Manual for seed potato production using Aeroponics

Ten years of experience in Colombia, Ecuador and Peru
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Editors:
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Aeroponics is a technique for producing potato minitubers (corresponding to the pre-basic seed category) in formal seed systems, that is, systems in which the State regulates the production and distribution of certified seed. As such, it is a technology that calls for certain conditions to be in place in terms of institution, infrastructure and human resources, which means that it is appropriate only for highly specialized seed producers.

In a wider context, aeroponics is part of an integrated proposal of the International Potato Center (CIP, by its acronym in Spanish) and its partners to manage seed potato degeneration. Degeneration is the reduction in yield or quality due to the accumulation of pathogens or pests in planting material through successive cycles of vegetative propagation. It is a core problem that has led to large sums being invested for the production and distribution of certified seed all over the world.

The predominant model at present promotes seed degeneration management almost exclusively through the use of certified seed, usually produced by the public sector, especially in the initial categories such as pre-basic seed.

The new strategy for managing degeneration also includes the use of certified seed, but with greater participation of the private sector. It focuses much more on the use of varieties resistant to the pathogens that cause degeneration, and on training farmers in ways to manage degeneration so that they can produce their own seed for a longer time without a reduction in their crop yields.

Aeroponics can form a part of this new strategy, since it is a technology that facilitates the production of large quantities of high quality minitubers at a low cost. This in turn allows producers to reduce the number of field multiplications of the initial categories of seed, which means that the certified seed obtained at the end of these multiplication cycles will be healthier and available in a shorter period of time and at a lower cost.

CIP and its partners—the Colombian Agricultural Research Corporation (CORPOICA, by its acronym in Spanish) and the National Institute of Agricultural and Livestock Research (INIAP, by its acronym in Spanish) of Ecuador—hope that this manual will be a valuable tool for all those who want to implement aeroponics.
In a general sense, this manual is a second edition of the Manual de Producción de Semilla de Papa de Calidad usando Aeroponía [Manual on Quality Seed Potato Production using Aeroponics]. The most significant differences from the first edition are that, on one hand, this version was prepared by a team of researchers who have worked with this technology and, on the other hand, it includes lessons from more than ten years of work with aeroponics in various countries of Latin America and Africa. Also, this time the information is more detailed, so that it can serve as a more effective guide for those who are interested in the topic.

The purpose of this manual is:

- To describe and analyze the conditions required for implementing aeroponics, its advantages and disadvantages as an option for potato minituber production; and to provide a profile of the potential users of this technology.

- To explain how aeroponics can be implemented based on our experience, in order to prevent possible failures.

- To share experiences from the use of aeroponics in Colombia, Ecuador, Peru and several African countries.

This manual is designed specifically for the technicians responsible for implementing aeroponics. It also offers useful information for individuals who need to make a decision whether or not to adopt this technology. It contains detailed descriptions that can be used by greenhouse operators who will be applying aeroponics in practice.

In terms of the geographic area for which the subject is addressed, this manual can be used as a reference for Colombia, Ecuador, Peru and other Latin American countries. Its use in tropical countries of Africa and Asia is also possible, provided that it is adapted to the local situation.

Each chapter was written by one or more authors who are experts in the subjects covered and subsequently revised by the editors. The manual also underwent pedagogical mediation to facilitate reading and comprehension and to make it more interesting and useful.

1 Otazú, 2010.
CHAPTER 1

BASIC CONCEPTS OF SEED POTATO PRODUCTION

Jorge Andrade-Piedra
WHAT DO WE PLAN TO DO IN THIS CHAPTER?

- Explain the importance of quality seed.
- Determine the factors that define seed potato quality.
- Explain what seed degeneration is and how to manage it.
- Explain what aeroponics is: its uses, how it works, its origin and why it has been adapted to the conditions of developing countries.
THE IMPORTANCE OF QUALITY SEED

How important is the seed in potato production?

Seed —or planting material, since potato is propagated using underground stems or tubers—is important for several reasons:

- It determines, to a large extent, the yield of a potato crop;
- It is the vehicle whereby improved varieties and native varieties are disseminated and maintained;
- It is a strategic tool for conserving a country’s food sovereignty and genetic diversity.

When a potato tuber can be considered high quality seed?

When it meets these conditions:

- **Healthy:** pests and diseases are below a predefined threshold.
- **Adequate physiological status:** it has sufficient maturity, humidity and energy to sprout and permit the growth of a vigorous plant.
- **Adequate physical status:** it does not have inert materials such as stones or soil, nor does it show physical damage, such as cuts.
- **Genetic purity:** it is of the required variety and isn’t mixed with seed potatoes of other varieties.

Quality seed potato.
In potato and other vegetatively propagated crops—that is, crops that are multiplied asexually using plant parts such as a root, stem, etc.—the principal factors affecting seed quality are health and physiological status. The physical purity and genetic purity are not quite as important, since the size of the tubers makes it relatively easy to remove any inert materials or seed potatoes of other varieties.

**SEED DEGENERATION**

**What is seed degeneration?**

Seed degeneration is the reduction of yield or quality caused by an accumulation of pathogens and pests in planting material due to successive cycles of vegetative propagation.

One of the factors that can explain low yield in potato crops is poor seed health, which is largely due to the phenomenon known as degeneration.

In fact, if degeneration did not occur, farmers could produce their own seed indefinitely, since it would always remain healthy.

On a global level, viruses are the most important cause of degeneration, but in the high-altitude areas of the Andes, other pathogens play a major role in degeneration, such as Rhizoctonia solani, Spongospora subteranea, Streptomyces scabies, Verticillium dahliae, Fusarium sp., Thecaphora solani, Phytophthora erythroseptica,Ralstonia solanacearum, Pectobacterium spp., Meloidogyne spp., Globodera spp., and Nacobbus aberrans, among others.

In Ecuador and Peru, farmers use an interesting expression to describe seed degeneration: they say “the seed is tired.”

**How is seed degeneration managed?**

There are three tactics for managing seed degeneration:

1. Use of varieties resistant to the pathogens that cause degeneration
2. On-farm seed management (positive selection, negative selection, etc.)
3. Purchasing healthy (certified) seed produced off-farm

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2 Thomas-Sharma et al., 2015.
4 Thomas-Sharma et al., 2015.

MANUAL FOR SEED POTATO PRODUCTION USING AEROPONICS
In most temperate countries, seed potato degeneration is primarily managed by purchasing healthy seed produced off-farm, usually certified seed. This seed is produced and distributed through what is known as a formal seed system regulated by the State.

In contrast, the use of certified seed potatoes is low in many countries in the tropics, (for example, 2% in Colombia; 7.6% in Ecuador; 0.5% in Peru). Nearly all potato farmers in the tropical zone save part of their harvest to use as seed in the next planting cycle. They may do this for several years and sometimes also obtain seed from other farmers or traders. This system is known as an informal seed system, because it isn’t regulated by the State.

However, the management of seed produced in the informal system is frequently poor. Typically, the tubers selected for use as seed are those that cannot be sold at market or eaten at home, because they are small and damaged by pests or diseases. They are also often stored in dark places or unsuitable containers, which causes their sprouts to be weak and uneven. When farmers plant such tubers, they get weak plants that emerge unevenly, affecting crop yield.

Towards an efficient management of seed degeneration

The dominant paradigm at present calls for seed degeneration to be managed almost entirely by purchasing certified seed. However, in the majority of tropical countries where vegetatively propagated crops such as the potato are produced by smallholder farmers, the use of certified seed remains low, even though significant investments in formal seed systems have been made over the years.

For smallholder farmers in countries in the tropical zone, the new strategy that CIP and its partners propose for managing seed degeneration in vegetatively propagated crops includes the integration of the three tactics mentioned above, in the following order of importance:

• **Use of resistant varieties**, which implies evaluating existing varieties, and breeding and disseminating new resistant varieties.

• **On-farm seed management**, which implies recognizing and improving the informal seed systems, by strengthening the capabilities of the farmers so that they will be able to keep their seeds healthy for a longer time using techniques such as positive selection and adequate seed storage.

• **Purchase of healthy seed produced off-farm**, which implies improving the formal seed systems (for example, through greater participation of the private sector) to produce and distribute healthy, certified seed of the right varieties and quantities, in a timely manner and at an appropriate price.

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6 Gildemacher et al., 2011; Omego et al., 2011; Schulte-Geldermann et al., 2012; Montesdeoca et al., 2012.
Everythi ng covered so far is useful for describing the characteristics of aeroponics. We already know: the importance of seed for potato farming; what defines high quality seed; what degeneration is; and what the new strategy for managing seed degeneration in developing countries proposes.

In this context, aeroponics is a technology derived from hydroponics, that is, it does not need soil. It has two main uses:

- as a rapid seed multiplication technology for commercial purposes,
- as a research tool.

As a commercial, rapid seed multiplication technology, aeroponics helps to manage seed potato degeneration by strengthening formal seed systems, that is, the systems that produce and distribute certified seed.

Important!

Using aeroponics, we can produce a large quantity of potato minitubers corresponding to the pre-basic seed category at a lower cost, larger volume and with higher health levels.

When large quantities of minitubers of high quality and low cost are available, it is possible to reduce the number of multiplications in the field, which means that the certified seed obtained at the end of these multiplication cycles will be healthier and available in a shorter time period and at a lower cost.

Important!

Aeroponics is an option for complementing and eventually replacing other technologies for the production of minitubers, such as the conventional method or semi-hydroponics.

As a research tool, aeroponics makes it possible to modify the environment in which the roots grow and to study the effect of these modifications on several processes. It facilitates the study of their morphology, the development of pathogens, the effect of concentrations of gases and temperatures, the effect of nutrients, etc. For example, aeroponics has been used to study the growth of the rice root.

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7 See Annex 1.
9 Truong and Beunard, 1978.
It also appears to be an option for space travel, since it allows edible plants to grow with a small amount of water\textsuperscript{10}.

Another interesting aspect of aeroponics is that it is a very attractive technology. In this sense, it can be used as a tool for communication and lobbying to attract resources for seed potato production and research.

It is common to receive dozens of visitors at sites where aeroponics is applied, but unfortunately many of them assume that it is the solution for all seed potato problems in developing countries. That assumption is wrong and should be discussed and corrected based on the concepts of seed degeneration management.

Nevertheless, aeroponics catches the attention of both public and private donors who could allocate funds for research and development in the area of seed potato production. For example, it is one of the core elements of projects that the United States Agency for International Development (USAID) supports in Africa\textsuperscript{11}, that the Ministry of Agriculture, Livestock, Aquaculture and Fisheries (MAGAP by its acronym in Spanish) supports in Ecuador, and Colombia’s National Seed Potato Plan, which the Colombian Agricultural Research Corporation (CORPOICA) and Colombian Agricultural Institute (ICA, by its acronym in Spanish) started in 2014 with funding from the Ministry of Agriculture and Rural Development (MADR, by its acronym in Spanish).

\textsuperscript{10} NASA, 2006.
\textsuperscript{11} CIP, 2011.
How does aeroponics work?

In aeroponics\(^{12}\), the roots of the plants grow suspended in the air, inside closed boxes (also called modules), and are fed a nutrient solution that is nebulized—turned into a mist—and then recirculated.

There are no solid substrates to sustain the roots, and this makes it possible to improve aeration and reduce both the environmental impact and production costs.

The boxes are located in greenhouses or net houses that can have systems to control temperature, humidity and light.

In the case of the potato, the initial planting material consists of in vitro plantlets or rooted cuttings. These plants develop, and after being given proper management that includes pest and disease controls, lowering of stems (equivalent to hilling up), pruning and training, they are harvested on various occasions (three to twelve times, depending on the variety) with yields that can be in excess of 3,000 minitubers per m\(^2\), per crop cycle.

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\(^{12}\) From the Greek αερο (aero) = air and πόνο (ponos) = work.
The minitubers range in weight from 0.5 to 30 g, although it is occasionally possible to obtain minitubers of up to 60 g. Depending on the conditions, the largest minitubers are planted directly in the field while the smaller ones are planted in germinating trays and later transplanted to the field, pots or hydroponic systems that use solid substrates.

**Where did aeroponics originate?**

Apparently, the earliest reports of aeroponics date back to 1922 with apples[13] and 1942 with pineapples[14] in the USA. In the 1990s, several experiments to adapt the technology for potato cultivation were carried out in South Korea[15]. Since then, there have been many studies on the use of aeroponics for potato production[16].

**Why is aeroponics being used in developing countries?**

Mainly because of the need to make certified seed potato more widely available, since it increases production of minitubers, reduces production costs, and results in healthier plants.

This is the story:

In 2005, CIP, in alliance with national partners, began the adaptation and dissemination of aeroponics in tropical countries in the Andes, Sub-Saharan Africa, and Southeast Asia. In the Andes, CIP’s main partners have been CORPOICA in Colombia and INIAP in Ecuador.

The objective of CIP and its partners was to adapt aeroponics to situations of limited resources, taking advantage of the environmental conditions of the tropical zone to reduce production costs. Whereas in countries in temperate zones, aeroponic greenhouses require expensive systems to control temperature and light, in tropical countries, greenhouses usually don’t need additional light and, if they are at high altitude (> 2,600 meters above sea level), the temperature can be controlled with simple systems such as windows, curtains, etc. Also, in various high-lying tropical zones, continuous year-round production is feasible, which further lowers production costs.

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[16] For example: Ritter et al., 2001; Christie and Nichols, 2004; Sun and Yang., 2004; Nichols, 2005; Farán and Mingo-Castel, 2006; Chang et al., 2008; Lakkireddy et al., 2012; Chipanthenga et al., 2012, Mateus-Rodriguez et al., 2013.
In a few words...

Seed is very important in potato production, because it:

- defines crop yield to a large extent;
- makes it possible to conserve and disseminate varieties; and
- helps to sustain a country’s food sovereignty and biodiversity.

Seed quality is determined by health, physiological and physical status, and genetic purity. In a crop like the potato, seed health and physiological status are the most important characteristics.

Poor health in seed potatoes is largely the result of seed degeneration. Degeneration is the reduction of yield or quality caused by an accumulation of pathogens and pests in planting material due to successive cycles of vegetative propagation.

Seed degeneration is managed using three tactics:

- Use of resistant varieties;
- Seed management; and
- Purchase of certified seed.

The dominant paradigm is for seed degeneration to be managed almost entirely through the purchase of certified seed. A new strategy involves the integration of the three tactics mentioned above, placing more importance on the use of resistant varieties and seed management, in particular with smallholder farmers.

Aeroponics is a cultivation technology that uses nutrient solutions instead of soil. The roots of the plants grow suspended in the air, inside closed boxes, and are fed with a nutrient-rich mist from a solution that can be recirculated.

As a rapid seed multiplication technique, aeroponics makes it possible to produce large amounts of healthier potato minitubers at lower cost and in larger volumes. It thus contributes to managing seed degeneration by ensuring greater and better production of certified seed.

