reputable firms. The use of clean substrates and good lighting will improve their quality, as will caring for our plants lovingly.

Chapter III
Substrates

What are they?

A substrate is the material medium in which the root system of the plant develops. In hydroponics, a large variety of substrates may be used, provided that they are not soil and are properly isolated from soil to prevent contamination. Substrates can be solid, such as river rock, or liquid, such as water.

Main function

When the substrate is water, its function is to maintain an appropriate balance of air and the nutrient solution, both of which are needed by the crops. In the case of solid substrates, these serve to "anchor" the plant, promote aeration, retain humidity and keep the roots in darkness, as required.

Every substrate has advantages and disadvantages. There is no ideal substrate. The important thing is to choose the substrate that is best suited to the type of crop and the environment in which it is grown, the proximity to the source of the substrate and, of course, the price.

In Costa Rica, the most commonly used substrates are volcanic or river rock, charcoal, rice chaff and coconut husk fiber.

Other substrates include waste materials from industrial and other local activities, such as rock dust, charcoal residues, ashes, ground brick, ground plastic, and sawdust. These materials must be sterilized and their granulometry adapted, i.e. the size of the particles must be adapted to the container you are going to use.

Characteristics

Substrates can be liquid (like water) or solid. The substrate should be inert, that is, it should not contain nutritive mineral elements. This makes it possible to establish very precise control of the plants' nutrition, something that is nearly impossible to achieve in soil due to the large number of reactions that take place in it. Having a balanced air/water ratio prevents the problem of lack of aeration due to excessive irrigation, with the consequent lack of oxygenation of the roots.

The substrate should be totally free of toxic elements, fungi, spores, bacteria and viruses that act as pathogens against plants. It must therefore be disinfected before being used and after each harvest. You can use chlorine – at 40 ml per liter of water – or the solarization (solar heating) method during the summer.

It should be easy to wash the salt off from the substrate. This partially helps to mitigate the production losses that occur in crops grown with substrates.

Types of substrate

- Organic
- Inorganic
- Enriched

Organic

In Latin America and the Caribbean there are a large number of organic substrates capable of storing nutrients, i.e. substrates that contain a store of nutrients provided by water that comes from the decomposition of plants and trees.

- Charcoal
- Rice chaff/chippings
- Sawdust
- Coconut husk fiber and other coconut byproducts
- Macadamia nut shells
- Peat moss

When using sawdust, try to obtain sawdust that is yellowish. Do not use sawdust from pine trees or red wood, as these contain substances that can affect the roots of the plants.

All substrates should be disinfected. Some must go through a more complex and time-consuming process to eliminate any possible impurities.

The anaerobic method (without oxygen) involves placing the **rice chaff** or the **sawdust** into a container with water and allowing it to ferment for some time before using it. How long depends on the climate: in colder climates it should be left longer. Once the process is complete, throw out the water and spread out the substrate to dry in the sun. The drawback with this method is that during the fermentation process, the chaff acquires a foul smell. The good news is that after drying in the sun the smell goes away. This substrate should only account for 20% of the total mixture.

Another way to disinfect rice chaff is by using the aerobic method (with oxygen). The chaff is placed in a container with water and washed. Then the water is changed every day for at least one week.

I prefer to use **coconut husk fiber** rather than rice chaff. In addition to having good physical and chemical properties, it is more stable than rice chaff, which degrades over time and starts releasing toxins that affect the growth of the plants. But if you decide to use rice chaff, I would recommend that you change it at least after every third harvest. Otherwise, the yields will decrease over time.

Charcoal is another good substrate and helps to create spaces between the other components of the substrate and the root of the plant. I would not recommend sawdust, as we seldom know what species it comes from; moreover, lumber mills generally throw it on the ground, where it can easily become contaminated with soil, bugs, and other contaminants.

Table 2 Physical and chemical characteristics of organic substrates

Substrate	Charcoal	Rice chaff	Sawdust	Coconut fiber
Weight	Low	Low	Low	Low
Moisture retention	Low	Low	Medium	High
Drainage	Good	Good	Medium	Medium
Degree of decomposition	Medium	High	Medium	Medium
Type of material	Inert	Inert	Inert	Inert
Aeration	High	High	Medium	Medium
Disinfection	Washing	Washing, fermentation	Washing, fermentation	Washing
Cost	Low	Low	Low	Medium

Inorganic

Inorganic substrates are inert materials that do not contribute anything to the plant, either physically, chemically or biologically. These include volcanic rock[7], river rock, river sand[8], rock dust, pumice stone, burned mineral coal, peat, and brick fragments that are used without previous processing.

Other inorganic substrates undergo transformations, including vermiculite[9], perlite[10], clay, rock wool[11], and synthetic materials such as polyurethane foam, phenolic foam and expanded polystyrene (Styrofoam).

Enriched

One example of an enriched substrate is peat moss[12]. Because it is generally imported into our countries, it tends

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7 Do not use calcareous rock as it releases calcium and alters the solution's pH.

8 Do not use sea sand. In the first place, removing it is illegal. Secondly, it has a high salt content that would interfere with the absorption of nutrients by the plant.

9 Vermiculite is basically composed of aluminum, magnesium and iron silicates and contains water. When subjected to heat, it expands to between eight and 20 times its original volume.

10 Perlite is a siliceous volcanic rock which, when treated with heat, expands between four and 20 times its original volume. This expansion is due to the presence of 2% to 6% water in its natural state. Expanded perlite is white, fairly light, and chemically inert. After its useful life, the material can be added to farm soil.

11 Rock wool is generally imported. It is an excellent medium because it is inert, sterile, porous and non-degradable and also provides good support for the root and acts as a temporary deposit for the nutrients, providing good oxygenation. It is composed of molten rock, although the best one is made from volcanic basalts, after eliminating the mineral oils they contain that repel humidity and prevent filtration.

12 Peat moss is composed of perlite, vermiculite and sphagnum.

to increase production costs. However, it has certain valuable properties that might convince you to use it: it does not require disinfection, it comes ready to use (which saves time and water), the granulometry is uniform (depending on the quality of the product), and it is an excellent medium for germination.

As mentioned previously, the various substrates can be used on their own or in different combinations, each of which has different physical characteristics. Careful selection of the mixture will ensure greater success when growing your crops. Some mixtures, in different proportions, have been tested with good results on more than 30 species of plants.

Table 3 shows the different combinations tested by the "Green Heart National Gardening Center" in Costa Rica. As noted earlier, there is no such thing as an "ideal" mixture or substrate. We must consider such factors as water retention, air supply, distribution, particle size, low apparent density, high porosity, a stable structure, low cation[13] exchange capacity, a sufficient level of nutrients that can be assimilated, a slightly acid pH, a low rate of decomposition, low cost, ease when mixing and disinfecting, and resistance to extreme physical, chemical and environmental changes.

Preparing the substrate

When using these substrates you must wash them at least three times in large containers to eliminate the small particles, which will float. You will know when the substrate is ready to use when the surface of the water becomes clear.

13 Cation is an atom or group of atoms with a positive electrical charge. Cation exchange is the process whereby a cation in solution is absorbed by a solid, replacing a different cation.

