Food and Agriculture Organization of the United Nations

Technical Fact Sheet

Hydroponics systems for smallholder vegetable production

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Introduction

Hydroponics is a modern agricultural technique for growing plants without soil. All the minerals the plants need are provided through a liquid nutrient solution, while the physical support for roots and stems is ensured by a variety of inert substrates and trellis systems. The main reasons to consider hydroponics include the reduced risk of soil-borne pests and diseases, an increased potential for higher quality harvests, and increased optimization of resources such as water, fertilizers, farm space and time/labour. However, it is a technique that requires farmers to be rigorous and efficient on a daily basis, as the slightest error, distraction or accident will compromise the expected harvest.

Farmers typically choose a hydroponics system based on the type of crop, the availability and cost of materials and inputs, and the environmental conditions.

Common elements of hydroponics systems

All hydroponics systems are characterized by the following essential elements:

- The **nutrient solution**, which is the mixture of water and soluble fertilizers.
- The **tank for the nutrient solution**, which is usually made of a plastic material. Its volume is determined by the type of crop, the number of plants, and the type of hydroponics system selected.
- The **source of light.** The presence and quality of the light must be ensured, both in terms of the minimum period of availability and the intensity necessary for the given crop.
- Waterproof **electrical conductivity (EC) and pH** meters, to monitor the quality of the nutrient solution and guide corrective actions. The cheapest and most practical meters are hand-held, while more expensive kits can provide automated readings, along with the option to automate the addition of nutrients when needed.

Figure 1. Lettuce growing in a greenhouse with the hydroponics technique

Figure 2. Hydroponics can eliminate soil-borne diseases and facilitate high-end, quality harvests

Depending on the climate and technology adopted, the following additional elements are also typically included as part of a hydroponics system:

- **Air pumps**, to maintain the oxygen levels in the nutrient solution.
- **Ultraviolet (UV) lamps**, to eliminate the potential hazard of pests and diseases in the nutrient solution, and to control algae development.
- **Timer switch modules**, to program routine operations such as irrigation, artificial light, and cooling systems.

Figure 3. Hand handled water proof pH and EC probes

Basic requirements

- **Water quality:** Saline water cannot be used for hydroponics, because the addition of soluble fertilizers for the nutrient solution will increase its salinity beyond what plants can tolerate. The water must also be free of organic residuals, pests and diseases – including human-borne diseases – and dispersed particles that may clog the system.
- **Environmental conditions:** Protected agriculture settings, such as greenhouses, offer a suitable scenario for hydroponics investments, as they allow for the control of both the climate and the temperature of the nutrient solution (which should remain below 25 °C). Outdoor hydroponics is possible, especially during the dry season, but presents greater difficulties in controlling for the negative effect of strong winds, intense light, pests and diseases, as well as the quality of the nutrient solution in the case of rain.
- **Planning:** Cost and availability considerations for all inputs, equipment and services must be carefully assessed and calculated beforehand, as any issues or interruptions (such as running out of stock) at any time can result in the loss of the harvest.

Compliance on all these conditions and requirements is essential at all times; if they cannot be met, operating a hydroponics production system is not advisable.

Figure 4. Tomatoes grown using the "Dutch bucket" system, a closed or recirculating system using substrate

Initial choices

Open vs closed systems

Depending on how the nutrient solution is managed, hydroponics systems fall into two broad categories: non-recirculating systems (open), and recirculating systems (closed).

- In non-recirculating or open systems, the nutrient solution is used only once to fertigate the plants; as soon as the waste nutrient solution flows out of the substrate, it is channelled away for disposal.
- In recirculating or closed systems, the drainage is collected and used again several times until it is completely consumed by the plants. Closed systems therefore have the advantage of superior efficiency and economy of water and fertilizers.

Factory vs locally made systems

In the case of experiments, trials and small operations (i.e. less than 100 m²), a locally made system can usually be considered a suitable option. For larger areas however, it is typically more convenient to seek out commercial and factory-grade materials. This will reduce costs while ensuring the quality, consistency and standardization of manufactured parts and form factors, which in turn will help with any future scaling of the investment and uniformity of production.

Figure 5. Comparing nutrient film technique (NFT) modules that are factory made (above) and locally made (below)

Types of hydroponics systems

Most set-ups can be grouped into three broad categories:

Substrate culture

These are closed systems in which drainage is collected from substrate holders (such as pots, bags, or boxes) through a system of pipes or gutters, which then convey the nutrient solution back to the main tank. They are particularly indicated for tall and long-cycle crops such as tomatoes, sweet peppers, cucumbers, strawberries, etc. The “Dutch bucket” system is a popular example of such systems.

Nutrient film technique (NFT)

These are closed or recirculating systems in which the nutrient solution flows constantly (or repeatedly at short intervals) through the bottom of special gutters into which the plants are placed such that their root extremities are submerged. Using net cups to contain the germination substrate and plants will facilitate operations such as seedling transport and plant harvesting. NFT systems are very popular for leafy vegetables (such as lettuce and herbs) in both large- and small-scale operations, due to their simplicity and flexibility – including in terms of the following advantages:

- Low-pressure water is needed at only one end of the canals, as gravity ensures drainage down a gentle slope (between 1 and 3 percent).
- The gutters are cheap, light, and easy to clean and move around as needed.
- The length of the gutters can vary based on the space available (they are usually sized between 2 and 6 m in length).