As a research tool, aeroponics makes it possible to modify the environment in which the roots grow in order to study the effect of such modifications on different processes.

As a tool for communication and political advocacy, aeroponics can be used to attract funds for seed production and research.
CHAPTER 1: BASIC CONCEPTS OF SEED POTATO PRODUCTION
CHAPTER 2

ANALYSIS PRIOR TO THE COMMERCIAL IMPLEMENTATION OF AEROPONICS

Víctor Otazú
Jorge Andrade-Piedra
WHAT DO WE PLAN TO DO IN THIS CHAPTER?

- Review the main factors that should be taken into account before implementing aeroponics for the commercial production of seed potato:
  - The minituber market and seed regulations.
  - Risks that can cause aeroponics to fail.
  - Technologies for producing minitubers that could replace or complement aeroponics.
  - A profile of the individuals or institutions that have the capacity to implement aeroponics.
**WHY IS AN ANALYSIS NEEDED BEFORE IMPLEMENTING AEROPONICS?**

Because even though aeroponics is a very promising technology for the commercial production of potato minitubers, it also implies risks. Attempts to implement haven’t always been successful because of factors such as: lack of a proper market study, deficient electricity service, polluted water, a climate that is too hot, etc.

The experience gained by CIP, CORPOICA and INIAP through the implementation of aeroponics over the past ten years, in more than 20 places, has provided useful information for identifying the main aspects that should be analyzed **before** using aeroponics for the commercial production of minitubers.

The analysis covers four areas:

- **The market**, to determine the demand for minitubers, and **seed regulations**, to determine the legal issues surrounding the sale of minitubers.

- **Risks involved**, to decide whether or not a specific place is suitable for the installation of an aeroponic facility, in order to avoid repeating past mistakes and to reduce current risks.

- **Technologies for minituber production that could replace or complement aeroponics.** This is particularly useful when the risk analysis shows that aeroponics cannot be used in a specific place and other technologies need to be found.

- **A profile of individuals or institutions that have the capacity to implement aeroponics.**

**MARKET STUDY AND SEED REGULATION ANALYSIS**

Before implementing aeroponics commercially, we need to ask and answer some questions:

- For what purpose do we want to produce minitubers?
- Is there a demand for potato minitubers?
- Can potato minitubers be sold?
These questions are very important. They are often neglected or asked too late, when the aeroponic system has already been built and the producer is faced with a lack of market or a legal vacuum preventing the sale of their minitubers. Both of these limitations can cause the whole aeroponic operation to collapse.

**Why do we want to produce minitubers?**

To obtain certified seed that can be used to replace farmers’ seed that has undergone degeneration.

However, it should be noted that the use of certified seed potatoes by small-scale farmers has been very low in developing countries, despite the great efforts that have been made to remedy this situation.

Therefore, before starting to implement aeroponics, it is very important to bear in mind that there are other options for managing seed degeneration that may be more efficient and effective, especially for small-scale farmers:

- The use of varieties resistant to the pathogens that cause seed degeneration (such as viruses, fungi, bacteria), which implies an arduous task of evaluation of existing varieties and of genetic improvement (breeding) to generate and distribute these varieties.

- On-farm seed management, consisting of simple tasks such as positive selection and good storage, which are within the reach of any producer of seed and commercial potatoes.

**Important!**

The production of minitubers by using aeroponics to produce certified seed is both complex and costly. Therefore, before starting implementation, we need to ask ourselves seriously whether or not it wouldn’t be better to use other methods to manage seed potato degeneration; for example, by planting resistant varieties —if available— and on-farm seed management.

**Is there a demand for potato minitubers?**

This information can be obtained through a market study, which is crucial for the success of aeroponics as a technology for producing potato minitubers commercially.

In practice, the minituber market in Colombia, Ecuador and Peru is very small, since the seed producers do not usually buy seed in the pre-basic category (minitubers), but rather seed in the categories of registered in Ecuador, and basic or registered in Peru and Colombia, to multiply them in the field and produce certified seed to be used by ware potato producers.
Individuals or companies interested in producing minitubers using aeroponics should develop the market for minitubers, or multiply them in the field until they obtain basic or registered seed (for sale to seed producers) or certified seed (for sale to ware potato producers). In this case, the market study should be for basic, registered or certified seed, and not for the minitubers.

Important!

Some important points to be considered in the market study are:

- possible buyers,
- geographic location of buyers,
- seed categories for which there is a demand,
- volumes demanded,
- potato varieties demanded,
- seasonality of the demand,
- required quality: health, physiological and physical status, genetic purity, size,
- price that the purchaser would be willing to pay for each category of seed (and for each size in the case of minitubers).

Specialized consultancy firms can be hired to do this study.

Is selling potato minitubers permitted?

An analysis of the seed potato regulations, specific to each country (Colombia\textsuperscript{17}, Ecuador\textsuperscript{18} and Peru\textsuperscript{19}), will indicate whether they may be sold.

In principle, if the interest is to produce minitubers within the formal system, that is, producing and selling seed under the official State regulations, the individuals or companies that wish to produce and sell potato minitubers using aeroponics need to register with the authorities responsible for monitoring seed production in their country.

\textsuperscript{17} ICA, 2003.
\textsuperscript{18} MAGAP, 2013.
\textsuperscript{19} INIA, 2009.
However, producing minitubers for commercial sale can be complicated by legal regulations:

- In Colombia, the Colombian Agricultural Institute (ICA) has regulations in place for the production and sale of seed potatoes covering the pre-basic category, the production of seeds in basic and registered categories in two field generations and the production of seeds in the certified category.

- In Ecuador, regulations for the production of seed do not include the pre-basic category (minitubers), which was adapted by INIAP as a special category for the production of seed potato internally. In that case, from the legal viewpoint, it is not possible to sell minitubers with State certification. What can be sold is the seed generated after multiplication in the field, be it basic, registered, or certified.

- In Peru, the regulations do include the marketing of pre-basic seed. However, the high price and small size of the minitubers are limiting factors for selling them. Seed producers are accustomed to planting tubers weighing 30 to 60 g in the field, and those tubers are usually not obtained using aeroponics.

**RISK ANALYSIS**

The Food and Agriculture Organization of the United Nations (FAO) published a guide\(^{20}\) that describes a methodology for identifying, measuring, managing, and communicating the biological risks that can be hazardous to human life or health. In this case, the risk is from biological organisms—or their products—that can cause diseases or damage either to human beings or the environment.

This FAO methodology for the analysis of biological risks was adapted by CIP to evaluate the risks that can cause a production technology like aeroponics to fail.

Before describing the methodology, it is important to understand that risk means: The possibility that something could happen with consequences that can cause damage.

In the case of aeroponics, risk can be regarded as: The possibility of having adverse effects on production.

\(^{20}\) Sensi et al., 2011.
To apply the risk analysis methodology to aeroponics in a specific area, we need to follow six steps:

1° Identify the most significant risk factors.
2° Qualify the impact of the risk factors using a scale.
3° Estimate the probability of occurrence of the risk factors using a scale.
4° Calculate the value of each risk factor.
5° Obtain the total risk value.
6° Compare the total risk value with predetermined values to obtain a recommendation.

**Step One.** Identify the most significant risk factors for the work area. According to CIP’s experience in Africa and the Andes region, the main factors in order of importance are:

- Power cuts or failures in the irrigation system.
- Unsuitable climate.
- Inadequate quality and/or quantity of water.
- Inadequate greenhouse.
- Low-quality planting material.
- Insufficiently trained staff.
- Inadequate logistics and administration.

Other factors could be included, depending on the local context, such as a lack of security, especially in remote areas, although this factor can be included under logistics and administration.
**Step Two.** Qualify the risk factors using a scale (1 to 5) to estimate the impact they could cause on the production system:

1 = Negligible  
2 = Not very significant  
3 = Moderately significant  
4 = Significant  
5 = Very significant

According to CIP’s experience, the impact values of the risk factors are as follows:

<table>
<thead>
<tr>
<th>Risk Factor</th>
<th>Impact</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power cuts or irrigation system failures</td>
<td>5</td>
<td>Very significant factor</td>
</tr>
<tr>
<td>Unsuitable climate</td>
<td>4</td>
<td>Significant factor</td>
</tr>
<tr>
<td>Inadequate quality/quantity of water</td>
<td>3</td>
<td>Moderately significant</td>
</tr>
<tr>
<td>Inadequate greenhouse</td>
<td>3</td>
<td>Moderately significant</td>
</tr>
<tr>
<td>Low-quality planting material</td>
<td>3</td>
<td>Moderately significant</td>
</tr>
<tr>
<td>Insufficiently trained staff</td>
<td>3</td>
<td>Moderately significant</td>
</tr>
<tr>
<td>Inadequate logistics and administration</td>
<td>3</td>
<td>Moderately significant</td>
</tr>
</tbody>
</table>

These values can be modified to reflect the conditions of each area, and based on the criteria of the people responsible for carrying out the analysis. For example, under certain conditions inadequate logistics and administration may be given an impact value of 5, that is, the same as the effect of power cuts.

**Step Three.** Estimate the probability of occurrence of each risk factor using a scale of 1 to 5

1 = Never  
2 = Seldom  
3 = Sometimes  
4 = Frequently  
5 = Always

The probability of occurrence varies according to the conditions in the place where the aeroponic system is constructed.
To give an example, we will take a hypothetical situation with the following values and their interpretation:

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Probability of occurrence</th>
<th>Interpretation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power cuts or irrigation system failures</td>
<td>3</td>
<td>Power cuts or irrigation system failures, sometimes.</td>
</tr>
<tr>
<td>Unsuitable climate</td>
<td>5</td>
<td>Unsuitable climate, always.</td>
</tr>
<tr>
<td>Inadequate quality/quantity of water</td>
<td>3</td>
<td>Inadequate quality/quantity of water, sometimes.</td>
</tr>
<tr>
<td>Inadequate greenhouse</td>
<td>2</td>
<td>Inadequate greenhouse, seldom.</td>
</tr>
<tr>
<td>Low-quality planting material</td>
<td>5</td>
<td>Low-quality planting material, always.</td>
</tr>
<tr>
<td>Insufficiently trained staff</td>
<td>2</td>
<td>Insufficiently trained staff, seldom.</td>
</tr>
<tr>
<td>Inadequate logistics and administration</td>
<td>1</td>
<td>Inadequate logistics and administration, never.</td>
</tr>
</tbody>
</table>

**Step Four.** Calculate the value of a risk factor by multiplying the impact by the probability of occurrence:

\[
\text{Risk} = \text{Impact} \times \text{Probability of occurrence}
\]

In the example, this would be:

<table>
<thead>
<tr>
<th>Risk factor</th>
<th>Impact</th>
<th>Probability of occurrence</th>
<th>Risk</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power cuts or irrigation system failures</td>
<td>5</td>
<td>3</td>
<td>15</td>
</tr>
<tr>
<td>Unsuitable climate</td>
<td>4</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Inadequate quality/quantity of water</td>
<td>3</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Inadequate greenhouse</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Low-quality planting material</td>
<td>3</td>
<td>5</td>
<td>15</td>
</tr>
<tr>
<td>Insufficiently trained staff</td>
<td>3</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Inadequate logistics and administration</td>
<td>3</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

**Total risk value** 74
Step Five. Add the values of each risk factor to obtain a total value that represents the risk of implementing aeroponics under certain conditions.

In the example, the total risk value is 74.

Step Six. Finally, compare the total risk value with the values of the following table, to obtain recommendations as to the feasibility—or lack thereof—of implementing aeroponics under the conditions in question:

<table>
<thead>
<tr>
<th>Total risk value</th>
<th>Recommendation</th>
</tr>
</thead>
<tbody>
<tr>
<td>24 to 33</td>
<td>Aeroponics can be implemented at no great risk.</td>
</tr>
<tr>
<td>34 to 43</td>
<td>Aeroponics can be implemented but with caution. Consider using a different seed multiplication technique.</td>
</tr>
<tr>
<td>44 to 120</td>
<td>It is most probable that aeroponics will fail, unless major modifications are made. Seriously consider using a different seed multiplication technique.</td>
</tr>
</tbody>
</table>

In the example, the total risk value is 74 and the recommendation would be to make major modifications before implementing aeroponics, because under the present conditions, there is a high risk of failure. A second option is to use a different seed multiplication technique, such as those described in Annex 1.

As shown in the above chart, the risk values for aeroponics range from 24 to 120. These values are explained as follows:

The value of 24 is obtained when the probability of occurrence of all the risk factors is 1 = never. This means that conditions are optimal for implementing aeroponics because:

There are never...

- power cuts or irrigation system failures,
- an unsuitable climate,
- inadequate water quantity and/or quality,
- inadequate greenhouse,
- low quality planting material,
- insufficiently trained staff,
- inadequate logistics and administration.
On the contrary, the value of 120 is obtained when the probability of occurrence of all the risk factors is 5 = always, that is, when the conditions are completely unsuitable for implementing aeroponics because:

There are always...

- power cuts or irrigation system failures,
- an unsuitable climate,
- inadequate water quantity and/or quality,
- inadequate greenhouse,
- low quality planting material,
- insufficiently trained staff,
- inadequate logistics and administration.

**RISK FACTORS: A DETAILED EXAMINATION**

**Power cuts or irrigation system failures**

This is the greatest risk factor in the process of aeroponic production, so the impact has been given the highest value: **5 = very significant**

We may have electricity on 29 of the 30 days in the month, but if the electricity is cut off during one afternoon on a very hot day or a pump is out of order for two or three hours, the aeroponic production will be severely affected.

**Important!**

.Failures in the electricity or irrigation system can lead to total loss in the aeroponic modules. This is particularly dangerous on holidays, when technical staff and greenhouse operators aren’t present to do emergency repairs.

There are some institutions that have reliable generator sets that switch on automatically when there is a power cut, as well as backup pumps and spare parts for other elements of the irrigation system, which are used to replace any damaged equipment immediately. If this is the case, we should give a value of **1 = never** to the probability of occurrence.

In most places where aeroponics has been implemented there are emergency generators, which are useful when the electricity is cut off for a few hours. However, if the power cut lasts a long time (several days), these generators are inadequate. In such cases, we should give high values to probability of occurrence (4 = frequently, or 5 = always).
A continuous supply of electricity and irrigation is so important that even if the rest of the risk factors have a probability of occurrence of \( 1 = \text{never} \), the system would still be doomed to failure if the electricity service is of low quality and there is no emergency generator set.

**Unsuitable climate**

This is another important factor, which has been given an impact value of \( 4 = \text{significant} \).

Although the limiting factor in terms of climate is nearly always the heat in tropical zones, in some places, as in the high-lying parts of the Andes and other mountainous areas, the limiting factor is the intense cold, at least in one season of the year.