Table 3 Substrate Mixtures			
Mixture	**Ingredients**	**Quantity**	**Container**
1	All the substrates on their own	100 per cent of the substrate	B, S (unless it is rock or sand), P
2	Chippings, charcoal, coconut husk fiber (in cold weather)	30 per cent chippings + 30 per cent charcoal + 40 per cent coconut husk fiber	All
3	Chippings, charcoal or pumice stone, coconut husk fiber	30 per cent, 30 per cent, 40 per cent	All
4	Chippings and charcoal (or others)	50 per cent chippings + 50 per cent charcoal (or coconut husk fiber, or pumice stone)	All
5	Chippings, sand, volcanic rock	40 per cent chippings + 40 per cent river sand + 20 per cent volcanic rock	B, P
6	Chippings, river sand	60 per cent chippings + 40 per cent of river sand	B, P
7	Chippings, sawdust	80 per cent chippings + 20 per cent sawdust	All
8	Chippings, volcanic rock	60 per cent chippings + 40 per cent volcanic rock	B-P
9	Coconut husk fiber, pumice stone or charcoal	50 per cent coconut husk fiber + pumice stone or charcoal pumice (charcoal)	All
10	Coconut husk fibers	100 per cent	B
11	Charcoal and coconut husk fiber (in Summer)	50 per cent-50 per cent	All

* Bed=B, Sleeve=S, Pot=P

If you decide to use volcanic rock, river rock or construction rock as a substrate in a bed or container, buy small rocks (roca quinta). Use a sieve that retains the particles larger than half a millimeter so you can eliminate those that are too small, which interfere with drainage and therefore with root aeration. Particles larger than 7 mm should also be discarded.

If you plan to use these substrates to germinate seeds, they should be put through a 3 mm caliber sieve, so as to have a light substrate with small particles. If you do not do this, the size and weight of the substrate will prevent the germination of small seeds, e.g. lettuce and celery seeds. Moreover, not using the sieve reduces the consistency of the substrate, limiting moisture retention and the healthy development of bulbs, roots and tubers.

Chapter IV
Water and nutrition

Water

Water is the most important element in the hydroponics system, because its quality can affect our crops. In Costa Rica, nearly every corner of the country is supplied with potable water, which guarantees its quality and ensures that it does not contain toxic elements. The same water that we drink is what we use in hydroponics, at a normal temperature (20 - 25 degrees centigrade).

Each crop has a specific tolerance to the toxic elements mentioned previously and to the total amount of salts (quantified by the measure of electrical conductivity) that its root system can tolerate without significantly reducing the yields. These levels must not be exceeded and this is achieved by carefully monitoring the water drained.

Some crops, such as tomato and melon, are more tolerant to salinity than others. Others, such as lettuce, are more sensitive. Therefore, if a closed water-based system is used for growing, it is necessary to control the electric conductivity. In a closed system a very high quality of water is needed, with a sufficient concentration of sodium and chlorides that the crops can assimilate without showing symptoms of toxicity.

In the summer months, demand for water increases dramatically due to evaporation associated with high temperatures and relative humidity. Water that contains too much calcium and magnesium (called “total hardness”) could create serious problems, and therefore it is advisable to carry out a physical-chemical analysis of the water.

If the dissolved salts in your water measure 200 ppm (parts per million) or more, we recommend an analysis to determine the calcium level. Excess calcium is the main factor that makes your water “hard”. If your water analysis reveals that the calcium content is greater than 70 ppm (mg/liter) you should treat it. Before setting up a water recirculation system, we recommend an analysis to assess the water quality. This will reduce costs and you will know exactly which nutrients to add.

Nutrition

Nutrient solutions

In addition to the non-mineral nutrients that plants incorporate through water, carbonic gas (CO_2) and oxygen (O_2) from the atmosphere -carbon (C) hydrogen (H) and oxygen (O) – plants absorb with different degrees of intensity, through the roots, other nutrients from decomposed organic matter or minerals.

To develop fully healthy plants need a formula composed of **17 elements**. Of these, three (Carbon, Hydrogen and Oxygen), are largely provided by the air and water. The remaining 14 are mineral elements that should be included in the nutrient solution.

These nutrients are:

- **Indispensable** for the survival of plants and are required in **different quantities**. Those needed in large quantities are: nitrogen (N), phosphorus (P) and potassium (K); in medium quantities sulfur (S), calcium (Ca) and magnesium (Mg); and, in very small quantities (minor elements) iron (Fe), manganese (Mn), copper (Cu), zinc (Zn), boron (B) and molybdenum (Mo). Recently, nickel (Ni) has been added to the list of essential elements due to its association with an enzyme called urease, which acts on the metabolism of nitrogenated compounds in plants.
- Useful but not indispensable for life: chlorine (Cl), sodium (Na), silicon (Si).
- Unnecessary for plants, but necessary for the animals that consume them: cobalt, iodine.
- Toxic to plants: aluminum (Al).

It is important to remember that if any of the aforementioned elements are added in the incorrect proportions, they may be toxic to the plants, especially those known as minor elements.

Classification of nutrients

These 14 nutrients, that are normally extracted from the soil and consumed by the plants, can be classified in three groups: major elements or macronutrients, secondary elements and minor elements or micronutrients.

Major elements or macronutrients

Nitrogen, (N) Phosphorus, (P) and Potassium, (K) are defined as the major elements because of the specific role they play. Nitrogen regulates the production of proteins and is essential for the growth of leaves and stems. Phosphorus is required for photosynthesis and assures the transfer of energy within the plant. Potassium is essential for the production of sugars and starches, as well as for cellular division.

Secondary elements

The secondary elements[14] are calcium, (Ca), sulfur (S) and magnesium (Mg). The latter is essential to absorb light and to neutralize toxic residues produced by the plant. Ca allows for the production and growth of cells, and must always be present on the tip of each root, leaf or flower, while S ensures the slow development of the plants.

Minor elements or micronutrients

Minor elements, also known as micronutrients, act in minimal quantities, basically as catalysts for different processes. There are seven minor elements: iron, manganese, boron, molybdenum, zinc and copper, nickel and chlorine[15]. These are not all the microelements involved in plant development, but the remainder (aluminum, (Al) cobalt, (Co) iodine, (I) selenium, (Se) silicon, (Si) sodium (Na) and vanadium (Vn)) are not usually included in the nutrient mixture, since they are already present as impurities in the water, or are added to other nutrients.

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14 Also called mesoelements.

15 Despite being essential, chlorine is required in minute quantities, as It can be toxic. It is generally present in water, and therefore is not included as a microelement when preparing the formula.

Unlike macroelements, which are weighed and adjusted according to the type of plant, stage of development and climate etc., microelements are seldom adjusted because they are used in such small quantities that weighing them is very complicated. For this reason, a fixed amount of a commercial mixture is generally added, reinforcing individual elements, whenever an analysis or the symptoms of the crop suggests the need for this.

Functions of the nutrient elements in plants

Of the 17 chemical elements considered necessary for healthy plant growth, 14 are mineral nutrients. Under natural growing conditions, these are found in the soil and enter the plant through the roots. A deficit of just one of these elements can limit or reduce the yields and, therefore, the grower's profits.