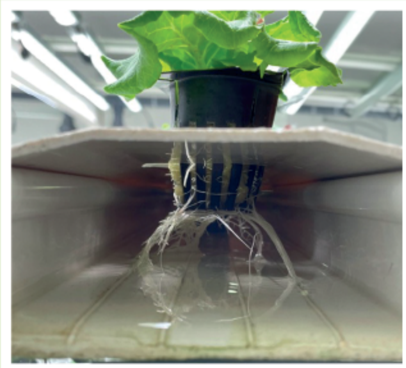

Figure 6. In NFT systems, only a thin layer of nutrient solution flows along the bottom of the gutter

A potential challenge with NFT systems lies in managing the temperature of the thin layer of nutrient solution, due to the exposure of the gutters to sunlight. If the solution temperature consistently exceeds 24 °C, actions should be taken. These can range from ensuring the tank for the nutrient solution is always in the shade, through to the addition of a chiller unit to reduce the temperature.

Deep water culture (DWC)

In this system, plants grow on the surface of containers made of concrete, wood or plastic, filled to a depth of 50–70 cm with nutrient solution. Commonly used to produce leafy greens, DWC systems are simple to build and easy to use, and with the addition of air pumps (to ensure that roots are oxygenated), there is no need to recirculate the nutrient solution. However, even at medium-scale operations (i.e. above 100 m²), the cost of construction for so many containers may become prohibitive, and farmers may want to consider NFT systems instead, which offer a more lightweight and flexible option. An evolution of DWC with shallower pools (i.e. between 10 and 20 cm) pools – known as the raft system – is also popular for large-scale operations, due to its relatively low initial cost. This system uses floating rafts, typically made of Styrofoam or other lightweight materials, with holes cut into the surface to allow the plants' roots to dangle in the water. Net pots can be added for further stability and to prevent the plants from falling through the holes.

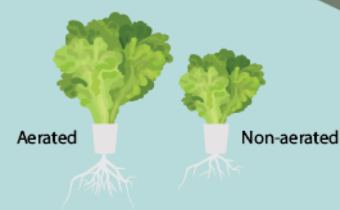

Figure 7. Comparison of aerated and not aerated plants using raft system

Figure 8. Air pumps and porous stones are common tools for restoring the oxygen content of the nutrient solution

Figure 9. Lettuce grown with the raft system

Nutrient solution management

In recirculating systems, the nutrient solution is continuously modified as plants withdraw nutrients – including water and oxygen – and release root exudates and other metabolic waste. For this reason, all nutrients need to be regularly reintegrated, while wastes should be eliminated with occasional flushes (typically once a week). The following basic indicators serve to monitor the quality of the nutrient solution and guide corrective action:

- **Electrical conductivity (EC):** Soluble fertilizers and/or fresh water must be reintroduced to maintain the EC at the target level. Using an EC probe is the best way to monitor and adjust nutrients level correctly.
- **Reaction (pH):** A slightly acidic nutrient solution (i.e. a pH around 6.5) facilitates the roots' active processes for nutrient uptake. In general, pH will vary based on the physiological activity of the roots, and will usually increase. Attention should be paid however, if instead the acidity tends to decrease, as this could signal intense bacterial or fermentation activity, which should be addressed.
- **Oxygen (mg/l):** The roots need oxygen to ensure all physiological activities. Each crop has different requirements and different levels of tolerance to the lack of oxygen. For example, tomatoes will show signs of toxicity at values below 7 mg/l, while lettuce can stand lower levels, such as 4 mg/l. It is easy to reintegrate oxygen through the use of physical mixing processes or air pumps. It should be noted that oxygen solubility in water decreases at higher temperatures. This is another reason why it is recommended that the temperature of the nutrient solution be kept around or below 25 °C; otherwise the oxygen level will drop too far.

	pH	EC
Water source	5–7	< 0.65
Nutrient solution for seedlings	5.5–6.5	< 0.85
Nutrient solution for green leaf y vegetables	5.5–6.5	1–1.4
Nutrient solution for fruits and vegetables (e.g. tomatoes)	5.5–6.5	2–2.7

Table 1. Recommended values of acidity (pH) and nutrients concentration (EC) for different group of crops

Nursery management

The seedlings should be produced in an inert substrate in the way that best fits the selected soilless system. For example, lettuce seedlings are produced in filtered pots, so that they can later be placed in the NFT or raft system with ease. Seedlings for taller crops such as tomatoes or cucumbers are usually grown in plastic trays containing coco peat, which will facilitate their move to the final pots containing the substrate. Hundreds of seedlings can be produced in small trays that are regularly flooded with the nutrient solution and drained. The most common germination substrate for hydroponics is coconut peat.