Potatoes require a relatively cold climate, especially at night. An ideal climate for the plants to grow in a greenhouse is from **18 to 25°C during the day, and from 8 to 15°C during the night**.

If these conditions are present most of the year round, the probability of an unsuitable climate are minimal. If the conditions are present for only part of the year, a higher probability of occurrence number should be considered.

Indoor greenhouse temperatures of more than 30°C for more than four hours can cause problems in the plants’ root system, and create conditions favorable for the development of pathogens. Temperatures of below 4°C can also cause damage to the plants.

To have a more precise idea of the climate in any specific region, it is good to examine the meteorological information from the past ten years. For high tropical zones like the Andes, the indoor greenhouse temperature can be estimated before it is built by adding 5°C to the average ambient temperature.

The Andean area, with altitudes ranging from 2,600 to 3,500 m.a.s.l., has favorable climate conditions for implementing aeroponics. There is normally no need to cool or heat the greenhouses, as producers in Europe or North America do, with increased costs.

If greenhouses with temperature control are available, it is important to be aware that this implies a higher production cost.
Inadequate quality and/or quantity of water

In most places where aeroponics has been implemented, the water was of good quality, both chemically and microbiologically, and there was plenty available. Therefore, this factor was given an intermediate impact value: 3 = moderately significant.

It should be noted that:

- Water from deep wells has good microbiological quality, although it may have problems with high mineral content.
- Shallow wells tend to become polluted, especially where there is torrential rainfall.
- Spring water may look good, and it usually has optimal indicators when analyzed, but it can become contaminated during the rainy season.
- Water from the potable water system of an urban area can contain too much chlorine.
- Water from lakes and rivers is not safe, because it can be polluted with chemical or biological waste. The pathogen most frequently associated with contaminated water is Fusarium spp.

Important!

Contamination of the irrigation system by pathogens that affect the plant’s vascular or root system can easily cause a total loss of production.

If there is the slightest doubt regarding the microbiological quality of the water, it must be filtered before using it for aeroponics. Another option would be to boil it, but that can be costly. At CIP’s research center in Huancayo (Peru), both options were tried and filtering was found to be the best method.
Inadequate greenhouse

This factor is given an intermediate impact value: **3 = moderately significant**.

Some institutions already have experience using greenhouses for multiplying seed potato and they are familiar with the design that could best be adapted for aeroponics. On the other hand, there are places where greenhouses have never been used, and it is even difficult to find masons capable of building them. In these cases it is recommended to get the help of a technician or other person with sufficient experience in this kind of work.

A greenhouse with temperature control should be given the minimum value for probability of being inadequate: **1 = never**.

A greenhouse with a design adapted to the characteristics of the zone, with good orientation, and with shade nets for sunny days has a low probability of being inadequate: **2 = seldom**.

On the other hand, a greenhouse with a low roof, deficient orientation and inadequate shade nets should be given a high value (**4 = frequently or 5 = always**) for probability of inadequacy. The same goes for a greenhouse that is not well maintained, has a poorly implemented pre-chamber, and has holes that let vector insects in.
Low-quality planting material

This factor has been given an intermediate impact value: 3 = moderately significant

To multiply seed potato using aeroponics it is recommended to use in vitro plantlets that are vigorous, healthy, and with an optimal physiological status.

If you do not have in vitro plantlets, cuttings or minitubers from aeroponics or hydroponics may be used.

Institutions that have their own in vitro multiplication systems usually produce vigorous plantlets that grow well. On the other hand, institutions that depend on others to supply them, sometime receive yellowy and weak plants, as a result of days in transit, which can have a negative impact on production.

In aeroponics, the process of rooting in sand\footnote{See Chapter 6. Management: Acclimatization in sand boxes.} prior to transplanting plantlets is useful for selecting well-developed plants and eliminating those with poor growth; and in this case, we could assign a low probability of poor planting material (1 = never).

It is important to know the variety that will be planted, since there are varieties that produce well with aeroponics and varieties that don’t. If a variety is used for the first time, it will need to be assigned a high probability of being low quality (4 = frequently or 5 = always).

Important!

Minitubers from the field or from a conventional greenhouse production system (pots or seedbeds) should not be used because even though they look healthy, they may be infected with pathogens.

Insufficiently trained staff

This factor has been given an intermediate impact value: 3 = moderately significant

Aeroponics requires specialized training for the staff in charge. Only then will staff be able to deal with the difficulties that may arise during a production cycle, and correct any problems that may appear.
The training should be given to implementing technicians and to greenhouse operators. It is the technical staff and greenhouse operators who manage the aeroponic module on a daily basis, and they need to be well trained and motivated for this.

Training at least two people with stable employment histories is recommended. It often happens that when the implementing technician or the greenhouse operator is on vacation or sick leave, they are replaced by people who haven’t had sufficient training, which can result in serious problems.

**Important!**

Insufficiently trained staff can make mistakes in the doses of pesticides or fertilizers, which could cause total losses in the modules due to intoxication of the plants.

**Inadequate logistics and administration**

This risk factor has also been given an intermediate impact value: $3 = \text{moderately significant}$

It refers to the support needed for hiring staff, purchasing inputs, implementing marketing plans, etc., that is, all the things required for running an aeroponic operation. This support depends on who will implement the project: an individual, a private company, a governmental organization (GO), a non-governmental organization (NGO) or a mixed enterprise.

Each of these has a different logistical and administrative structure, which determines whether or not they will be able to respond to the demands of running an aeroponic system. Their response capacity is especially evident in emergencies, such as:

- the need to replace a damaged pump,
- the purchase of fuel for the emergency electric generator,
- the appearance of an unexpected pest that must be controlled immediately, etc.

**Important!**

A poor logistical and administrative capacity for responding to emergency situations can easily result in a total loss of aeroponic production.

22 See Chapter 3, Human Resources.
Private companies usually have efficient logistical and administrative systems in place, since their ability to stay in business depends on them. On the other hand, the logistical and administrative systems of some public institutions may be inefficient.

**Examples of risk analysis under real-life conditions**

What follows are the results of risk analyses in four experiences in Colombia, Ecuador and Peru:

<table>
<thead>
<tr>
<th>Country, institution, city</th>
<th>Peru</th>
<th>Ecuador</th>
<th>Colombia</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Risk factor</strong></td>
<td>CIP Huancayo</td>
<td>CIP Lima</td>
<td>CIP-INIAP Quito</td>
</tr>
<tr>
<td>Power cuts or irrigation system failures</td>
<td>$5^a \times 1^b = 5^c$</td>
<td>$5 \times 1 = 5$</td>
<td>$5 \times 1 = 5$</td>
</tr>
<tr>
<td>Unsuitable climate</td>
<td>$4 \times 1 = 4$</td>
<td>$4 \times 4 = 16$</td>
<td>$4 \times 1 = 4$</td>
</tr>
<tr>
<td>Inadequate water quality</td>
<td>$3 \times 3 = 9$</td>
<td>$3 \times 2 = 6$</td>
<td>$3 \times 3 = 9$</td>
</tr>
<tr>
<td>Inadequate greenhouse</td>
<td>$3 \times 1 = 3$</td>
<td>$3 \times 1 = 3$</td>
<td>$3 \times 3 = 9$</td>
</tr>
<tr>
<td>Low-quality planting material</td>
<td>$3 \times 1 = 3$</td>
<td>$3 \times 1 = 3$</td>
<td>$3 \times 1 = 3$</td>
</tr>
<tr>
<td>Insufficiently trained staff</td>
<td>$3 \times 1 = 3$</td>
<td>$3 \times 1 = 3$</td>
<td>$3 \times 1 = 3$</td>
</tr>
<tr>
<td>Insufficient logistics and administration</td>
<td>$3 \times 1 = 3$</td>
<td>$3 \times 1 = 3$</td>
<td>$3 \times 1 = 3$</td>
</tr>
</tbody>
</table>

**Total risk value***

- Peru: 30
- Ecuador: 39
- Colombia: 36
- CORPOICA Bogotá: 28

*Impact x* probability of occurrence = risk

- 24 to 33: Aeroponics may be implemented at no great risk.
- 34 to 43: Aeroponics may be implemented, but with caution. Consider the use of another seed multiplication technique.
- 44 to 120: Aeroponics is very likely to fail, unless major modifications are made.

We can draw interesting conclusions from this chart:

- The conditions at CIP in Huancayo are optimal for implementing aeroponics, except with regard to water quality: the water comes from a shallow well and in the rainy season it is prone to contamination. To solve this problem, the water was filtered before preparing the nutrient solution.
• The conditions at CIP in Lima and in Quito (in partnership with INIAP) are adequate for implementing aeroponics, but it needs to be done with caution because:

  o in Lima, the limiting factor is the climate, which is too hot between December and April. To deal with this situation, the aeroponic system is used starting in May,

  o in Quito, the main limiting factors are the microbiological quality of the water and a greenhouse that does not provide ideal conditions for aeroponics (very low roof and deficient ventilation). To address these problems, a microbiological filter was installed and several adaptations were made to improve ventilation in the greenhouse.

• The conditions at CORPOICA in the Savannah of Bogotá—Tibaitatá Research Center—are optimal for the technique, because:

  o the risk of power cuts has been reduced by installing automatic transfer generators;

  o the climate is cold and dry (the location is at 2,600 m.a.s.l.) with a low probability of frost; and

  o the water is potable, without the risk of contamination by pathogenic agents.

Risk analyses carried out by CIP for other aeroponic projects in the Andes and Africa enable us to draw more general conclusions:

• The total risk values in these experiences range between 30 and 57. The lowest values belong to experiences managed by private companies and the highest values correspond to those managed by public institutions. This would indicate that aeroponic projects are more likely to be successful if they are managed by private companies. However, this doesn’t mean that there aren’t any success stories in public institutions that implement aeroponics for commercial purposes, an example being the case of CORPOICA in Colombia.

• The risk analysis helps to identify critical factors that need to be managed by the individuals or institutions wishing to implement aeroponics.

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23 In one production cycle there was contamination by a root pathogen and it is suspected that the spores entered via the irrigation water.
24 Similar analyses are available of two more experiences in Peru (INIA in Huancayo and MINAG in Huancavelica), one experience in Ecuador (INAP in Sangolquí), and seven experiences in Africa: Burundi (Gisozi), Ethiopia (Holetta), Mozambique (Lichinga), Kenya (Kigoni, Kisima and Molo), and Tanzania (Mbeya). The risk analyses of these experiences are available and may be requested from Víctor Otaú: viota68@gmail.com
The main risk factor for aeroponics is a failure in the electrical system. In places with deficient electric power service, the implementation of aeroponics has been unsuccessful or has produced very small quantities of seed. The use of reliable, emergency generator sets is indispensable under such conditions, and this implies additional costs for their purchase and maintenance.

The risk factors associated with climate and water quality are difficult and expensive to modify, calling for a large investment in systems for greenhouse temperature control, as well as the use of filters, drilling of wells, etc. This underlines the need to make an appropriate site selection for implementing the greenhouse, in terms both of altitude (which largely defines temperature in the tropical zone), and of access to sources of good quality water with a reliable supply.

Other risk factors, such as planting material quality, staff capacity, logistics and administration can, in theory, be managed to ensure a successful aeroponic operation. However, under real-life conditions, institutional environments often prevent changes from being made in those areas.

ALTERNATIVE TECHNOLOGIES FOR MINITUBER PRODUCTION

The risk analysis enables us to identify situations where aeroponics has a high probability of failure. In such cases, it will be necessary to make modifications to overcome the risk factors, or identify other technologies for producing potato minitubers.

For example, if there is a deficient electrical service in the place where you intend to implement aeroponics, you need to buy an emergency generator set. If it isn't possible to do this, you will have to abandon the idea of implementing aeroponics and look for another technology suitable for the conditions of that place; that is, a method that doesn't require a constant supply of electricity.

Besides the technical criteria, economic criteria must also be considered when selecting the technology that is the best adapted to the local conditions. Indicators such as the yield also need to be taken into account.

Annex 1 gives a brief description of the advantages and disadvantages of aeroponics and of three alternative technologies for potato minituber production: conventional, semi-hydroponics, and the nutrient film technique.26
**Integrated system for minituber production**

One of the main disadvantages of aeroponics is the high risk of total loss. This can be caused by a power cut or by the failure of any element of the irrigation system; by contamination of the irrigation system with a pathogen; or by an error in the preparation of the nutrient solution or in the application of a pesticide, etc.

At the same time, a significant part of aeroponic production consists of minitubers weighing less than 5 g, which cannot be multiplied directly in the field, but can be multiplied in a greenhouse using other technologies.

In this regard, to prevent the high risk of total loss, and to make the best use of the smallest minitubers, we should evaluate whether it would be appropriate to use aeroponics as part of an integrated minituber production system, in which several technologies are combined. An example of this system is shown in Annex 2.

**PROFILE OF INDIVIDUALS OR INSTITUTIONS WITH THE CAPACITY TO IMPLEMENT AEROPONICS COMMERCIALLY**

According to the experiences of CIP, INIAP and CORPOICA, the profile required for individuals or institutions that wish to implement aeroponics commercially should combine business, economic, administrative and technical capacities, in that order of importance.

- **Business capacity.** From the business perspective, aeroponics is a technology to meet market requirements and to earn profits. In this context, the individual or institution that wishes to implement it must have an entrepreneurial vision, and the skills for drawing up a business plan and implementing it efficiently and effectively.

- **Economic capacity.** Aeroponics is one of the most costly and complex technologies for producing potato minitubers. Therefore, the person or institution wishing to implement it must have sufficient funds to construct or adapt a greenhouse and equip it, to hire technical and administrative staff and give them labor stability, and to undertake the production and marketing processes.

- **Administrative capacity.** Economic resources alone aren’t enough; these resources need to be available at the right time, because with aeroponics, there is a high risk of total loss, which could be due to power cuts, or the entry of pathogens into the irrigation system, or imbalances in the nutrient solution, which makes the ability to respond immediately to emergency situations of critical importance.
Before implementing aeroponics, it is important to undertake a rigorous evaluation to determine whether or not you have the necessary capacities. If you conclude that you are lacking in any of these capacities, you should consider using less expensive and complex technologies such as the conventional or semi-hydroponic methods.

**Technical capacity.** Aeroponics requires staff skilled in the construction and management of greenhouses and irrigation systems, plant nutrition, plant physiology, and pest and disease control. Individuals or institutions wishing to implement aeroponics must have sufficient support from specialists to cope with any technical challenges that may arise, especially at the initial stage of adaptation to local conditions.

Before implementing aeroponics, it is important to undertake a rigorous evaluation to determine whether or not you have the necessary capacities. If you conclude that you are lacking in any of these capacities, you should consider using less expensive and complex technologies such as the conventional or semi-hydroponic methods.

In the Andean region, aeroponics is still in the initial phase of dissemination, so it is premature to predict the type of institutions that will be able to implement it successfully. However, CIP’s experience in Africa shows that most successful cases occurred in the private sector, particularly at companies with experience in greenhouse production.