Table 4 Characteristics of macro-nutrients

Element	Funtion in the plant	Deficiency Symptoms
Nitrogen N	- Gives plants intense green color. - Promotes leaf growth.	-Yellowish green color. - Slow development limited growth. - Apparent on old leaves.
Phosphorus P	- Promotes growth of roots, flowers and fruits. - Promotes the production of flowers and seeds.	- Purplish leaves and stems. - Weak steams/ - Poor germination of seeds.
Potassium K	- Provides vigor and resistance to diseases.	- Lower leaves have scorched edges and tips, tend to roll up.

Localizing deficiency symptoms in plants is closely associated with the speed at which the nutrients move from the old leaves towards the growth points; in the case of the mobile elements (N, P, K) that are rapidly transferred, the symptoms first appear on the **oldest** leaves. Immobile elements, such as calcium and boron, cause deficiency symptoms in the growth points.

In some elements, the degree of mobility is related to the degree of deficiency, the species and the nitrogen level. When there is very little mobility of copper, zinc and molybdenum from the old leaves toward the new ones, then the plants are deficient in those elements.

Sources used to prepare the nutrient solution

We know that plants require 17 elements for healthy development. These elements may be found in different sources. Table No.5 below contains our recommendations regarding the best sources.

Table 5 Sources

Source	Element	Characteristics
Potassium Nitrate KNO_3	N, K	Very soluble Salt
Potassium phosphate monobasic KH_2PO_4	P, K	Corrects deficiencies de phosphorus
Magnesium sulfate $MgSO_4$	S, Mg	Cheap, highly soluble, pure salt
Fetrilon combi (minor elements)		
Iron Chelate	Fe Cit	Best sources of iron
Boric Acid H_3BO_3	B	Best source Of boron
Calcium Nitrate (Ca) $(NO_3)_2$	N, Ca	Very soluble salt

Formulas

Since the middle of the nineteenth century different formulas have been tried out. Several of these are shown below, including the one used by the *"Centro Nacional de Jardinería Corazon Verde"* [16]. Solutions A and C contain the major elements and solution B contains the **minor elements**.

Table 6 Formula No.1

Formula	Salt	Quantity in grams per liter
Solution A	Ammonium Sulfate	3.0
	Potassium Phosph.	5.7
	Magnesium sulfate	11.4
Solution B	Iron chelate	2.0
Solution C	Calcium Nitrate	48.6

Table 7 Formula No.2

Formula	Salt	Quantity in Grams per liter
Solution A	Monoamonic phosphate	34.0
	Potassium nitrate	110.0
Solution B	Magnesium sulfate	123.0
	Copper sulfate	0.10
	Manganese sulfate	0.60
Solution C	Zinc sulfate	1.2
	Boric acid	1.5
	Ammonium molybdate	0.005
	Iron chelate	10.0
	Calcium nitrate	208.0
	Calcium Nitrate	

16 At the start of our courses we used the formulas developed by the Instituto Nacional de Aprendizaje (National Training Institute) INA. However, we have tried out different formulas and this has enabled us to provide our students with an appropriate formula.

Table 8 Formula No.3		
Formula	**Salt**	**Quantity in Grams per liter**
Solution A	Potassium nitrate Magnesium sulfate Monopotassic phosphate	115.6 106.6 49.4
Solution B	Fetrilon Combi 1 Iron chelate (10% p/p) Boric acid	5 2 1
Solution C	Calcium nitrate	155

The nutrients required by the plant are applied in the form of nutrient solutions. The correct administration of mineral nutrition is crucial to the success of hydroponic crops, since this is what allows the plants to develop and produce.

Plants obtain all their nutrition requirements through the nutrient solution which contains all the elements necessary for normal growth and development, since the substrates generally used are inert. This allows for a precise control of the minerals supplied, according to the crop, climate, development stage, in order to obtain optimum crop yields.

Given that the substrate is inert, we must be very careful about deficiencies in the solutions and in the pH since these can seriously damage to the crop.

Preparing the "Mother" Nutrient Solution

The "mother" solution is a concentrated mixture of nutrients, and should therefore be diluted before use:
Steps:

1. *Sterilize three bottles and label them (a 1-liter bottle "A", a half-liter bottle"B" and a another 1-liter bottle "C")*
2. *Clean the measuring device each time it is used for the different solutions.*
3. *Fill the bottle with water.*
4. *Dissolve the contents of bag "A" in the 1- liter bottle labeled "A", dissolve the contents of bag "B" in the half-liter bottle and dissolve the contents of bag "C" in the 1-liter bottle marked "C".*

Depending on the results of the water analysis, the crop and the climate conditions, begin preparing the nutrient solution that fits your needs. Various nutrient solutions are available for vegetable crops, either online or in specialized books, but in general there is little variation in the mineral elements and their quantities. However, if you wish to produce a particular crop on a commercial basis we recommend adjusting the solution to the specific needs of that crop and analyzing the drained solution at least every 15 days to gradually adjust the solution to the needs of the crop.

The nutrient solution is usually prepared at concentrations of **100 and 200 times**, separating the fertilizers that are incompatible with each other, such as Ca, and then adding 1% to water in a recipient in which the pH (normally with citric acid) and the electrical conductivity are adjusted. In the dry season it is best to use a less concentrated nutrient solution (maintaining the balance) and a more concentrated one during the rainy season. While the nutrition requirements of plants are similar during both seasons, their need for water is much greater during the summer months.

Procedure for preparing the "Mother" solution

- Solution A 1 liter
- Solution B 0.5 liter
- Solution C 1 liter
- Weigh each of the elements of the chosen formula separately. This should be done using an accurate set of scales. Do not mix the elements until required.
- Select three 1-liter plastic containers (you can use plastic soft drink bottles). Label each one using an indelible marker: recipient 1 letter "A", recipient 2 letter "B", and recipient 3 letter "C".
- Fill bottles up to the middle with water and pour the elements that you have weighed into each of the containers. Never mix these without the water.
- Add the nutrients of the formula to each recipient. A funnel will help to avoid spills.
- Gradually add more water, until you have one 1 liter in the containers marked with the letters A and C and 0.5 liter in container B.
- Shake well and make sure that all the powder has been dissolved.
- Store in a cool, dark place (under the sink or in a cupboard) and out of the reach of children.
- This amount of mother solution is enough to make 200 liters of nutrient solution, as shown below.

APPLYING THE NUTRIENT SOLUTION: HOW, WHEN AND HOW MUCH

The frequency and volume of the nutrient solution applied depends on the type of substrate used (volume and physical-chemical characteristics), the crop (species and stage of development), the size of the container, the crop and irrigation systems used and the prevailing climatic conditions.

In areas with temperatures of 18 - 24 degrees Celsius we can apply one and a half liters of solution per square meter. We can also apply 100 cc per individual plant. In 1-meter sleeves apply 1 liter. If it does not drip add another half liter.

Plants should be **fed daily**. The best time to administer the nutrient solution is between six and eight in the morning, though water requirements will vary considerably throughout the day, and from one day to another.

The solution should be applied to the roots, trying to avoid wetting the leaves to prevent damage and the appearance of diseases.

Under no circumstances should plants be allowed to suffer from water stress, as this will affect their final yield. We should also avoid excessive waste of water with nutrients.