Production management

Lettuce in NFT or raft systems: From seed germination to seedling development (i.e. 15–20 days), the plants remain in the germination trays, occupying minimal space and requiring little fertilizer (the EC should remain below 0.8). Only after this period should they be moved to the NFT gutters or trays, for the following 30–35 days of growth and until they are ready for harvesting. In this way, harvests may be planned or targeted for every 30–35 days, ensuring that every harvested plant is replaced by a new seedling. For optimized harvest rates, new batches of seedlings should be produced at the same rate as planned harvests (for example every 30–35 days). A common strategy used by farmers is to run several batches of plants that are delayed by a fixed number of days, in order to have regular harvests (for example, every day or every week).

Basil in NFT or raft systems: Four to six seeds of basil can be grown in the same pot of substrate, for a nursery period of 15–20 days. Once they are moved to the gutters or rafts, they can be harvested as entire plants after around 30 days. Basil can also be sold as cuttings, and up to three harvests every 15 days can be obtained before replacing the plant with a new seedling. In this case, the stems must be cut above the shoot level, or the plant will not regrow.

Tomatoes, peppers, cucumbers and cucurbits in general: All efforts must be made to keep the plants in production as long as the season allows, and all good horticultural practices such as trellising, pruning, and lowering the crops will contribute to maximizing production.

More generally, operations such as checking and adjusting the quality of the nutrient solution must be carried out at least twice a day, every day, as part of an effective and rigorous routine.

Light management

The quantity of light must be assessed and monitored for optimal productivity:

- The intensity indicates the energy carried by the light. Higher levels of photosynthetic activity rate and plant development are associated with higher levels of light intensity. However, beyond a certain amount of intensity, which is called the saturation point, there will be no further advantage, and excessive luminosity will instead lead to light stress, causing a decrease in plant performance and cellular damage. Light intensity is measured in lux (lx), and a lux meter is an affordable and portable tool to measure it.

- The period indicates the number of hours of daily exposure that plants have to a source of light. Longer periods of daily exposure will result in increased plant production and faster development. Lettuce needs a minimum period of 6 hours for growth, and can receive up to 14–16 hours with beneficial effects on productivity, whereas the recommended period for tomatoes is 8–14 hours. At the same time however, all vegetable crops must also undergo a minimum period of 6–8 hours of darkness per day, known as the dark period, to allow the necessary physiological processes to occur during this time. Continuous exposure to light causes leaf wounds, as well as reductions in plant development and harvests.

To maximize productivity, efforts should be made to expose the plants to the correct intensity of light for the longest possible period each day. Ranges of light intensity and periods are specific for each crop (see Table 2).

Growing plants	Minimum necessary light intensity (lx)	Light saturation point (lx)	Recommended period (min-max h)
Tomato, watermelon	3 000	70 000	Vegetative phase: 8-16 Flowering/fruting phase:8-12
Cucumber	2 000	55 000	All phases: 8-16
Lettuce	1 500	25 000	Vegetative phases: 6-16

Table 2. Recommended ranges of intensity and period for managing light quantity and quality for selected crops.

Light quantity must be measured at the top of the plant canopy at different moments of the day, and corrective actions can be applied as needed, for example by cleaning the plastic covers of the greenhouse or more efficiently managing the shade nets (i.e. by retracting them in the early morning and at the end of the day when there is less light, and releasing them during the middle hours of the day when the light intensity and heat may otherwise exceed the tolerance threshold).

Artificial lighting

Grow lights or lamps can support farmers in meeting or increasing their daily targets for light periods and intensity, and are available in the following scenarios:

- as supplemental light, typically in greenhouses, to extend the light period during short winter days; and
- as total provisioning for the light period and intensity, for indoor environments where there is no exposure to sun light.

Specific grow lights are commercially available for growing crops; they are designed and built to provide the intensity that plants need and to last a long time in agricultural environments. A popular choice in the past was the high-pressure sodium (HPS) grow light, for its capacity to emit light at an elevated intensity, but it is being replaced by light-emitting diode (LED) technology, which – although more expensive – is about 80 percent more energy-efficient, and can provide a refined light spectrum that is optimized for plant production. In addition, LED lamps emit far less heat than HPS lamps, and therefore have less impact on the management of environmental conditions (e.g. ventilation, cooling, etc.). Before considering artificial lighting however, investment running costs must be carefully considered. For example, LED technology uses between 100 and 120 watt-hours per square metre (Wh/m²) to provide the light needed to grow lettuce, and around 400 Wh/m² for tomatoes. These values should be multiplied by the area of cultivation to obtain an indication of energy consumption and electric load.

Maintenance

After every harvest, the materials that will be reused – such as the filtered pots, trays, rafts and gutters – must be cleaned to avoid the spread of diseases. Chlorine solutions may be used to wash these materials, as long as they are rinsed afterward in fresh, clean water and left to dry for at least two days to ensure all the chlorine evaporates (as it would be toxic to the new plants). As an alternative, hot steam may be used for the same purpose.

Keeping extra quantities of growing material (e.g. pots, gutters, etc.) on hand to use as buffer stock is a good practice, as it allows cleaning operations to be conducted without affecting the planned production rate.

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