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27 See Chapter 3, Human Resources.
Before implementing aeroponics, we need to do an analysis of four areas:

- the seed market and seed regulations,
- the risks,
- minituber production technologies that could replace or complement aeroponics, and
- the profile of individuals or institutions with the capacity to implement aeroponics.

The market study and analysis of seed regulations help us define the purpose of producing minitubers, whether there is a demand for them and whether they can be sold.

The risk analysis enables us to define and qualify the risks that could lead to failure, using a numerical scale. Among these risks, the most significant ones are:

- power cuts or irrigation system failures,
- unsuitable climate,
- inadequate quality and/or quantity of water,
- inadequate greenhouse,
- low-quality planting material,
- insufficiently trained staff, and
- inadequate logistics and administration.

If the risk analysis identifies situations in which there is a high probability of failure in implementing aeroponics, it will be necessary to make modifications to overcome risk factors or identify alternative technologies for producing potato minitubers.

Alternative technologies include the conventional method, semi-hydroponics and the nutrient film technique (NFT). The combination of several of these technologies in an integrated minituber production system helps to reduce the risks while making use of the complementary aspects of the different techniques.

It is very important that you complete an evaluation to determine whether or not you have the necessary capacities before you start implementing aeroponics. That evaluation should cover business, economic, administrative and technical capacities.
CHAPTER 3

HUMAN RESOURCES

Jorge Andrade-Piedra
WHAT DO WE PLAN TO DO IN THIS CHAPTER?

- Describe the characteristics of the staff required for the implementation and management of aeroponic production.

- Share some experiences related to human resources.
WHAT STAFF IS NEEDED TO IMPLEMENT AEROPONICS?

For the installation and management of aeroponics, the following staff is required:

- Technical staff
- Greenhouse operators
- Specialized workers
- Administrative staff

Photo: Peter Kromann.
Two types of technical staff are needed:

- implementing technical staff and
- specialized technical staff

**Implementing technical staff**

These technical staff are responsible for leading the construction of the infrastructure, initial testing of the aeroponic system and production.

Their specific responsibilities are:

- To organize and supervise the design and construction of the aeroponic system (greenhouse, modules, irrigation system, etc.) with technicians and workers specialized in greenhouse construction and the installation of irrigation equipment.

- To design and implement an initial stage of testing and adaptation of aeroponics to local conditions (this process is also known as validation).

- To plan and supervise production:
  
  - Design and implement a marketing plan for the minitubers and/or the seed potatoes produced from them.
  
  - Design and implement a production plan, including plans for transplanting and harvesting, integrated pest and disease management and plant nutrition management.
  
  - Train and supervise the greenhouse operators in management, harvest, and post-harvest tasks.
  
  - Arrange the administrative support needed to monitor production costs, hire specialized workers, purchase equipment and inputs, implement emergency plans, etc.
  
  - Arrange help from specialized technicians (civil engineers, plant physiologists, phytopathologists, entomologists, etc.) as needed.
Candidate profile

- Should ideally be an agronomist or a professional from a linked discipline such as biology, environmental engineering, etc.; or have graduated from a technical agricultural institute.

- At least three years of experience in greenhouse management.

- Basic knowledge of: plant physiology and nutrition, identification and control of crop pests and diseases, electricity, and management of irrigation systems.

- Capacity to solve problems autonomously and pay attention to details; curious and willing to innovate; a strong sense of responsibility and commitment.

- Availability to work on holidays and overtime

Training period

The technical staff should obtain experience in managing aeroponics under a system of succession of functions. That is, he or she could start as a junior technical staff and, after a period of at least two crop cycles, assume the position of implementing technical staff.

Another option is for him or her to do an internship of a few weeks at a facility with a functioning aeroponic system. If that isn’t possible, this manual can facilitate the learning process; however, in the latter case, it is recommended that at least the first crop cycle be regarded as a training cycle.

In countries that produce flowers for export (for example, Colombia and Ecuador), it is possible to hire staff that has already been trained in managing greenhouse production and who can act as implementing technical staff for aeroponics. In most cases, these technical staff will not have experience in potato cultivation, but they can acquire the necessary knowledge by using this manual and consulting other specialized literature on potato production.
Specialized technical staff

These are experts in relevant areas of aeroponics implementation. Their function, in general terms, is to advise the implementing technical staff in their respective areas of expertise, whenever their services are required.

Their specific responsibilities are:

- To support the implementing technical staff in the design and construction of the greenhouse and the irrigation system, the marketing plan, and any other area for which their support is needed.

- To help with problem solving and whenever unexpected situations arise (such as toxicity or nutrient deficiency, a pest or disease, damage to the irrigation system, etc.). They need to be available and able to respond quickly, often in a period of one or two days, or even hours.

Candidate profile

- This type of technician should have been trained in at least one of the following areas: plant physiology, phytopathology, entomology, biotechnology, installation and management of irrigation equipment and greenhouses, electricity, electronics, civil engineering, economics, etc.

- Should have completed university or graduate-level studies and have at least three years of experience in his or her field.

GREENHOUSE OPERATORS

The greenhouse operators are key members of the aeroponics team because they are the ones who carry out the agricultural management tasks.

Their specific functions, under the supervision of the implementing technician, are:

- To keep the greenhouse and its surroundings clean.

- To carry out maintenance and emergency repairs on the infrastructure and equipment.

- To prepare the plants for the greenhouse environment prior to transplanting (conditioning).

- To transplant, lower stems (hill up), prune, and train the plants.
- To prepare pesticide mixtures and apply them following the standards for safe handling of pesticides.
- To prepare nutrient solutions.
- To harvest and select the minitubers.
- To change the plastic, micro sprinklers, etc., in the aeroponic modules

**Candidate profile**

- Secondary education, at least.
- Ability to do manual work meticulously.
- Sense of responsibility and commitment, attention to detail, curiosity, desire to learn.
- Availability to work on holidays on rotating shifts
SPECIALIZED WORKERS

To complete tasks that require specific trades: builders, plumbers, carpenters, electricians, etc.

Their roles are:

- To build the greenhouse and aeroponic modules.
- To install the irrigation system.
- To do repairs to the infrastructure and equipment, and to complete maintenance under the supervision of the specialized technicians.

Candidate profile

- Preferably with technical studies.
- At least three years of experience in their field.
- Commitment to completing their work on the scheduled dates.

ADMINISTRATIVE STAFF

Responsible for the administrative processes needed to facilitate the work of the technicians and operators.

Their specific responsibilities are:

- To provide support for the implementation of a marketing plan for the minitubers and/or seed potatoes produced from them.
- To keep the books and record the production costs.
- To facilitate the hiring of operators and technicians.
- To get quotes and purchase equipment and inputs such as fertilizers, pesticides, in vitro plantlets, etc.
- To pay salaries and overtime wages.
- To manage a quick-access fund for emergency situations.

Candidate profile

- Secondary or tertiary education.
- At least two years of experience in their field.
- Planning and problem-solving skills.
There can be no doubt that human resources are a key element for the success of aeroponic production. However, we have encountered frequent problems, such as:

- A lack of willingness to work on holidays.
- A lack of administrative support and difficulty accessing an emergency fund.
- Staff turnover.
- Working with students.

The following are some of the difficult situations that can occur:

**A lack of willingness to work on holidays**

Aeroponics requires constant monitoring, on workdays and holidays, especially during the initial testing stage and adaptation of the aeroponic system to local conditions (validation). Nevertheless, in public enterprises, organizing overtime and authorizations is often so complicated, administratively, that it can create setbacks and even total losses. For example, if an irrigation pump breaks down on a Friday night and it is not repaired in the following 12 hours but on Monday, it is most likely that the plants will have reached the point of permanent wilting and will die.

Therefore, staff must be available at all times to monitor the aeroponic system, especially at the initial validation stage. This is a point in favor of private companies that are already in the business of greenhouse production (like the flower industry in Colombia and Ecuador), since they have mechanisms for maintaining constant monitoring of their greenhouses, by having their staff work in shifts during holidays.

**A lack of administrative support and difficulty accessing an emergency fund**

Aeroponics needs efficient administrative support at all stages, from the construction of the infrastructure and validation of the system to implementation at the commercial level. However, this doesn’t always happen and the responsibility for hiring staff, getting quotes for inputs, doing the purchasing, etc., is sometimes given to the implementing technician.

This burdens the technician with a work overload that can affect his or her technical responsibilities. The problem is even worse if the purchases of inputs or equipment repairs cannot be done quickly, especially in emergency situations.
It is thus important to have efficient administrative support and an easily accessible fund to cover emergency situations, especially in the case of public enterprises, where bureaucratic procedures can be excessively cumbersome. This is another point in favor of private companies that normally have agile mechanisms for unscheduled purchases or repairs.

Staff turnover

It sometimes happens that a certain staff member is trained, but then employed in another position with different functions, which implicates a loss in terms of time and money.

For example, in Peru, a local government that had aeroponic greenhouses got a new mayor, which led to the removal of the technician who had been trained to run them and the hiring of another technician who had no experience in aeroponic potato production. In a similar case in Kenya, a technician trained in aeroponics was sent to a training course on another topic, and she was replaced by an agricultural worker with no experience in the area. In both cases, the production of the aeroponic system was seriously affected.

Since staff turnover can hardly be avoided, it is thus advisable to have a staff succession plan, to ensure that trained staff will gradually train new staff members so that they will be able to act as replacements when needed.

Working with students

In Ecuador, during the validation stage of aeroponics, we worked with agronomy students who did the validation work as part of their dissertation. The technology was, indeed, validated and three dissertations were published.

However, when each dissertation had been completed, the process of training for the following student started again from zero, meaning that experience acquired was lost.

In such cases it is thus recommended that an implementing technician monitor the students and, at the same time, capitalize on the experiences that are generated, especially those that aren’t reported in the dissertations but are nevertheless important.
In a few words...

Human resources are very important for the implementation of aeroponics. The following staff is needed: technical staff (implementing and specialized), greenhouse operators and administrative staff.

The greatest responsibility falls to the implementing technician who directs the processes of infrastructure construction, initial testing of the aeroponic system, supervision of greenhouse operators and specialized workers, and coordination with administrative staff. The implementing technician must be sufficiently trained and motivated to perform his or her functions in the greenhouse.

The specialized technicians —experts in different fields that are relevant for aeroponics (greenhouse construction, irrigation system installation, plant physiology, etc.)— advise the implementing technician in their area of expertise.

The greenhouse operators do agronomic management tasks under the training and supervision of the implementing technician. They are the people who are in permanent contact with the plants and therefore play a key role in the production process.

Specialized workers carry out the tasks of their trade (building, carpentry, plumbing, etc.) as needed. They are particularly important for constructing, installing, and maintaining the infrastructure: the greenhouse, aeroponic modules and irrigation system.

The administrative staff performs support functions to facilitate the work of the technicians and operators.

To overcome any problems that could hinder the aeroponic production, it is important to bear in mind that:

- Staff needs to be able for work on holidays whenever necessary.
- Sound administrative support is essential, for example to facilitate access to an emergency fund for unexpected situations.
- A staff succession plan is needed to ensure that when an experienced staff member leaves, it will not affect the aeroponic system’s implementation.
- When working with students, an implementing technician should supervise them so that he or she can make use of any experience acquired once the students have completed their research.
CHAPTER 4

INFRASTRUCTURE

Byron Potosí
WHAT DO WE PLAN TO DO IN THIS CHAPTER?

- Describe the infrastructure details that are necessary for an aeroponic system to work, so that the implementing technical staff can design, commission, and supervise its construction and maintenance.

- Share results and lessons learned from Ecuador, Colombia and Peru.
WHAT INFRASTRUCTURE IS NEEDED FOR IMPLEMENTING AEROPONICS?

For this topic, we need to cover the following aspects:

- Site selection
- Human resources
- Greenhouse and other installations
- Aeroponic modules
- Irrigation system

SITE SELECTION

For good results in aeroponics, it is important to select a suitable site on which to build the infrastructure.

The following criteria are useful:

**Suitable climate**

In the Andes region, climate is greatly influenced by altitude and, to a lesser extent, by the latitude. Good potato production has been achieved with aeroponics in greenhouses at elevations between 2,600 and 3,500 m.a.s.l. without sophisticated temperature control systems. At these altitudes, an average temperature of 18 to 25°C during the day, and 8 to 15°C during the night can be maintained in the greenhouse for at least six months of the year. The maximum temperature in the greenhouse should not rise above 30°C and the minimum should not fall below 4°C.

**Constant electricity supply**

This is an essential factor for aeroponics: it is indispensable in order for the irrigation system to work. We must, therefore, have a safe source of electricity supply and an alternative source (generator set) in the event of an emergency.

**Available irrigation water**

There must be a stable supply of good quality water in sufficient quantities.

**Flat land with leveled ground with good drainage**

To prevent the accumulation of water and masses of cold air that occur in dips and hollows in the ground.

**Easy access**

To facilitate the building of the infrastructure, as well as the entry and exit of materials and staff members.

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29 In CIP-Quito indoor greenhouse temperatures of between 35 and 37°C have been recorded at noon. The plants tend to wilt, but in the afternoon they recover.
Far from dusty areas
If possible, the selected site should be far away from dusty areas, because dust can build up on the greenhouse roof and reduces the passage of light to the inside, as well as contaminating the plantlets.

Near inhabited areas
Where the staff can live, in order to avoid long journeys to work and, if necessary, to enable a quick response to any problem that may arise with the crop or in any of the components of the infrastructure.

Protected from strong wind
To prevent damage to infrastructure.

Far from obstacles that cause shade
To take full advantage of sunlight.

With security
To prevent theft or damage to the facilities.

Far from other potato crops
To reduce the risk of transmission of diseases and pests to the aeroponic crops.

With sufficient additional space
For possible future expansion plans.

HUMAN RESOURCES

Specialized help is required for the construction and installation of aeroponic infrastructure. Supervision is the responsibility of the implementing technical staff, while the construction and actual installation will be done by specialized technical staff and specialized workers.

Depending on the scale of the project, the greenhouse may be built by workers who specialize in greenhouse construction or by specialized companies that are contracted.

For the construction of the aeroponic modules, either a carpenter or a locksmith is needed, depending whether they are made of wood or metal. Installing insulation sheets and plastic isn’t complicated, so the greenhouse operator can do that.

Advice from specialized technical staff and specialized workers (plumber and electrician) are needed for the installation of the irrigation system.
Greenhouse or net house

A greenhouse is a facility covered with transparent materials that let the sun’s rays in so that the interior environment heats up and photosynthesis takes place in the plants. It protects plants from rain, frost, hail, birds, insect pests, etc.

Depending on its design, a greenhouse permits a certain level of control of temperature, light, and relative humidity for the benefit of crop development.