In the summer or in a hot climate crops will need to be hydrated more often than in the rainy season or in a cold climate. During the dry season, we should not only apply the solution more frequently but we should also add water to the substrate. In the rainy season the solution should be applied before it rains and if it is raining a lot it should be applied twice, one dose very early in the morning and the other before it rains.

On a very hot or windy day, we recommend applying pure water to the substrate before applying the solution. It is important to keep the substrate moist because otherwise the plant will be unable to take in the nutrients from the substrate. If the temperature increases considerably, only half the concentration should be applied since plants need more water than nutrients in high temperatures. The solution should be applied as early as possible in the morning, never when the sun is strong.

The plant should receive water when it needs it, and at the right time. We can also apply a watering-on-demand system using solar radiation sensors which trigger the watering system upon reaching a certain level of accumulated radiation, but this would require a substantial investment.

It is recommended that you apply **only water to the plants once a week**, in order to flush away any excess salts that have remained. Use double the amount of water normally applied, but without adding nutrients. Between 20 and 50% of the solution should be drained off to prevent the accumulation of toxic ions and an excessive increase of electrical conductivity in the root area.

The excess nutrient solution that is drained away from containers during daily watering can be reused in the next waterings. At the end of the week, this liquid can be discarded.

Although not ideal from the point of view of efficiency, in very sunny regions where the heat is intense during the day, it could be applied in the early evening to prevent scorching of the leaves. This problem can also be avoided by using a small amount of water to wash off any excess nutrient solution that might remain on the plants.

Application and dosage

For small plants (i.e. from newly germinated to ten-day old seedlings) or those newly transplanted (between the first and seventh day after transplanting) and in warm climates, we recommend applying low concentrations of solution, in other words half the dose.

After the tenth day of germination, when the plants have generally been transplanted, the full dose can be applied. In very cold weather plants also require more food and therefore the full dose should be applied.

Use a medium concentration when temperatures are very high and it is very sunny, because plants need more water than nutrients during these periods.

Table 9 Concentrations of nutrient solution

Quantities				
		Concentrate		
Concentration	Water (lt)	A (cc)	B (cc)	C (cc)
Total	1	5	2.5	5
Half	1	2.5	1	2.5
One quarter	1	1.25	0.5	1.25

For older seedlings (ten days after germination or on the seventh day after being transplanted), the full concentration should be used (5 cc of A, 2.5 cc B and 5cc of C per liter of water applied). This concentration should also be applied during cold or very cloudy weather, because in these conditions the plant consumes more nutrients.

If you are growing hydroponic forage crops use one-quarter of the concentration, i.e. 1.25 cc of solution A, 0.5 cc of Solution B and 1.25 of C per liter of water), and begin watering one day after 50 % of the seeds planted in the tray have germinated.

Afterwards, as you gain more experience, you can reduce the concentrations, but always maintaining the same proportion of 5:2.5 between the major and minor elements. Never exceed the recommended dose, as this could damage the plants.

VOLUME OF NUTRIENT SOLUTION PER SQUARE METER

Using these prepared concentrations apply between **2 and 3.5 liters of nutrient solution for every square meter of crops,** according to each particular case.

The lowest volume of nutrient solution is used when the plants are small and in cool or cold climates; the largest when the plants are preparing to bloom or are forming their usable parts (roots, bulbs, tubers), or in hot climates.

If you notice that the substrate dries out a lot during the day, either due to very high temperatures, or windy conditions in the growing area or because the substrate lacks good moisture retention capacity, apply an additional quantity of water, but without nutrients. This extra moisture is essential, because if the substrate dries out the plant will no longer absorb the nutrients it contains.

You will gradually learn more about variations related to the concentration of the solution, the amount to be applied and other details associated with good nutrition as you acquire more experience and skill in crop management, but always in consultation with technicians or other trained people.

Commercial solutions

Commercial formulas generally come pre-prepared, so you only need to take out the required dose per liter, mix it and apply it with water to the substrate.

Nutrients for hydroponics should not be confused with foliar (leaf) fertilizers. These are a complement, not a substitute for nutrition through the roots. For example, tomato crops may benefit from a foliar fertilizer based on calcium nitrate, if you are using a general formula.

Remember that the nutrient solution contains all the elements required by plants for normal development and is absorbed by the roots, whereas the foliar fertilizer is only a complement to fertilize the leaves. Foliar fertilizers are absorbed through the leaves and not through the roots. They are manufactured with very pure salts so that they can be easily absorbed by the leaves, and are therefore quite costly.

The agricultural markets in each country generally offer a complete range of products to feed hydroponic crops. When purchasing one of these products always ask the salesperson for information about the dose, method, season and frequency of application.

It is important to make sure that all commercial formulas contain the 13 nutrients that plants need for healthy growth and production, as the substrates do not contain nutritional elements. Whatever is not provided by the nutrient solution will not reach the plant, thereby causing nutritional deficiencies that will affect the quantity and quality of the yields.

In some countries commercial presentations are available in granulated form and are mixed with solid substrate. These products, which are more costly, are applied just once to the substrate; for the next three months, it is only necessary to add water, as the product gradually releases the nutrients it contains. Some slow-release products are not recommended for edible plants and their use is restricted to ornamentals. It is very important to follow the manufacturers´ technical recommendations, which usually appear on the outer label of the container.

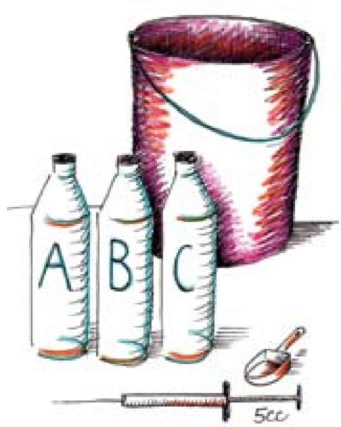
Cleaning and Maintenance

Hydroponic crops should be kept free of dust and plant debris to prevent diseases and to discourage insects.

Hydroponic crops are affected by rain, temperature, solar radiation, wind, relative humidity, pests and diseases. Some of these factors can be controlled under certain conditions, for example, by working in greenhouses. Although many vegetables are resistant to some of these factors, we must always remain vigilant in order to take timely decisions and minimize the damage to the plant. Methods to control some of the main pests and diseases that affect vegetables are discussed in another chapter of this book.