In the Andes, and in other tropical highland areas, potatoes can be produced in simple greenhouses, without costly temperature control systems, during most of the year. Of course, more sophisticated greenhouses can be built, but that would be an unnecessary expense because the climate conditions in the region are suitable for this type of crop.

The greenhouse recommended for aeroponics in the Andean region is a relatively simple construction, made up of:

- a support structure,
- a roof, and
- walls of anti-aphid net.

This type of greenhouse is known as a net house, because the walls are made of netting instead of the glass or plastic used in traditional greenhouses.

Below we give some general recommendations for the construction of a net house. More detailed specifications can be found in specialized texts on greenhouse construction.
**Orientation**

The orientation of the net house (north-south or east-west) is important to ensure the appropriate environment.

Generally speaking, the most important factor for orienting a net house properly is the temperature, which is defined by the movement of the sun during the day.

The roof of a net house located in countries in the Andean region offers a larger heating surface if it has a north-south orientation, which is recommendable for cold areas. On the contrary, for hot areas, an east-west orientation is recommended to reduce the heat that can build up on sunny afternoons.

Other factors, such as wind direction, presence of obstacles, etc., should also be taken into consideration when determining the orientation of a net house.

**Width**

This depends on the number of aeroponic modules to be constructed, which, in turn, is defined by the quantity of minitubers to be produced. In the Andean region, some of the net houses used for aeroponics have widths ranging from 5 to 20 m.

**Length**

The length also depends on the number of modules to be constructed. In the Andean area, some of the net houses used for aeroponics have lengths ranging from 15 to 40 m.

**Height**

A net house with a high roof helps to cool the interior during the hot hours, so this is recommended for hot areas. On the other hand, greenhouses with a low roof are warmer, so they are recommended for cold areas.
Although there have been experiences with net houses 2.6 m-high at their lowest point, the height recommended for growing potato with aeroponics is **4.5 m**, in order to provide enough space and environmental conditions suitable for crop development, particularly for varieties of the andigena type, which tend to grow to nearly 2 m in an aeroponic system.

### Structure of the net house

The structure is the frame of the net house—foundation, beams, cables, etc.—that supports the roof and other implements.

It should be:

- Light and resistant,
- Made of low-cost material that is easily preserved,
- Made of material that enables a roof to be fixed to it.

The structure can be made of either metal or wood.

**Metal**: use angular beams measuring 5.08 cm by 10.16 cm (2 by 4 in) or round tubing, galvanized and zinc coated to prevent rusting.
In net houses with tube structures, the outer walls need to be anchored to the ground with galvanized steel cables.
**Wooden:** use beams measuring 10.16 x 10.16 cm (4 in by 4 in) or cylindrical wood (10 to 15 cm in diameter).

Depending on the quality of the wood and its treatment, net houses with wooden structures may have a short useful life. They are only recommended for places where wood is plentiful and inexpensive.

The wooden parts of a structure require a certain amount of care to prolong their useful life and prevent rotting.

**It is best to:**

- Use treated wood; never recently cut wood.

- Remove the bark from the roundwood timbers, since it can propagate pests that reduce the wood’s durability.

- Burn the surface of the end of the roundwood that is to go into the foundation holes and paint it with tar to waterproof and prevent it from rotting.
As far as the quality of the wood is concerned:

- It should be free of insects, fungi, lichens, etc.
- Preferably use the straightest possible roundwood timber with few knots.
- The main posts should have a diameter of more than 12 cm.
- Roundwood timber used for roof beams should have a diameter of more than 10 cm.
- Sawn wood used on roof should be 10 x 15 cm.
- Beams can be joined with metal angles of different designs.

**Cover or Roof**

Glass, polycarbonate, or polyethylene can be used.

**Glass** was traditionally used for greenhouse roofs because it lets the sunlight in and prevents heat from escaping. This characteristic of glass is interesting, since greenhouses with glass roofs lose less heat at night than greenhouses with simple plastic roofs. Nevertheless, glass is currently being replaced by advanced plastic materials.
**Polycarbonate:** is a plastic material that has replaced glass and, in some cases, polyethylene, because it is more economical. It is used for covering greenhouses because of its resistance and durability.

**Polyethylene (plastic):** the polyethylene sheeting that is used to cover greenhouses or net houses is formed with several layers, usually three. This type of plastic is also called coextruded. Additives are combined in the middle layer using substances that give the sheeting different properties to improve the temperature conditions inside the greenhouse, as well as the durability and resistance of the plastic sheeting itself.

The most frequently used additives are:

- **Anti-drip.** Reduces the surface tension of water drops that condense overnight, keeping them from dripping onto the crop, which reduces the risk of disseminating crop diseases.

- **With UV filter.** This type of plastic can filter and even block the sun’s ultraviolet (UV) rays. There are different degrees of filtration depending on the concentration and type of additives. Plastic sheeting with filters that block all UV radiation can alter the behavior of insect pests and virus-transmitting insects, so it is called ‘anti-vector’ or ‘anti-virus’ sheeting.

- **Anti-dust.** This is a film that has low electrical charge in its top layer, which keeps it from accumulating dust, which reduces the amount of sunlight entering the greenhouse.

- **Light diffusion.** This characteristic allows the light to disperse evenly in the greenhouse, which can increase the efficiency of photosynthesis.

- **Infrared radiation.** This additive allows infrared radiation to enter the greenhouse but prevents the radiation that the foliage gives off at night from escaping.

**Important!**

For any material, it is important to take into account its quality — since there are different qualities available on the market — and its useful lifetime.
**Roof design**

The shape of the roof influences the amount of sunlight entering the net house. A round one is the most effective. However, the shape most widely used is the gabled roof, because it is easy to construct.

It is important to leave openings at the top of the roof (zenithal openings) to enable hot air to leave the greenhouse.

**Walls**

Some net houses have walls made of brick or block with a height of 80 cm to 1 m, which are known as dwarf walls. An anti-aphid net, which has 16 x 10 threads per cm² and apertures of 0.4 x 0.8 mm is placed above the dwarf wall and attached to the metal or wooden structure.
This design (dwarf wall and anti-aphid net) is used on the front, sides, and back of the net house in order to take advantage of the wind to reduce the temperature on hot days, while at the same time preventing insect pests from getting in.

Sponge insulation or a similar material needs to be added where the roof and walls meet to prevent the entry of insect pests. The zenithal openings in the roof should also be covered with anti-aphid netting.

Floor

The floor can be soil covered with gravel, pumice stone\(^\text{30}\) or a similar material. This prevents the workers’ shoes from coming into direct contact with the soil, thereby preventing dust. The pumice also retains humidity after being watered, and this lowers the temperature. The disadvantage of this type of floor is that it cannot be cleaned.

The floor can also be made of cement or concrete, which means it can be cleaned. However, the cost is higher.

\(^{30}\) Pumina or pumice stone, very common in the Andean highlands of Ecuador. It is a volcanic igneous rock, very porous, with low density, white or gray in color.
Mechanisms for controlling temperature

Inside the net house, the temperature can be controlled with:

- Plastic curtains
- Electric ventilators
- Wind extractors
- Roof sprinklers
- Shade net
- Irrigation and sprinkling
- Ventilation duct

Plastic curtains

In places where frost occurs, plastic curtains should be used to cover the anti-aphid net on the four sides of the net house. These curtains are closed at night when there is risk of frost and opened during the day to permit aeration.

Electric ventilators

Ventilators with a diameter of 60 to 90 cm (24 to 36 in) may be installed at a height of approximately 3 m above ground level, covered by anti-aphid net and placed at both ends of the net house (front and back walls):

- The ventilator at the front pulls air from outside and introduces it into the net house.
- The ventilator at the back blows air from inside the net house to the outside.

In this way, the ventilators help to push the hot air through the net house, lowering the temperature and reducing the humidity on the leaves of the plants.

Wind extractors

In net houses that don’t have zenithal openings, it is possible to install wind-powered extractors on the roof to enable hot air to leave the net house.

Roof sprinklers

Roof sprinklers can be placed on the roof of the net house. They should switch on automatically when the indoor temperature rises above 25°C.
During the initial stages of potato cultivation with aeroponics (from 15 to 30 days after transplanting), it is important to maintain temperatures of 15 to 20°C (to prevent dehydration of the plantlets) and low solar radiation (to prevent leaf scorch).

An effective way of maintaining this temperature range and reducing radiation is to place a black net\(^\text{31}\) over the roof that provide 40 to 60% shade.

**Shade net**

During the initial stages of potato cultivation with aeroponics (from 15 to 30 days after transplanting), it is important to maintain temperatures of 15 to 20°C (to prevent dehydration of the plantlets) and low solar radiation (to prevent leaf scorch).

An effective way of maintaining this temperature range and reducing radiation is to place a black net\(^\text{31}\) over the roof that provide 40 to 60% shade.
Another option is to use Chromatinet®. These are colored shade nets that control plant growth characteristics, stimulating photosynthesis by means of light spectrum management. For example, a blue net at 50% can be used. However, more research needs to be carried out with these before making recommendations.

Irrigation and sprinkling
The temperature inside the net house can be reduced by watering the ground. Also, automatic sprinkling systems can be installed to switch themselves on when the indoor temperature goes above 25°C. In this case, it is important to evaluate the need for preventive applications of contact fungicides, in order to prevent damage from pathogens that are favored by high humidity such as Phytophthora infestans.

Ventilation duct
This is made of transparent polyethylene with holes along the entire length and is placed under the net house’s ridge beam. One end of the duct is connected to a ventilator, covered with anti-aphid net that introduces cooler air from outside into the net house. The ventilator can be switched on by a temperature sensor or manually during the hottest hours.
Other facilities

Pre-chamber

A pre-entrance chamber is a small room with double doors at the entrance to the net house that prevents insect pests from entering and provides a space where people can disinfect their shoes, hands, etc.

Two plastic tubs (foot baths) should be placed on the floor inside the chamber that those entering the net house can use to clean their shoes. In one of them, place a 1% sodium hypochlorite solution (one part 5% commercial chlorine to four parts water) with a sponge, and in the other, place lime. As they enter, people should first put their shoes in the recipient with chlorine, and then in the recipient with lime. A sprinkler with antiseptic alcohol (70%) should also be available for their hands.

The pre-chamber can be 2 x 3 m in area; a bigger space is not needed.

32 See Annex 3. Examples of how to prepare sodium hypochlorite or calcium hypochlorite solutions.
33 Take care of clothes because chlorine can discolour them.
**Storehouse**

The storehouse is where net house inputs and other materials are kept and where harvested minitubers are selected and stored, so that they can turn green and sprout under the right temperature, humidity and diffused light conditions.

It is recommended that the storehouse be near the net house and the machinery house.

Depending on storage requirements, storehouses can have different areas. They must contain safe cabinets for storing materials and inputs such as fertilizers, tools and the clothing and boots used by greenhouse operators and technicians.

They should also have shelves where seed can be stored. If there is high minituber production, it is recommended that there be one storehouse exclusively for storing seed, to avoid theft. The storehouse should have a temperature that allows proper sprouting of tubers (between 12 and 18°C), relative humidity of 90 to 95%, good ventilation, diffused light, anti-aphid net insulation and protection from rodents.

**Cold room**

If high yields of minitubers are expected in each crop cycle, it is good to have a cold room to store them for a short time (one to two months), before moving them to sprout under the required conditions. Minitubers should be stored at 4 to 5°C temperature, 90 to 95% humidity and without light.

**Machinery house**

This is a closed, secure place with a cement floor and opaque roof where the irrigation equipment is stored: the pumps, tanks, timer, filters, etc.

This space enables the producer to keep the nutrient solution at a temperature of around 15°C. It also allows producers to make the most of the space in the net house, since all equipment is located inside the machinery house.
The generator set can also be located in the machinery house, but it is advisable to keep it in a special construction at a distance from the net house to prevent problems from the noise and exhaust that it produces.

**Other facilities**

Other facilities that need to be built are offices, toilets and dressing rooms for the staff.

These facilities should be near the net house, to ensure permanent monitoring of the crop and so that an immediate solution can be found for any problems that may arise.

**Maintenance**

The following maintenance activities on a net house must be done regularly, especially before the cultivation cycle begins.

- Check that there are no holes in the roof (leaks) or in the walls, net, and door through which insect pests can get in.

- Clean with water the inside and outside of the roof, anti-aphid net, curtains, and walls to remove dust, and disinfect with a 0.25% sodium hypochlorite solution. 

**Important!**

ALWAYS use gloves when handling sodium or calcium hypochlorite.

In the case of the pre-chamber, it is important to do an overall cleaning once a week with 0.25% sodium hypochlorite, including floor, walls, and ceiling. It is also necessary to change the hypochlorite and the lime for disinfecting footwear on a weekly basis.

The cooling equipment for the cold storage room must be given regular maintenance, following the manufacturer’s recommendations.

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34 See Annex 3. Examples of how to prepare sodium or calcium hypochlorite solutions.
THE AEROPONIC MODULES

These are rectangular boxes into which the planting material (in vitro plantlets or rooted cuttings) is transplanted. They can have wooden or metal frames that support walls of 4 to 5 cm-thick boards of expanded polystyrene insulation (Styrofoam, also known as Espumaflex, Tecnopor, Icopor or Plastoformo in different countries).

The module’s interior must be lined with black plastic, which makes it dark and waterproof.

The function of the modules is to insulate the plants' roots from environmental conditions.

Materials required for construction of wooden aeroponic modules:

- Wooden boards (7 by 4 cm)
- Wood preservative
- Screws, 7.62 cm (3 in)
- Nails, 7.62 cm (3 in)
- Wood paint (glossy)
- Insulation boards, 4 or 5 cm thick styrofoam, 1 m wide and 2 m long
- Transparent silicone
- Black plastic sheets, 0.1524 mm thick
- Bicolored plastic (white on one side and black on the other) to cover the lid of the module
- Duct tape
Technical specifications

The modules should have the following dimensions:

- **Black hose, 1.27 cm (0.5 in) or 1.91 cm (0.75 in) in diameter**
- **To make holes in the insulation boards:**
  - Pencil or marker
  - Ruler
  - Galvanized pipe or metal rod, 1.27 cm or 1.91 cm with a T form, or a drill
  - Gas burner to heat the pipe
  - Saw or knife to cut hose
  - Sharp object for perforating

**How do you build an aeroponic module?**

**Technical specifications**

The modules should have the following dimensions:

- **Height:** between 80 cm and 1 m
- **Width:** between 1 and 1.2 m
- **Length:** varies depending on the dimensions of the net house. Construction of modules longer than 15 m is not recommended because the longer the module, the more difficult implementation becomes because a greater slope is needed at one end for drainage of the nutrient solution, making it more difficult to manage the aerial part of the plants. Also, if a module becomes contaminated, there will be greater loss of plants and tubers.
To permit drainage of the nutrient solution for return to the tank, the modules must have a double slope: lengthways (3 to 4%) and crossways (2 to 3%). A 5.08 mm diameter pipe should connect the lower end of the module with the nutrient solution tank.