Procedure for preparing the nutrient solution

- *Weigh separately all ingredients of the formula selected.*
- *Label three empty 2-liter plastic soft drink bottles A, B and C.*
- *Pour ½ liter of water into each bottle and then add the previously weighed ingredients. Never mix the ingredients together without adding water.*
- *Add the nutrients of the formula to each bottle.*
- *Slowly add more water until there are 2 liters in bottles A and C, and 1 liter in bottle B.*
- *Shake until all the powder is dissolved.*



Solution A 2 liters
Solution B 1 liter
Solution C 2 liters

Pest control system

Garlic extract

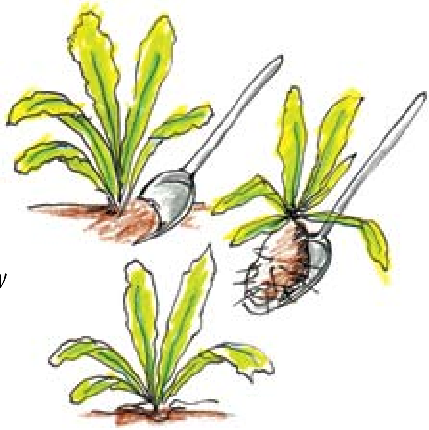
Step 1. *Peel and crush the cloves of several heads of garlic (30 cloves) into a soft paste.*

Step 2: *Put the paste into a glass or plastic container and add enough boiling water to cover it completely.*

Step 3: *Keep the container sealed for five days. It is now ready for use.*

Step 4: *Add three to four tablespoons (30 cc) of this mixture for every ½ liter of water, and apply to the plants using an atomizer or spray bottle.*

Transplanting



Using a garden trowel, gently remove the plantlet from the substrate. Holding the plantlet by the stalk, transplant it to the soil. Build up a small mound of earth around the plant and add the nutritive solution.

Weeding and hilling. *If a residue forms on the seed bed due to constant watering, break up the compacted substrate and build up a mound of substrate around the base of the plant to hold it firmly in place.*

Chapter V

Germination, preparation, planting and management of seedbeds or nurseries

Seedbeds or nurseries are simply small spaces where we provide optimal conditions to guarantee the germination of the seeds and the initial growth of the seedlings.

Special care should be taken when sowing seeds to prevent problems during their development. Not all seeds need to be sown in a seedbed; many can be planted directly. Table 11 shows the crops that require a seedbed.

Direct planting

Several species need to be planted directly in their final site. Some of these species do not withstand transplanting, while others develop very vigorously from the beginning and do not require special care during their early days.

Among the species that adapt well to direct planting are: peas, cilantro, beans, strawberries, melon, watermelon, radishes and carrots.

Seedbed planting

Species that have very small seeds and therefore produce weak seedlings in the early days of life should first be planted in nursery or seedbed. Some of the species that should first be sown in seedbeds and then transplanted are: basil, celery, broccoli, onion, cauliflower, lettuce, bell peppers, cabbage and tomato.

Direct or nursery planting

A few crops, such as turnips and beetroot, adapt easily to both systems - in other words, they can be planted directly or in seedbeds.

Seeds

The seeds used in hydroponics are the same as those used in traditional agriculture, although in developed countries some species have been especially adapted for hydroponics.

When purchasing seeds make sure that they are produced and distributed by reputable firms that specialize in seeds - the advantages of the hydroponic system should not be squandered by using any type of seed. Buying small packets of seeds at supermarkets or other non-specialist stores does not guarantee good quality seeds. Many such packets do not have an expiry date and remain on the supermarket shelves for a long time. In addition, we do not know how the packet was handled (was it exposed to the sun, did it get damp?).

Seeds are generally inexpensive, with the exception of hybrid varieties[17] such as tomato, which can cost up to US$ 0.75 each, thereby increasing production costs. However, these varieties are more vigorous and produce higher yields. All these aspects should be considered when buying seeds.

In recent years, there has been a lot of talk about **transgenic seeds** and a major debate has developed around this subject between those in favor and those against.

Transgenic seeds are genetically modified and their basic characteristics are altered to make them resistant to certain pests and diseases, thereby increasing yields. However, they also have a number of disadvantages such as the fact that since they are more resistant, they contaminate and eliminate local varieties. The seeds produced by these plants are sterile, due to the application of so-called "Terminator" technology, which completely sterilizes the progeny of the genetically improved seed. This means that farmers do not have the option of buying the improved seed once and then planting their progeny, but must buy new seeds for each harvest, thereby becoming dependent not only on the seed but also on the associated **production technology**.

Although it has not yet been proven that genetically modified crops affect those who consume them, there is a very strong opposition movement against GMOs, especially in Europe, where mandatory labeling of transgenic products has been introduced to give consumers the option of deciding whether or not to buy them. Nowadays nearly 95% of soy crops are transgenic.

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17 A hybrid seed is an improved seed obtained by crossing two varieties of the same species. It produces up to 35% more than local varieties, is more resistant to diseases and insects, and responds well to improved practices and to the use of fertilizers. However, sometimes these are not readily available, and cannot be re-planted since they revert to the original characteristics of the parent seeds, are more expensive and little known.

We therefore recommend using good quality seeds (not transgenic ones) since our output and the quality of our crops will depend in great measure on the quality of the seed that we use.

GERMINATION TEST

Before planting your seedbed or nursery, we recommend doing a simple germination test to assess the quality of the seeds. This procedure will also save time and money.

For the germination test place a given number of seeds, for example 50, on moist paper towels or paper napkins. Cover the seeds with more paper towel and keep them moist in a place well away from the sun. Check the seeds every day, counting those that have germinated and noting down the results in a table as shown below. The number of days for observing the germination process will be determined by the average for each species.

If, after four weeks have passed (depending on the average number of days required for germination), some plants do not appear, it means that some seeds did not germinate and are most likely dead, either because they were old or due to poor care, such as exposure to the sunlight or lack of watering, for example.

Table 10 Germination Test

Number of days	Seeds germinated
6	1
7	4
8	8
9	10
10	11
11	5
12	1
TOTAL	40

Germination test: $\frac{\text{\# seeds germinated X 100}}{\text{\# seeds planted}}$

40/50 X 100 = 80% regular germination
Optimum: 85-100%, Regular: 60-84%, Poor: less than 59%

What is a seedbed or nursery?

A nursery or seedbed is a small space where our seeds will germinate and take their first steps toward becoming healthy, strong seedlings. The quality of the seed and the care given at this stage will be a crucial factor in determining the yield and quality of production.

Substrates

It is even more important to take care with the preparation of substrates for a nursery than when preparing it for the beds or sleeves. Never use soil in a seedbed if you plan to transplant the seedlings to hydroponic substrates.

Characteristics

The substrate should be light, soft, clean and uniform, with fine particles.

- **Size of the particles:** Very large or heavy particles must be removed, as these prevent the development of the newly sprouted seedlings. Ideally, particles should measure less than 3 mm and this is achieved by using a 3 mm sieve.
- **Moisture:** This should be closely controlled as neither the seeds nor the newly sprouted plants will develop unless they have sufficient moisture.

Some of the most commonly used materials for germination are charcoal mixed with coconut fiber, pumice stone, fine sand with rice husk. The ratio to be used when mixing two materials is 1:1. Imported peat moss, which is based on sphagnum moss, is a very good inert material, but more expensive than local mixtures such as fine sand combined with rice husk.

The substrates used in nurseries for hydroponic plants should never contain soil, as this might contaminate our crops with bacteria, fungi and other germs that may be present.

Containers for nurseries: You can use wooden boxes measuring a maximum of 40 x 40 cm, with a depth of 5 to 8 cm, or recycled plastic materials or plastic trays with cells (spaces to place the seed) specially designed for nurseries.

Making a seedbed or nursery

- **Step 1: Select a suitable container.** You can use wooden boxes, fruit boxes or purpose-made plastic trays with cells (holes).
- **Step 2: Clean the container and select a growing medium or substrate.** Thoroughly clean the chosen container before proceeding to fill it with the prepared substrate, which should be moist. Place some of the substrate in each space or cell of the tray and gently tamp down to prevent air pockets. Moisten a little more before planting.
- **Step 3: Add the substrate.** The substrate must be moist before it is placed in the container. If a box is being used, the substrate should be spread evenly so that when the furrows (rows where the seeds are placed) are made and the seeds are planted, some will not be deeper than others, as this might prevent their uniform germination and initial growth.

There should be no air in the substrate; it is therefore advisable to lightly press down the substrate to guarantee that no air pockets remain. The cells of the tray or recipient should be filled leaving sufficient space so that we can later cover the seed with more substrate.

Furrows can be made with the help of a small wooden stick or pencil. Their depth and spacing will depend on the size of the seed and on the size of the plants in their early stages.

- **Step 4: Plant the seeds.** After carrying out the germination test we proceed to sow the seeds. The seeds are placed one by one in the cells of the tray or in the furrow of the box at the distances recommended for each species. Then, using our finger tips we gently cover the seeds with substrate, expelling any excess air that may have remained around the seed and maximizing its contact with the substrate.
- **Step 5:** Moisten the substrate. The seed is waiting for the necessary stimulus to germinate. This happens when it absorbs sufficient water for the outer case or coat to open and then the embryo inside begins its development. For this reason, seeds that have a very hard outer case should be soaked in water for a few hours in order to soften it and accelerate germination. The procedure varies for each crop. For example, cilantro seeds may be left in water overnight and planted the following day. This simple task will accelerate their germination by 1 to 3 days.

  Water the seeds once again and then cover the seedbed with newspaper in normal weather, and with paper plus a black plastic sheet during cooler weather, to accelerate the germination slightly.

- **Step 6: Find a safe shady place.** Once the seedbed is ready we place it in an area away from direct sunlight and out of reach of children and pets. An ideal place in our house is under the kitchen sink or in a cupboard.
- **Step 7: Daily watering.** After planting, water the seedbed, sprinkling the water on top of the newspaper once a day (in very hot places water more frequently, in very cold places monitor the humidity level). The substrate should be kept moist, not waterlogged.
- **Step 8: Remove the newspaper.** When the first seed has germinated, remove the newspaper[18] and leave the seedbed exposed to the light. However, it must also be protected from excess sunlight and cold and this is done by using a simple cover during the hours when there is greatest risk of dehydration or cold.
- **Step 9: Apply the nutrient solution.** From the moment the first seed germinates, it should be watered daily with the nutrient solution at half its concentration. There should be sufficient air since the germinating seed - the embryo - breathes. For this reason, it is important to take care with the amount of water given.
- **Step 10: Weeding and Hilling.** If a "crust" should form on the surface of the seedbed due to continuous watering, use a small stick or pencil to break up the tight substrate. In other words, **weed** and then gather up the substrate around the base of the plant to anchor the roots more firmly and improve their development. This task is called **hilling**. Both tasks, weeding and hilling, are also necessary when the plants are transplanted to their final place.

18 If our nursery is not uncovered on time (when the first leaflets appear) the seedlings will become stretched-out looking for the light and will be of no use for transplantation. Plants whose stalks have the appearance of white threads will never be strong and will not turn into healthy adult plants

- **Step 11: Hardening off the seedlings.** Some growers carry out this task to help strengthen the plant tissues and prepare seedlings for the more difficult conditions that they will encounter once they have been transplanted. Hardening off involves reducing the amount of water applied to the seedlings 5 days prior to transplanting and giving them greater exposure to the light. It is important to ensure that the process does not damage the plant. The other tasks – hilling-up, weeding and inspection of plants – should be continued.
- **Step 12: Transplanting to the final place.** Never hold the plant by the leaves, always by the stem. Use a small trowel, wooden spatula or large spoon, insert it into the substrate and remove the plant gently. Hold it by the stem and place it in its final position. Hill-up the substrate and add the nutrient solution.

In general, seedlings are ready to be transplanted when they have five true leaves[19] or when they reach a height of 10 cm, in the case of lettuce, celery, mustard, Swiss chard, endive and celery, or a height of 8 to 10 cm in the case of tomatoes, cabbage and cauliflower and 15 cm in the case of onions. Transplanting should preferably be done in the afternoon/evening or on cloudy days, to avoid excess heat.

To plan our crops effectively, we need to know the time (in days) between planting and germination; germination and transplanting; and transplanting and harvest. This is shown in Table N°11 below.

19 The first two leaflets or seed leaves known as “false leaves” are really the dicotyledons. These fall off and then the true leaves appear.

Table 11 Vegetables and aromatic plants

Vegetables/ Plants per square meter	Type of Planting	N° seeds per gr.	N° grams per $10m^2$	Depth of planting in cm Distance between plants in cm	Germination average **(days)	Germination to transplantation (days) dap	Germination to harvest (days)	Production per square meter
Swiss chard(21)	Nursery	60	10	1,5/15 -20	7-14	18-25	70-75 c.p.	25-30 units
Garlic* (115)	Direct/ Nursery	Cloves	….	2/8	8	….	115-135	4-6 kg
Basil	Nursery	700	4,5	0,5/20-25	5-8	25-30	60	3-4 kg
Celery (21)	Nursery	2500	0.5	c.s./15-20	8-15	40-55	60-75	30-40 units of 0.5 kg
Peas (67)	Direct	3		3/5-10	5	….	60-70	4-7 kg
Squash (4)	Direct	3	10	3/100	10		90-110	25-30 units
Eggplant (5)	Nursery	350	0.5	1/45-55	7-10	20-25	60-80	10-12 kg
Watercress	Direct	450	10	1,5/10-15	2-7	….	50 perennial	
Broccoli (11)	Nursery	300	4	1/25-35	3-8	20-25	60-75	20-25 units
Onion (67)	Nursery	250	10	1/12-15	6-10	35-40	75-80	6-8 kg
Spring Onion (101)	Nursery	250	8	1/10-15	6-12	35-40	50-60	15 bunch/ month
Chives (54)	Nursery	300	8	0,5/10-15	6-12	35-40	60-65	25 bunches
Sweet Pepper	Nursery	150	0.5	1/30-45	7-15	30-35	80-85 c.p.	15 a 20 unit/plant
Cauliflower (9)	Nursery	300	0.3	1/30-40	3-8	20-25	75-85	
Cilantro(162)	Direct	90	5,5	2/15-20	10-15	….	50-55	25 bunches
Spinach (28)	Direct	100	40	2/17	8	15-20	75	
Strawberry * (13)	Direct			Stolons or shoots/25	15	….	90	