**Construction procedure**

The module’s frame can be made of wood or metal. In the first case, wooden boards are used attached to one another with screws and nails.

For the construction of wooden modules, use a type of wood that can resist both the weight of the plants and deterioration caused by humidity. Once the wooden frame is completed, it should be treated with a wood preservative to prevent the destruction by pests. Afterwards, it should be painted with enamel paint to waterproof it.

If the frame is metal, galvanized angles are used. This type of structure is more costly but has a much longer lifespan, and it doesn’t need the same maintenance every two or three cycles that a wood structure does to protect it from deterioration caused by humidity.
At the top of the frame, vertical beams and crossbeams should be placed every 1.25 m, to make the structure strong and to support the insulation boards. The crossbeams also serve for the attachment of irrigation hoses. There should also be crossbeams along the floor of the structure at every 62 cm.

Attach insulation boards permanently to this structure (side walls and floor) using a hot stiletto or knife to cut them and silicone to attach them to the frame. At the lowest end of the module floor, open a hole in the insulation board for the drainage pipe that takes the nutrient solution back to the tank.

The modules should have side windows measuring 50 x 50 cm located every 80 cm to permit minituber harvesting. Those windows are made by cutting squares in the insulation boards with the required dimensions.
The next step is to cover the inside of the modules with black plastic, 0.1525 mm thick, using duct tape. The function of the plastic is to prevent filtration of the nutrient solution and exposure of the root system to light. If light enters the module, the stolons tend to become aerial stems, which reduces minituber yield.

A double curtain of the same plastic should be placed on the inside of the windows. The inside curtain must be larger to prevent nutrient solution from escaping and light from entering the modules.

On the outside of the windows, a bicolored plastic curtain with a strip of wood at the bottom should be attached to the module, which can be rolled up when harvesting. This curtain prevents light from entering the module.
A hole needs to be made in the plastic on the floor of the module to permit drainage of the nutrient solution.

The lids of the modules should be made from insulation boards with holes measuring 1.27 to 1.91 cm (0.5 in to 0.75 in) in diameter, into which the plantlets are introduced.

The procedure for making the holes and lining them with hose is as follows:

- Before making the holes, examine the distribution of the micro sprinklers to ensure that all plants will be bathed in nutrient solution.

- Mark the insulation board with a pencil or marker, using a ruler, forming squares to indicate where to make the holes that the plantlets will be placed in, based on the required density.

- Make holes from 1.27 to 1.91 cm (0.5 in to 0.75 in) in diameter at the intersection of the lines with the T-shaped galvanized pipe, after heating one end with a burner. A drill can also be used.

- Cut the hose into sections 6 to 7 cm in length.

- Push a piece of hose into each hole. The plantlets will be placed into these hoses during transplantation.

- As an alternative to the hoses, a hot metal bar can be used to perforate the insulation board and heat-seal the sides of the holes.

The module lids should be covered on all sides with a bicolored plastic with the white side up on the outside to reflect light and reduce the temperature inside the module, and black on the underside to ensure total darkness inside the module.
After lowering stems (the equivalent of hillling up) between 30 and 40 days after transplanting, a 20 to 40 cm wide skirt of bicolored plastic should be placed between the cover and the module’s frame using duct tape, to prevent light from entering it.

If nets will be used for training the plants, metal pipes or wooden posts 5 cm in diameter need to be installed every 3 m on each side of the module, to attach the training nets to.
Maintenance of the modules includes the following activities:

- **Before the beginning of the crop cycle**, wash the pipes using a 1% sodium hypochlorite solution. This solution should circulate in the system for three days. After this, the pipes are washed with running water for another three days. It is also necessary to disinfect the modules—inside and outside—with a 1% sodium hypochlorite solution.

- **Every week**, clean the dust accumulated on the modules with a damp sponge with 1% sodium hypochlorite solution.

- **Each crop cycle**, change the bicolored plastic covering the lids.

- **Every other crop cycle**, change the black plastic that lines the inside of the modules and the insulation boards of the lids.

- **Every three crop cycles**, do maintenance of the wood, applying preservative and enamel paint, to prevent damage from humidity.
If the budget permits, it is recommended to have at least two independent irrigation systems in each net house. This reduces the risk of total loss from pathogens that may enter the irrigation system, or from intoxication due to errors in the preparation of the nutrient solution.

It is not worth having independent irrigation systems for each module, because of the high implementation cost. However, this type of independent system is used for research, because it enables the researcher to try different treatments (for example, different plant densities, nutrient solutions, varieties, etc.).

For modules 5 to 10 m long, the following materials are required, noting that they may be adapted to the particular conditions of each place:

**Pumps and accessories**

- Centrifugal pump, 5 to 75 HP
- Hydropneumatic tank
- Pressure switch
- Pressure gauge
- Check valve, 2.54 cm (1 in)
- Air valve, 2.54 cm
- Shut-off valve, 2.54 cm
- Disc filter, 2.54 cm with outlet and male-type inlet
- Electric valve with solenoid

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35 Submersible pumps may be used, in which case hydropneumatic tank isn't needed.
Micro sprinkler system and plumbing:

- Micro sprinklers with nozzle, 1.1 mm in diameter (flow: 61 liters per hour)
- Plastic tank, 500 to 1000 liters
- PVC pipes, 2.54 cm (1 in)
- Foot valve, 2.54 cm
- PVC elbow joints, 2.54 cm
- Nipples, 2.54 cm
- Universal joints, 2.54 cm
- Irrigation hose, 16 mm
- Hose joints, 16 mm
- PVC pipe for drainage, 5.08 cm (2 in)
- Teflon tape

Filter system

- Microbiological filter (active carbon filter and UV lamp)

Control system

- Pump control panel
- Timer
- Electric wire, number 12

Emergency generator set and accessories

- Portable or stationary generator set
- Manual or automatic transfer panel
- Automatic circuit breaker
- Accessory electrical equipment
**Installation of tanks, pumps, and piping**

The nutrient solution tank, the hydropneumatic pump, the pump control panel, the timer, and the microbiological filters should be located in the machinery house.

The tank should be below ground level so that the nutrient solution from the modules flows back into it by gravity after each irrigation session. It should be set inside a cement outer tank to prevent contact with soil, which reduces the risk of contamination and maintains an adequate temperature for the nutrient solution (15°C).

The tank’s capacity will depend on the size of the modules. A 500-liter tank is sufficient for an effective production area of 20 m² (area of modules).

The nutrient solution tank and the outer cement tank must remain closed to avoid contamination.

The pump is connected to the tank through a pipe that has a foot valve at the beginning. Accessories such as the hydropneumatic tank, pressure switch, pressure gauge, check valve, air valve, shut-off valve, disc filter and electric valve with solenoid should be installed nearby.
**Placement of micro sprinklers**

In the upper middle part of the modules, two lines of black hoses 16 mm in diameter should be positioned at a distance of 30 cm from each other, to which micro sprinklers will be connected, 60 cm apart from each other. The hoses should be attached to the crossbeams of the modules.
The water that is to be used for preparing the nutrient solution should be filtered before it enters the aeroponic system, especially in areas where there are doubts about water quality. This is done using microbiological filters with active carbon and a UV lamp, located between the water source and the aeroponic system. This removes water-borne pathogens.

The recirculating nutrient solution must also be filtered:

- Use a disc filter in the irrigation system piping, after the shut-off valve and before the electrical valve. The disc filter will remove any impurities from the nutrient solution, such as pieces of roots.

- Ideally, a microbiological filter can be placed after the disc filter, to remove pathogens that can affect the crop from the solution that is being recirculated.

**Control system**

This consists of a panel for switching the pumps on and off. For automating the irrigation, we use a timer, which is calibrated according to the crop’s requirements. The timer is connected to an electrical valve with solenoid, which allows the nutrient solution to pass through as scheduled.
Emergency generator

In the event of power cuts, there must be a generator available all the time. This generator may be portable or stationary and should preferably be of the automatic transfer type, that is, one that switches itself on if there is a power cut. The capacity of the electric generator needed will depend on the number of pumps in the irrigation system.

Important!

A spare pump and other spare parts, such as pressure switch, micro sprinklers, electrical valve, and plumbing items, are crucial for keeping the irrigation system working well and they must always be available. Also, the implementing technical staff and at least one greenhouse operator must be trained to change them if they become damaged.

Maintenance of the irrigation system

The irrigation system must be constantly monitored to ensure that it is working properly. The following actions are required:

- Disinfect the solution tank with 1% hypochlorite every time the nutrient solution is renewed.

- On a daily basis, check for leaks in the pipes, since they result in a drop in pressure in the micro sprinklers and, consequently, an uneven distribution of the nutrient solution to the roots. They also cause mechanical damage to the pumps. If a leak appears, that part of the pipe should be dismantled, plumbing items replaced, and all the parts properly adjusted.

- While checking the pipes, don’t forget to check if the micro sprinklers are working properly and, if necessary, clean or change them.

- Wash ring filters once a week. This prevents the micro sprinklers from getting clogged up. In the case of the microbiological filters, follow manufacturer recommendations for their maintenance.

- Monitor the ranges of pressure at which the pumps should be working: between 20 and 40 psi or between 15 and 35 psi. These pressure ranges depend on how long the pump has been in use. When the pump is new, the former range is used; and when the pump has been used for one or more cycles, it should be within the second range to ensure uniform irrigation of the roots.

Important!

psi: pounds-force per square inch. 1 psi = 6.895 kPa

36
If the pressure is not within the ideal ranges, the spare pump must be installed and the damaged one sent off for maintenance. Usually, when the pump shows a decrease in pressure, the mechanical seal needs to be replaced, as it wears out with use.

- Perform maintenance on the emergency generator, the pumps, and other parts of the irrigation equipment following the manufacturer’s recommendations; thorough maintenance should be completed after each crop cycle.

**Waste management**

Every so often, the non-degradable materials have to be replaced, such as plastic (every two crop cycles) and insulation boards (every four or five crop cycles). These wastes should be managed in keeping with local regulations.

Ideally, these waste materials can be used for other purposes. For example, the plastic from the modules could be used to construct plastic barriers for management of *Premnotypes vorax*; while the insulation boards are useful in cold rooms, or to make pens for small animals, etc.
What does our experience tell us?

IN ECUADOR

About independent irrigation systems

The following were constructed in the first cycle of aeroponics:

- Four modules, 15 m long x 1 m wide.
- A single irrigation system for the four modules.
- Each module had one irrigation hose in the upper central part.

In the second and subsequent cycles, the following were constructed:

- Eight smaller modules (5 x 1 m).
- Independent irrigation systems for each module (a total of eight).
- In each module, a double line of hose was installed in the upper part.

Lesson learned: Having independent irrigation systems for each aeroponic module allows us to evaluate the treatments and determine the best one for growing potatoes with this technique. For example, different nutrient solutions were tried as well as rhizobacteria that promote plant growth. Also, with the double sprinkler hose, the distribution of the nutrient solution to the roots was even; as was, consequently, the growth of the plants in each module.

About the characteristics of the net house

To control the indoor temperature, certain adaptations were made to the net house, because it had originally been constructed for other purposes:

- The glass roof was painted white, but this considerably reduced the light passing through. The paint was thus removed and a shade net was placed on the roof, which is used only when there are high temperatures.
- Two ventilators were placed at the ends of the net house to extract hot air.
- Four wind extractors were placed on top of the roof.

Lesson learned: It is important to build a net house that complies with the technical specifications for an aeroponic system; otherwise we need to foresee the possible problems that may arise.
About the nutrient solution tank

In the first three crop cycles, the nutrient solution tank was in contact with the soil in the net house. This meant that the nutrient solution became heated (＞15 °C) and also that it was exposed to dust, because the lid was not adequate. In the fourth cycle, a cement casing was built for the tank and the design of the lid was improved.

**Lesson learned:** A cement tank built to protect the plastic tank containing the nutrient solution will prevent dust from entering it and keep the nutrient solution at a suitable temperature (15°C).

About the need for a generator set

In the first three crop production cycles, there was no emergency generator set. Whenever there were power cuts, we ran the risk of losing the entire production.

For the fourth cycle, a portable electric generator was purchased, and in the fifth cycle a stationary electric generator was installed (this supplies the entire research station).

**Lesson learned:** To implement aeroponics, an electric generator, either portable or stationary, is indispensable.

IN PERU

About the use of covers

At the CIP-Lima experimental station, a cover with anti-aphid net was at first used on the walls and roof. However, on days with a light drizzle of rain, water with dirt would drip onto the plants, causing leaf diseases. Later, a net house was adapted with a fiberglass roof and sidewalls covered with anti-aphid net.

**Lesson learned:** To produce quality seed with aeroponics, it is indispensable to have a construction with a rigid roof, to protect the crop from adverse abiotic factors.

About the system for cooling the nutrient solution

In zones with a hot climate or hot season (for example, Lima from December to April), the temperature of the nutrient solution can exceed 30°C, which produces stress in the plants and interferes with tuber formation.
To address this situation, a cooling system was installed for the nutrient solution, using a cooling coil through which a cold gas circulates connected to a cooling unit and a temperature control unit. This made it possible to keep the temperature at around 15°C, ideal for potato tuber production.

**Lesson learned:** In aeroponics there are three important temperatures: that of the net house (day: between 18 and 25°C; night: between 8 and 15°C); that of the nutrient solution (about 15°C); and that of the aeroponic module (between 15 and 16°C). If an aeroponic system is installed in areas with a hot climate, it is necessary to install a cooling system for the nutrient solution, which increases the infrastructure and maintenance costs and adds an extra level of complexity to the aeroponic system. This underlines the importance of selecting a good site for the net house.
IN COLOMBIA

About the use of plastic curtains
The net house is located near secondary roads, and passing vehicles produce a great deal of dust, which came into contact with the plants. To prevent this, plastic curtains were placed on the walls.

Lesson learned: The use of plastic curtains prevents dust from entering. However, they need to be opened at noon to prevent the temperature from rising. This once again underlines the importance of making a good selection of the site for the net house.

The aeroponic infrastructure used in Colombia by CORPOICA, in Ecuador by INIAP and CIP, and in Peru by CIP is described in Annex 4.
Infrastructure is one of the most important factors for successful implementation of aeroponics, so the technical specifications must be carefully taken into account prior to construction.

The main aspects to bear in mind are:

**Site selection.** The site where the greenhouse is to be constructed should be at an elevation of 2,600 to 3,500 m.a.s.l., with an average daytime temperature of between 18 and 25°C and average night temperature of between 8 and 15°C. The site must have a permanent supply of electricity, quality water for irrigation and roads in good condition to facilitate access. It should also be near inhabited areas, have protection against strong wind, and be at a distance from other commercial potato crops.

**Human resources.** For the implementation of an aeroponic greenhouse, trained staff is needed in specific areas of construction, including workers at companies specializing in greenhouse construction and the installation of irrigation systems. All these workers should be supervised by the implementing technical staff at all times.

**Net house.** This is a relatively simple construction, consisting of a supporting structure, roof, and anti-aphid net walls. The frame may be wooden or metal, with a rounded or gabled roof, which can be glass, polycarbonate or polyethylene.

The most common temperature control methods for net houses are: plastic curtains, electric ventilators, wind extractors, sprinklers on the roof, shade net or watering the floor.

Other facilities that form part of the infrastructure are: the pre-chamber, the storehouse, the cold room, the machinery house and administrative offices.

**Aeroponic modules.** These are rectangular boxes inside which the plants grow and form tubers. They can have a wood or metal frame that support walls of Styrofoam insulation board on all sides, the inside of which are covered with black plastic.

**Irrigation system.** By means of the irrigation system, a nebulized nutrient solution is fed to the roots of the plants using micro sprinklers.
CHAPTER 5

THE POTATO PLANT: ECOPHYSIOLOGY AND MINERAL NUTRITION

Darío Barona
Julián Mateus-Rodríguez
Fabián Montesdeoca
WHAT DO WE PLAN TO DO IN THIS CHAPTER?

• Understand potato physiology and its relationship with the productivity of tubers, with emphasis on the processes and mechanisms that determine their growth, yield and quality.

• Facilitate management of an aeroponic crop by understanding the plant’s physiology in relation to the environment (weather, access to nutrients, etc.).
The potato (Solanum spp.) is a plant that was domesticated in the Peruvian-Bolivian Altiplano, or high plateau region. It develops a fibrous and highly branched root system from the radicle of a seedling that can sprout from a seed tuber, from an in vitro plantlet, or from adventitious roots of plantlets obtained from tuber sprouts or rooted cuttings, which could be used as planting material for aeroponic modules.

In aeroponics, the potato crop can cover the whole surface of the aeroponic module within 35 to 40 days from transplantation. The growth of the foliage is the result of two combined processes:

- branching,
- appearance and expansion of leaves.

The tubers are formed from the thickening of the medulla and cortex of underground stems called stolons. Tuber formation begins with the development of the stolons, followed by the actual tuber bulking, that is, the thickening of the subapical region of the stolons. These processes are affected by environmental factors such as temperature and photoperiod.

If the stolon is exposed to sunlight, it forms an aerial stem with roots instead of tubers.

The development of the stolons is controlled by the conditions prevalent at the stem base: humidity and darkness, which induce the production of plant hormones—gibberellic acid, abscisic acid and indoleacetic acid—that stimulate the development of stolons and tubers. In addition, the presence of a high quantity of nitrogen, sunlight and heat induce the production of cytokinins, which stimulate the development of aerial stems and leaves.  

**Important!**

The formation of leaves on the stolons could occur in aeroponic modules if they are not closed properly (so that light enters them) or in the event of temperature variations.

**WHAT FACTORS INFLUENCE THE DEVELOPMENT AND GROWTH OF POTATO TUBERS?**

The main ones are:

- Genetic
- Physiological age
- Photoperiod and light quality
- Humidity
- Nutrients
The genetic factor, that is, the variety, largely defines production in the field and also in aeroponics. In the Andean countries, the number of minitubers per m² obtained with aeroponics has varied between 500 (variety Serranita) and 3200 (Canchán), which indicates the influence that genetic factor has on yield.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Minitubers per m²</th>
<th>Site</th>
</tr>
</thead>
<tbody>
<tr>
<td>Canchán</td>
<td>3200</td>
<td>CIP-Huancayo</td>
</tr>
<tr>
<td>Perricholi</td>
<td>2500</td>
<td>CIP-Huancayo</td>
</tr>
<tr>
<td>Yungay</td>
<td>2575</td>
<td>CIP-Huancayo</td>
</tr>
<tr>
<td>Serranita</td>
<td>500</td>
<td>CIP-Lima</td>
</tr>
<tr>
<td>Chucmarca</td>
<td>600</td>
<td>CIP-Lima</td>
</tr>
<tr>
<td>INIAP-Fripapa</td>
<td>997</td>
<td>CIP-Quito, INIAP</td>
</tr>
<tr>
<td>INIAP-Puca Shungo</td>
<td>940</td>
<td>CIP-Quito, INIAP</td>
</tr>
<tr>
<td>INIAP-Yana Shungo</td>
<td>1023</td>
<td>CIP-Quito, INIAP</td>
</tr>
<tr>
<td>INIAP-Victoria</td>
<td>3105</td>
<td>CIP-Quito, INIAP</td>
</tr>
<tr>
<td>INIAP-Libertad</td>
<td>2797</td>
<td>CIP-Quito, INIAP</td>
</tr>
<tr>
<td>Superchola</td>
<td>1960</td>
<td>CIP-Quito, INIAP</td>
</tr>
<tr>
<td>Diacol Capiro</td>
<td>850</td>
<td>CORPOICA-Tibaitatá</td>
</tr>
<tr>
<td>Parda Pastusa</td>
<td>650</td>
<td>CORPOICA-Tibaitatá</td>
</tr>
<tr>
<td>ICA Única</td>
<td>950</td>
<td>CORPOICA-Tibaitatá</td>
</tr>
<tr>
<td>Pastusa Suprema</td>
<td>650</td>
<td>CORPOICA-Tibaitatá</td>
</tr>
<tr>
<td>Roja Nariño</td>
<td>750</td>
<td>CORPOICA-Tibaitatá</td>
</tr>
</tbody>
</table>

Varieties differ in their foliage, in the number of stolons, in the branching pattern of secondary stolons and in tuber formation. Those that have the greatest genetic influence of the andigena subspecies tend to form more abundant foliage, longer stolons, and a larger number of tubers than the varieties with the greatest genetic influence of the tuberosum subspecies.
For example, the Canchán variety (ssp. andigena) and the INIAP-Victoria (andigena x tuberosum type) have longer stolons, and high production of tubers; whereas the INIAP-Libertad variety (ssp. tuberosum) and the INIAP-Frippapa (tuberosum x andigena type) are characterized by shorter stolons and less branching.

**Physiological age**

The physiological age of the planting materials has a clear effect on the development of the plants, affecting both the stolons and tuber formation, mainly the time that tuberization begins.

As the physiological age of the planting material increases, induction of tuberization (the formation of tubers) also increases, that is, all the physiological processes of the plant accelerate and the plant induces the production of tubers faster or, in extreme cases, senescence (physiological maturity) occurs before tuberization.

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42 Barona, 2012.
In the field, planting minitubers that have been stored for a long time and are physiologically very mature results in small plants, which begin their tuber formation and senescence quickly.

**Photoperiod and quality of light**

The beginning of tuber formation in potato plants is greatly influenced by the duration of daylight.

Induction to tuber formation in the varieties of the Andean region is promoted by the short photoperiod, which in this case is about 12 hours of light and 12 hours of darkness. This is why there is no need to provide additional lighting in the net house for aeroponics in the Andean area.

On the other hand, the potato varieties from higher latitudes tuberize in the long photoperiods of the summer, when daylight lasts more than 16 hours and nights are short.

An increase in the intensity of solar radiation would normally be associated with an increase in the final yield; but in extreme cases, high levels of radiation are also associated with high temperatures and excessive transpiration (high deficits of evaporation) that can cause low yields.

Once the minitubers have been harvested, we need to consider the effect of “diffused light” —light that does not reach them directly— during storage.

Diffused light produces the following effects in the stored minitubers:

- **Greening.** The skin and the flesh of the minitubers take on a green color, as a result of the production of chlorophyll and solanine, which have a bitter taste, and can make them toxic. The greening confers a certain degree of resistance to the penetration of pathogens and the attack of insects and other animals.

- **Breaking apical dominance.** Many potato varieties tend to break apical dominance in the presence of diffused light. Minitubers stored under these conditions will thus have a larger number of sprouts. Also, the need to remove the apical sprout before planting is reduced.

- **Sprout production.** Diffused light results in the production of good quality sprouts (short and vigorous).

- **Appearance of root primordials.** Diffused light also leads to the production of root primordials, which are the structures that will later form the roots of the future plant.
The potato is adapted to cold tropical climates, with temperatures that can range from 18 to 25°C in the daytime to 8 to 15°C at night.

**Important!**

Indoor greenhouse temperatures higher than 30°C for more than four hours can cause problems in the plant’s root system and create conditions favorable to the development of pathogens. At the same time, temperatures lower than 4°C can cause damage to the plants.

In potato plants, the net carbon assimilation rate, that is, the increase in weight of the plant per foliar area unit, is greatest between 18 and 23°C.

Above 25°C, the net assimilation rate does not rise significantly, while the maintenance respiration continues to increase, which means the plant breathes and expends more energy than it generates by photosynthesis.

In the case of aeroponics, the temperature inside the module is very important. Low temperatures induce tuber formation, whereas high temperatures inhibit it.

High temperatures inhibit tuber formation both in short photoperiods and long ones, although the degree of inhibition is greater in long photoperiods (more than 15 hours of daylight).  

**Important!**

Inside the aeroponic modules, the ideal temperature for starting tuber formation is between 16 and 19°C.

The development rate (elongation) of the stolons depends on the temperature inside the aeroponic module. Maximum elongation occurs close to 18°C, while at temperatures lower than 9°C and higher than 20°C, it diminishes.

In an aeroponic system, the temperature of the nutrient solution can be controlled. For example, at CIP-Lima, production can take place in the summer because the nutrient solution tank has a water cooler that keeps the temperature at an average 15°C, ideal for potato tuber production.

43 Monteith, 1969; Li, 1985; Kooman, 1995; Vandam et al., 1996.
Once the minitubers have been harvested, we need to pay attention to temperature effect during storage. Minitubers show damage when they are exposed to very high or very low temperatures:

- Low temperatures (below 2°C) cause damage due to internal freezing.

- High temperatures (above 25°C) cause acceleration in respiration and a higher oxygen requirement and they can discolor the tuber’s inner tissue as a result of asphyxia. The presence of “hollow heart” (damage produced inside a tuber due to rotting or desiccation of the inner tissue) is a symptom that can develop in tubers exposed to high temperatures.

**Nutrients**

Plant nutrition is crucial for the proper management of aeroponics. The nutrients are added to the water, through salts or fertilizers, and are absorbed by the plants’ roots.

With nutrition, we can influence:

- development of the leaf area,
- induction of tuber formation, and the number and weight of tubers.

Nutrients are classified as macronutrients and micronutrients:

**Macronutrients:** are those that the plants use in large quantities and that are present in their tissues in quantities of up to 4% of their dry weight.

The macronutrients are: nitrogen, phosphorous, potassium, calcium, magnesium and sulfur.

**Micronutrients:** are those that are present in the plant’s tissues in quantities of no more than 200 parts per million.

The micronutrients are: iron, manganese, copper, zinc, boron, chlorine, and molybdenum.
## Description of the principal nutrients

### Nitrogen (N)

**Form of absorption:**
The plants can absorb this nutrient in the form of nitrate ion (NO\(_3^-\)) or ammonium ion (NH\(_4^+\)). They can also absorb nitrogen in organic form (amino acids), both through the roots and through the aerial part.

**Physiological functions:**
It forms part of a large number of organic compounds required for the growth and development of the plants, such as: amino acids, proteins, coenzymes, nucleic acids, chlorophyll, etc. It favors the vegetative growth, good appearance, and green color of the plant.

**Deficiency symptoms:**
Pale leaves and a reduction in the plant’s growth and yield (size and number) are signs of nitrogen deficiency.

**El exceso de nitrógeno causa:**
- Delay in tuber initiation.
- Lengthening of the crop cycle.
- Excessive foliar growth, which hinders plant management and creates a microclimate favorable to pests and diseases.
- Hollow heart and cracks in the tubers.
- Increased susceptibility to pests and diseases.
- Reduction in specific gravity of the tubers.

**Important!**

High levels of nitrogen can inhibit tuber formation.
**Phosphorous (P)**

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>The plants absorb phosphorus in ionic form, as phosphate (H$_2$PO$_4^-$), although in exceptional cases they can do so in the form of acid phosphate anion (HPO$_4^{2-}$).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>At the beginning of tuber formation, an adequate availability of phosphorous ensures that the plant will form a large number of tubers. Afterwards, phosphorous is an essential component for the synthesis, transportation, and storage of starches.</td>
</tr>
</tbody>
</table>
| Deficiency symptoms: | Phosphorous deficiency leads to a reduction in initial vigor, produces delay in maturation, and reduces yields. Typical symptoms are:  
  - Reduction in the yield, both in number and size of tubers.  
  - Dwarfism of plants.  
  - Yellowing of old leaves.  
  - Young leaves are small and dark green in color. |
| An excess of phosphorous causes: | Interference with other elements such as calcium and zinc, causing their deficiency. |

**Potassium (K)**

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>The potassium is absorbed in form of ion K$^+$.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>The potato requires large quantities of potassium, since it is crucial for its metabolic functions, such as the movement of sugars from the leaves to the tubers, and the transformation of sugar into potato starch.</td>
</tr>
</tbody>
</table>
| Deficiency symptoms: | Potassium deficiency delays the absorption of nitrogen and the plants' growth; it also reduces their yield, quality, and resistance to diseases. Typical symptoms are:  
  - Necrosis on leaf margins.  
  - Premature leaf senescence. |
| An excess of Potassium causes: | Reduction in specific gravity of the tubers and reduction in absorption of calcium and magnesium. |
### Calcium (Ca)

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>Calcium is absorbed in the form of $\text{Ca}^{2+}$ ion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>It participates as a structural component of cellular walls and membranes, which contributes to the plant’s rigidity.</td>
</tr>
<tr>
<td>Deficiency symptoms:</td>
<td>Calcium deficiency interferes in the development of the roots, causes deformation in the sprouts, and could reduce quality and yield. Calcium deficiency in the potato tubers reduces their storage capacity, due to the fact that calcium is a principal component of the cell walls. Typical symptoms are:  - Curling and yellowing of young leaves at the top.  - Scorching of leaf tips.</td>
</tr>
<tr>
<td>An excess of Calcium causes:</td>
<td>Reduction in magnesium absorption, hence it is associated with symptoms of magnesium deficiency.</td>
</tr>
</tbody>
</table>

### Magnesium (Mg)

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>Magnesium is actively absorbed in the form of $\text{Mg}^{2+}$ ion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>Like calcium, magnesium is of great importance in the energy metabolism.</td>
</tr>
<tr>
<td>Deficiency symptoms:</td>
<td>Reduced photosynthesis, because magnesium is the key element in this process; reduced tuber formation, and drop in yield. Magnesium deficiency can lower the plant’s yield by more than 15%. It also causes damage to the minitubers during storage. The symptoms of deficiency are:  - Yellow and brown leaves.  - Leaves that wilt and die.  - Delay in growth of plants.  - Early maturation of the crop.  - Skin of the tubers cracked and of uneven color and texture.</td>
</tr>
<tr>
<td>An excess of Magnesium causes:</td>
<td>Reduction in calcium absorption, hence it is associated with the symptoms of calcium deficiency.</td>
</tr>
</tbody>
</table>
### Sulfur (S)