Lettuce (28 fl., 23 sust.)	Nursery	1000	0.5	0,5/15-20	3-5	15- 18 floating 20-25 substrate	45 floating 55 substrate	20-25 20-25
Melon (11)	Direct	40	0.5	3/60-100	6-8	….	85-100	15-50 units
Mint	Direct	12.000	0.5	1/30	15	….	50	
White radish	Nursery/ Direct	350	0.5	1,5/10-15	6	15-20	60-75	50-100 roots
Oregano	Direct	12.000	0.5	0,5/20-30	15	….	90-180	4 plants
Potato	Direct	….	….	8-10/15-30	7-10	….	90-120	15-25 kg
Cucumber (11)	Direct	35	0.5	3/75-90	3-5	12-14	45-60	8-10 kg
Parsley (45)	Nursery	650	10	1/10-15	10-18	40-45	55-70 c.p	15 bunches
Leek (81)	Nursery	250	0.5-2	1,5/10-15	6-12	35-40	60-65	15 bunches /month/ 10-12 kg
Turnip (200)	Direct	120	50	1/5	3-5	…..	25-35	20 bunches/ 5-8 kg
Beetroot (54)	Nursery/ Direct	50	10	2/5-10	6-10	30-35	60-65	30 units/ 15-20kg
Cabbage (11)	Nursery	300	1.5	1/30-35	3-8	25-30	60-70	20 a 25 units/ 10-12 kg
Red cabbage or Radicchio	Nursery	300	1.5	1/30	7	25-30	75-90	20 units/10 kg
Arugula	Nursery			1/20			60	
Watermelon (5)	Direct	6	8 s.	4/100	10	….	90-100	20-30 units
Tomato (8)	Nursery	350	0.5	1/60	7-12	25-28	80-85	10-15 kg/plant
Thyme (28)	Nursery	6000	1	0.5/17	12	30-35	75 c.p.	
Green beans	Direct		6,5	3/20-25	3-6	…..	45-50	4-5 kg
Carrot (100)	Direct	1000	10	1,5/3-6	10-15	…..	65-85	25-30 kg
Marrow (4)	Nursery		40 s	3-5/70-100	6-8	12-14	45-50	70-100 units

*Vegetative or asexual reproduction
** Depends on the variety, the climate and the management

DAP Days After Planting
s. seed

a.s almost superficial
c.h. Continuous harvest every 2 to 3 weeks

Table prepared by Laura Pérez E. for the “Centro Nacional de Jardinería Corazón Verde"

Chapter VI

Pest control and management

It is important to learn how to recognize the organisms that generally live in crops. Not all of these are harmful to plants - on the contrary, some are beneficial because they feed on pests. Among the most common beneficial insects we have **ladybirds** (**lady bugs**), which feed on flea-beetles, mealy bugs, fungi, thrips and moth eggs; **lacewings**, which feed on flea-beetles, mealy bugs, whitefly and moth eggs; and tiny parasitic **wasps** such as ***Encarsia Formosa***, which are widely used to control whitefly in greenhouses. None of these beneficial insects feeds on plants.

There are also beneficial fungi such as ***Beauveria bassiana*** known to have as many as 400 host plants.

Pests are living organisms that cause damage to crops, and their presence in large numbers affects production. Pests may be insects, bacteria, fungi or viruses. To prevent attack by pests, it is first of all essential to feed the plants well. Secondly, we must take precautions in regards to their nutrition, the environment in which they develop, the cultural practices appropriate to each crop, daily inspection of the plants' health, temperature and changes of climate, the cleaning of tools, people's contact with the plants, the quality of water used, and the disinfection of the substrate.

Main diseases

The main diseases that affect hydroponic plants are caused by contamination of the substrate, poor management and the lack of preventive measures.

- **Fungi**: Phytium, Cercospora, Alternaria, Rhysoctonia, Septoria, Leveilula.
- **Bacteria**: Erwinia

The best way to combat diseases is through good crop management practices, proper watering, and sterilization/disinfection of trays, substrates and recipients.

Insects

The most common pests are insects, especially **whitefly, leaf miners, flea-beetles or aphids.**

The latter are particularly destructive and appear mainly during hot, dry weather, although they also cause problems in cooler weather.

Types:

- **Chewing insects** (grasshoppers, crickets, caterpillars)
- **Borers** (stem-mining flies, leaf miners).
- **Sucking insects** (aphids and whitefly)

Leafminers

These are flies with white spots on the thorax. Their larvae form small trails on the leaves provoking a decrease in photosynthesis.

Whitefly

These are very small white flies that suck the sap from the plant, causing yellowing (chlorosis) and transmitting diseases and viruses.

Aphids

These vary in color (green, brown) and particularly enjoy the tender young parts of plants. They produce a sticky secretion that attracts ants and develops a black fungus known as **sooty mold** or **fumagina**.

Thrips

These are sucking insects that attack the entire plant, causing deformities. They occur mainly in tomato, sweet pepper and onion.

Insect control methods

- **Daily inspections**

No crop is immune from diseases or pests. Crops should be inspected on a daily basis, preferably in the morning and late evening, as not all insects have the same habits. The idea is to detect the presence of adult insects (looking for a place to lay their eggs) and locate their eggs, or to find grubs, caterpillars or flea-beetles in their early stages of development and destroy them.

These efforts will undoubtedly reduce the number of insects present, since the constant and gradual elimination of insects at different stages of development will help break their life cycle. Our regular visits and careful inspection of the plants and their new leaves and shoots, will also create a "hostile environment" for the pests, which will hopefully look for another place to live, feed and breed.

When rice husk is used as a substrate, either alone or in a mixture, birds often cause damage to plants when they come in search of rice grains. They may also eat small seedlings and the seeds of lettuce, radish, peas or other vegetables that we have planted.

- **Use good seed**, disinfect as prevention.
- Keep plants **well nourished**.
- Plant **various crops** of different families. Do not plant crops of the same family together, as this attracts insects. For example, when planting cauliflower do not plant cabbage, radish, watercress, turnip or broccoli because these belong to the same family, i.e. Crucifers.
- Plant crops at the **correct distance** from each other.
- Avoid **excess moisture or dryness.**
- **Remove damaged leaves.**
- Keep a **record of pests**.
- **Companion planting**. Examples of companion planting include: lettuce with cabbage or onion; celery with tomato, leek or garlic; beetroot with cauliflower, lettuce.
- **Companion planting with aromatic plants.** Plant aromatic plants that act as a barrier or repellent to other insects. For example, garlic, rue, oregano, mint, eucalyptus. Plant tomato with basil, and rosemary with cauliflower or carrot.
- **Place plastic flags** of an intense yellow color impregnated or sprayed with oil (the cheapest) near crops. The color yellow attracts many species of insects that get stuck when they alight on the plastic sheet, e.g. **leafminers** and **whitefly**. **Blue** plastic flags impregnated with oil attract other types of insects such as thrips.
- Place **light traps** on top of or inside a container with water and burnt oil for one or two hours each night.
- Use **bait or traps** to control slugs and snails. An effective method is placing a little amount of beer inside the cap of a jar. These pests are attracted by the odor.
- Encourage **beneficial insects** such as ladybirds, wasps and others.
- Use different kinds of **scarecrows**.

- Apply **biological insecticides** such as Neem oil.
- Apply **repellents based on aromatic herbs and other products.**

A good complement to these techniques - which on their own will reduce possible damage by pests – is a weekly application of extracts or juices from the following plants: garlic, hot chili peppers, eucalyptus, oregano, nettles, rue, tobacco and others.

Most of these substances act as repellents due to their strong odors and discourage adult insects from laying their eggs. Any larvae that are already on the crop will descend from the foliage to the substrate where they cannot cause any damage. It is best to alternate the different extracts each week.

Examples:

Recipe 1

Soap, vinegar and garlic.
Crush one head of garlic in 125 ml. of water and in another container place 250 ml of hot water and 30 g of soap. Dilute the mixture in 16 liters of water. This insecticide is used to control ***red spider, whitefly, and larvae.***

Recipe 2

Garlic extract
Step 1: *Peel and crush the cloves of several heads of garlic (30 cloves) until a soft paste is formed.*
Step 2: *Put the paste into a glass or plastic container and add enough boiling water to cover it.*
Step 3: *Keep the container well sealed for five days. After this, it is ready for use.*
Step 4: *Add three to four spoonfuls (30 cc) for every half liter of water and then spray over the crops with an atomizer.*

Recipe 3

Basil extract

Apply 5% juice extract (five grams of plant extract per 100 milliliters of water). Basil leaves or Ocimum basilicum (Lamiaceae or Labiatae), repel flea-beetles and red spider.

Recipe 4

Bar soap or detergent (soap powder)

*A **concentrated solution of blue bar soap** (of the kind used for washing clothes) or detergent can also be used. Dissolve one bar or 2 tablespoons of soap or detergent in one liter of hot water. Allow it to cool down and when it reaches room temperature apply it with an atomizer as a spray. Leave the solution on for ten minutes and rinse with clean water. This is very effective for controlling flea-beetles, mealy bugs and small larvae.*

Chapter VII

Costs and profits

Benefits

Hydroponics is a highly productive activity that requires constancy and dedication, plus a little time every day. It is something in which the whole family can participate, from children to elderly people, depending on the amount of time they have available.

Hydroponics produces **social** and **economic benefits**.

The social benefits are mainly related to improvements in the family life quality because they eat better, thus improving their health and they can obtain some income by selling the products of their hydroponic orchard. At the same time, there is often a noticeable change of attitude among families and communities: they stop being passive onlookers and become **actively engaged** in their own development process.

Even children assume positive attitudes through these productive activities: they learn to value agricultural work, begin to develop an environmental awareness and acquire a better understanding of subjects such as chemistry, mathematics, ecology, physics and others.

Financial Profits

We can expect to obtain economic benefits or profits by continuously and systematically growing crops in areas larger than **30 square meters**, providing financial reward for the costs incurred and the work done.

Various tests have shown that the total cost of production can be covered with the sale of just 13 lettuces. If we grow 30 lettuces in a square meter, it means that with less than half the lettuces, we have covered all our expenses and the rest is profit that can be reinvested in a new harvest.

If we wish to sell our products, we must prepare a **plan** to ensure that we have crops all year round.

To determine the financial yields it is first necessary to establish the production costs and the sale price. The difference between the two is the **profit**. Production costs are of two types:

- **Installation or start-up costs**
- **Variable operating costs** to cover each production cycle.

Installation costs include the cost of setting up the beds or sleeves, (depending on which system we are using) and materials such as plastic, substrate, hoses, tools etc. - in other words, the investment needed to start up. We must also include the equipment required for the preparation, storage and application of nutrients and natural insecticides, such as containers, buckets, atomizers and others. These costs will be amortized over several harvests.

The operating costs include water, nutrients, oil, and pest control products (garlic, mint etc.), a notebook for technical and accounting purposes and the labor costs.

Example: Production costs for 1 square meter of lettuces in a bed.

Table 12 Fixed Costs			
Inputs	**Total cost /m² (US$)**	**Amortization Number of Harvests (US$)**	**Assessed Value per m²**
Wooden Container	5.00	20	0.25
Black plastic	0.50	5	0.10
Rock/charcoal	6.00	10	0.60
Tools	1.00	10	0.10
Equipment	1.50	10	0.15
Labor	2.00	10	0.20
Subtotal			1.40
Contingencies			0.50
Total fixed costs m²			1.90

Table 13 Variable Costs		
Inputs	**Total Cost/ m² (US$)**	**Assessed value per m²/ harvest (US$)**
30 Nursery seedlings 35 days	0.75	0.75
Nutrient solution	0.65	0.65
Natural insecticides	0.05	0.05
Labor	1.75	1.75
Subtotal		3.20
Contingencies 5%		0.15
Total variable costs		3.35
Total cost (fixed costs + variable costs)		5.25

In areas where it is very cold or very hot the cost of protecting the crops should also be added. This increases the cost per square meter by approximately two dollars.

Income

Estimating the loss of two out of every 30 lettuces, we obtain 28 units, whose sale price is estimated at US$ 0.30. This produces a gross income of US$ 8.4 / m².

Profit = Total income – Total cost

Profit = 8.40 – 5.25 = US$ 3.15 per m²/lettuce harvested.

$$\text{P.I. (Profitability Index)} = \frac{\text{Profit x 100}}{\text{Total Investment}}$$

$$\text{P.I.} = \frac{3.15 \times 100}{5.25} = \mathbf{60.95\%}$$

The fixed costs can be reduced if wooden pallets[20] are used or second-hand wooden crates and cheaper substrates.

We can obtain the profitability of other crops using the Table above.

20 Used for loading and stowing cargo in sea ports or airports or to pack large household appliances in warehouses. A bed can be made from two dismantled wooden crates.

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Biography of the Author

Laura Perez Echeverria did her undergraduate work in the Agricultural Economics Department of the School of Agronomy of the University of Costa Rica. In 1988, she earned a Master's Degree in Business Administration from the National University of San Diego, California. In the same year, she earned a Master's Degree in Economic Policy, with emphasis on the external sector, from the National University in Heredia, Costa Rica. She has participated in numerous international events and courses on hydroponics and gardening. In 2007, she organized the First International Congress on Hydroponics, in Costa Rica. She is the Director of the "Centro Nacional de Jardineria Corazon Verde" (Green Heart National Gardening Center), a school and working nursery where more than 20 courses are taught, including three on different levels of hydroponics. She is the author of numerous books and scientific articles.

She has taught at the National University in Heredia for 30 years. She has also worked with governmental, private, and nongovernmental institutions, specializing in the management, planning, implementation, monitoring, systematization and evaluation of development projects. She has taught training courses and facilitated other training exercises, exchanges of experiences and systematization processes.

She was a member of the staff of the UNDP and IICA for 10 years. She has been an international consultant in the area of economic and social development from a gender perspective (poverty, public policy, projects, child labor). She has 25 years experience in managing and leading projects and work teams and has been an advisor to small-scale enterprises. She has worked in all the countries of Central America, Panama, Mexico, Brazil, Venezuela, Peru, the Dominican Republic and Uruguay. She also worked with the following international organizations: UNESCO, IDB, IFAD, UNIFEM, Canadian Cooperation, ALOP, FOLADE, HIVOS, IIHR, PROMICRO, WORLD BANK, ILO and IPEC.

Contents

Long years in the field of education have taught us that simplicity and complexity can go hand in hand. In some books, beginners are introduced to techniques that turn out to be highly complicated and difficult to apply. Laura Perez shows us that it is possible to explain ***hydroponics*** *clearly, while maintaining the interest of the reader. Everything in her book has been tested and proven to be effective. All the guess work has been removed.*

The author's primary goal is to teach, and to encourage readers to try their hand at hydroponics.

IICA

Inter-American Institute for Cooperation on Agriculture

Corazón Verde

Centro Nacional de Jardinería