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>In the form of sulfate anion (SO$_4^{2-}$).</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>The most important function of sulfur is its participation in the protein synthesis.</td>
</tr>
</tbody>
</table>
| Deficiency symptoms: | • Reduction in growth.  
• Pale green or yellow leaves.  
• Reduction in number of leaves. |

### Iron (Fe)

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>Iron is actively absorbed in the form of Fe$^{2+}$ or Fe$^{3+}$.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>It is essential for the synthesis of chlorophyll.</td>
</tr>
</tbody>
</table>
| Deficiency symptoms: | Symptoms appear in the youngest leaves. They are:  
• Chlorotic interveinal areas (yellowish pigmentation between the veins of the leaf), the veins remain green.  
• In cases of serious deficiency, the whole leaf is chlorotic. |

### Manganese (Mn)

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>Manganese is absorbed as Mn$^{2+}$.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>It forms part of the chloroplast membrane. It is the activator of several enzymes, including those that intervene in the synthesis of fatty acids and the formation of DNA and RNA.</td>
</tr>
</tbody>
</table>
| Deficiency symptoms: | • Black or brown spotting on the youngest leaves.  
• Yellowish leaves.  
• Poor skin finish of the tubers.  
• The tubers are more easily damaged during storage. |
### Copper (Cu)

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>Copper is absorbed as Cu$^{2+}$ ion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>It intervenes in the processes of photosynthesis and respiration.</td>
</tr>
</tbody>
</table>
| Deficiency symptoms: | • Young leaves become flaccid and wilted.  
                          • Terminal buds fall and flower buds develop.  
                          • The leaf tips become necrotic. |

### Zinc (Zn)

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>Zinc is actively absorbed as Zn$^{2+}$ ion.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>It is fundamental in the synthesis of auxins and indoleacetic acid (IAA). It also participates in the activation of certain enzymes.</td>
</tr>
</tbody>
</table>
| Deficiency symptoms: | • The young leaves become chlorotic (green or light yellow). They are narrow, their edges curl upward, and their tips show scorching.  
                           • Other foliar symptoms are: green veins, erect appearance, and dead tissue spots |

### Boron (B)

<table>
<thead>
<tr>
<th>Form of absorption:</th>
<th>The plant absorbs boron in the form of boric acid.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Physiological functions:</td>
<td>Boron regulates the transportation of sugars through membranes and also plays an important role in cell division and development, as well as in the metabolism of auxins.</td>
</tr>
</tbody>
</table>
| Deficiency symptoms: | • Death of the sprouts, so plants have bushy appearance with short internodes.  
                           • Thick leaves, curled upward.  
                           • The tissue of the leaves darkens and collapses.  
                           • Brown necrotic spots appear on the tubers and spots form inside them. |
### Chlorine (Cl)

<table>
<thead>
<tr>
<th><strong>Form of absorption:</strong></th>
<th>Chlorine is actively absorbed as Cl⁻ ion.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physiological functions:</strong></td>
<td>Its function is associated with the oxygen cycle in the process of photosynthesis. In a small amount it is an essential micronutrient for plants, but in excess it can be toxic.</td>
</tr>
</tbody>
</table>
| **Deficiency symptoms:** | - Leaves fall off.  
- Curling of leaflets.  
- Bronzing and chlorosis similar to manganese deficiency.  
- Severe deficiency inhibits root growth. |

### Molybdenum (Mo)

<table>
<thead>
<tr>
<th><strong>Form of absorption:</strong></th>
<th>The plant actively absorbs molybdenum as molybdate anion molibdato (MoO₄²⁻).</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Physiological functions:</strong></td>
<td>Molybdenum is a component of the enzymes nitrate reductase and nitrogenase; the first is indispensable in the reduction of nitrates, the second in the biological fixation of nitrogen.</td>
</tr>
</tbody>
</table>
| **Deficiency symptoms:** | - Interverinal spotting (dead tissue spots between veins of leaves).  
- Marginal chlorosis of the oldest leaves.  
- Upward curling of leaf margins. |
WHAT ARE THE PHENOLOGICAL STAGES OF THE POTATO CROP?

The potato presents six phases of development, also called phenological stages, which we need to be familiar with if we are to manage potato cultivation successfully using aeroponics.

The phenological stages are:

1. Rest period of the seed (dormancy)
2. Sprouting
3. Emergence
4. Stem development
5. Tuber initiation and flowering
6. Tuber development (bulking)

1. Rest period (Dormancy)

This is the period between the harvest and the sprouting. While dormant, the eyes of the tubers are inactive, with no processes of differentiation of tissues or cell division, even when the tuber is in environmental conditions suitable for their development.

For the minituber produced in aeroponics, this stage lasts from a few days to three months or more, depending on the variety. The potatoes of the two subspecies of Solanum tuberosum: ssp. tuberosum and ssp. andigena pass through a period of relative inactivity prior to sprouting; on the other hand, chaucha or criolla potatoes of the Solanum phureja species do not present dormancy.

The dormancy also depends on the temperature and light conditions under which the minitubers are stored. High temperatures reduce dormancy, while low temperatures prolong it.
In fact, to prolong dormancy, we can decelerate the physiological processes by placing the minitubers in a cold room at 4°C. Minitubers harvested immature and those exposed to light have longer periods of dormancy.

The dormancy can be broken or induced by injuries or by some diseases in the minituber; in these cases, sprouting occurs in less time. It can also be induced by chemical treatment, submerging the minitubers in a solution of gibberellic acid, in doses of 1 to 5 parts per million (ppm) per volume of water.

The duration of the dormancy period is the determining factor for defining the best time for planting. For example, if a variety has a dormancy period of three months, the planting date will be at least three months after the harvest of its minitubers.

**Important!**

The period of dormancy ends with initiation of growth of the first sprout.

### 2. Sprouting

This occurs when the sprouts of the tubers start to appear, following the period of dormancy. Three states are distinguished:

- Apical dominance
- Multiple sprouting
- Senescence

**State of apical dominance.** This happens when the first sprout appears at the apex of the tuber. The degree of apical dominance depends on the potato variety and on the postharvest management of the minitubers (low temperatures favor apical dominance).
If the tubers show apical dominance, we need to remove the sprout and place them in an environment with temperatures between 15 and 20°C, with 90 to 95% relative humidity, with diffused light, and good ventilation, to stimulate the development of the rest of the sprouts. Minitubers with a weight below 8 g should not have the sprout removed, as that will cause them to lose vigor.

- **State of multiple sprouting.** This is when the tuber has several sprouts. When the minitubers are stored with diffused light and in moderate temperatures, they produce short, strong sprouts, ideal for planting.

Once the tubers have sprouted well, they are ready to be planted. In the case of minitubers harvested in aeroponics, it is ideal for them to have at least three strong, short sprouts (1 to 2 cm) before they are planted in the field.

**State of senescence.** After the multiple sprouting period, the tuber grows old. The signs are excessive branching in the sprout; long, weak sprouts; and also diminutive tubers forming directly in the sprouts. Such tubers should not be used as planting material.
3. Emergence

The sprouts emerge from 8 to 20 days after planting, when the tubers are planted in the field at a depth of 5 to 10 cm and they have adequate conditions for growth (temperature and soil humidity).

In the case of aeroponics, this stage would be transplantation (using rooted cuttings or in vitro plantlets), since this is the beginning of the plant’s leaf and root development.

4. Stem development

At this stage — between 20 and 50 days in the field, and up to 80 days after transplantation in aeroponics— there is simultaneous growth of foliage and roots. In aeroponics, a specific nutrient solution has to be used for the development of the plant.

5. Tuber initiation and flowering

Flowering is the sign that the potato is beginning to form stolons or initiating tuber formation. In aeroponics, we find that for early improved varieties this occurs 40 days after transplantation; in intermediate varieties, 40 to 50 days; and in late varieties, 50 to 80 days.

In native varieties, we find a large variation in the times of tuber initiation, ranging from 40 to 90 days after transplantation, depending on the variety\textsuperscript{45}.

The nutrient solution must be changed to induce tuber formation, for example, using the final solution of Universidad Nacional Agraria La Molina (UNALM), Peru.

6. Tuber bulking

At this stage, the minitubers may be harvested and stored.

In aeroponics, it has been seen that the plants complete the stage of minituber development and reach physiological maturity (senescence) in approximately 150 days in early improved varieties; 180 days in intermediate varieties; and 250 days in late varieties.

In some native varieties of the andigena subspecies, senescence is reached between 220 and 250 days after transplantation.

In the cases of both improved and native varieties, the period for reaching physiological maturity depends on the variety, the management and the environment.

\textsuperscript{45} Medina, 2014
In a few words...

Understanding the physiology of the potato plant is essential for good management of the aeroponic crop. The factors that influence the potato plant’s growth and which must be taken into account in crop management are the following:

**Genetic:** the varieties with the greatest genetic influence of the andigena subspecies tend to form more abundant foliage, longer stolons, and a larger number of tubers than the varieties with greater genetic influence of the tuberosum subspecies.

**Physiological age of the planting material:** this has a direct effect on the development of the plants. Physiologically old material (such as rooted cuttings) tends to produce fewer tubers, but larger in size compared with the use of physiologically young material (in vitro plants).

**Photoperiod:** the varieties of the Andean region form tubers in short photoperiods (about 12 hours of light and 12 hours of dark). For this reason, in the case of aeroponics in the Andes (and other tropical regions), it is not necessary to provide additional light in the net houses for those varieties.

**Temperature:** the potato crop is adapted to cold tropical climates with temperatures of approximately 15 to 25°C in the daytime and 8 to 15°C at night. Indoor greenhouse temperatures higher than 30°C and lower than 4°C can affect the crop.

Six physiological stages are distinguished in the potato crop. The most important for aeroponics are stem development, tuber formation and tuber bulking, since the yield obtained depends on these.
CHAPTER 6

MANAGING THE AEROPONIC POTATO CROP

Jacqueline Benítez
Darío Barona
Carlos Chuquillanqui
Magali García
Peter Kromann
Fabían Montesdeoca
WHAT DO WE PLAN TO DO IN THIS CHAPTER?

- Explain the importance of hygiene standards for managing an aeroponic crop.
- Present the steps for preparing the nutrient solution.
- Describe the processes of:
  - Preparing material for transplantation
  - Transplanting into the aeroponic modules
  - Lowering of stems (equivalent of hilling up)
  - Pruning
  - Training
  - Integrated pest and disease management
  - Harvesting and storing the minitubers
WHY ARE THERE HYGIENE STANDARDS FOR AEROPONICS?

Jacqueline Benitez

Because they are necessary to reduce the risk of contamination. It is important to remember that any contamination of the irrigation system by pathogens that affect the plant’s vascular or root system can cause total loss in the modules. This means that hygiene management in the net house and the other facilities is essential for the production of minitubers using aeroponics.

Factors that produce contamination

The production of high quality minitubers from in vitro plants or cuttings must comply with the quality control parameters of the regulations in force in each country, which is the basis for obtaining the other seed potato categories.

It is thus necessary to consider some elements that could constitute a danger for the entire seed potato production system in aeroponics: the air and water, people, equipment and instruments.

Air and water

The net house is not an enclosed environment and therefore drafts of air and any water that enter it are sources of contamination, since they can carry spores of microorganisms that could grow if the conditions are right. Likewise, when the doors of the net house are opened, the air that comes in can bring insects— in particular those that are virus vectors—causing contamination of the plant material.

People

It is often people who cause contamination in the net house, either directly or indirectly, because they can carry microorganisms and insects on their hands, in their clothes, and especially on their shoes. The greenhouse operators who are in contact with the plants, the technical staff and all other people who for any reason enter the net house, can contribute to spreading contaminating agents.

Equipment and instruments

In minituber production, different pieces of equipment and tools are used: backpack sprayers, tweezers, scalpels, etc., which when handled and carried can also introduce insects and microorganisms.
What are the hygiene standards for management of the net house?

These are the most important:

- Restrict entry into the net house to staff not working in that area. The greenhouse operators must not enter the net house if they have just come from the field.

- Wash hands with abundant soap and water before entering.

- Any person entering the net house must, in the pre-chamber, put on an apron and plastic boots reserved exclusively for this use and not take them off while he or she remains there. Disposable aprons and overshoes are a good option for receiving visitors.

- Keep two trays (footbaths) in the pre-chamber at the entrance of each greenhouse: the first filled with a 1% sodium or calcium hypochlorite solution and the other with agricultural lime. People should stand in each tray — the solution first and lime second — before entering the production area. The chlorine solution loses efficiency with time and should be renewed after a lot of people pass through or, at very least, every seven days. Care must be taken with clothes when stepping onto the first footbath because the chlorine solution can bleach them.

- People should place their hands in a 70% solution of antiseptic alcohol, especially if they are going to handle the plants, for example, lowering the stems, taking samples, etc. Disposable latex gloves can also be worn, with frequent applications of antiseptic alcohol (70%).

- In the pre-chamber, always have one of the two doors closed to prevent drafts of air from entering the net house, and any air-borne insects with them.

- Do not let the equipment and tools used for aeroponics be taken to other areas, especially not to the field.

- Disinfect tools prior to using them for stem lowering (equivalent to hilling up), pruning or other tasks with a 1% sodium or calcium hypochlorite solution.

- After making cuts in each plant, disinfect the blade of the scalpel with antiseptic alcohol (70%) and pass it over a flame, to prevent the propagation of pathogens.

- Do not smoke in the net house.

- Since pesticides are used, eating and drinking in the net house are forbidden.

- Do not touch the plants unless absolutely necessary.

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46 See Annex 3. Examples of how to prepare sodium hypochlorite solutions.
- Do not use the net house as a storage place for equipment, tools, etc.

- Clean all the surfaces inside the net house, especially the modules, with a 0.25% hypochlorite solution, to remove the dust that accumulates and that could contain pathogen spores.


**EXPERIENCES AND LESSONS LEARNED**

**What does experience tell us?**

- Our experience has shown that hygiene standards are not easy to implement with staff that is not used to taking these types of precautions. The technical staff need to know the standards so that they can train the greenhouse operators, put the standards into practice to give the example, and then follow up to ensure that staff applies them.

- Since aeroponics is a very attractive technique, there are always people interested in visiting aeroponic greenhouses. This should be avoided as much as possible. Ideally, visitors should observe the aeroponics operation from outside the net house, to prevent contamination. After a visit, disinfecting the floors of the net house by aspersion with a 0.25% sodium or calcium hypochlorite solution is recommended.
HOW IS THE NUTRIENT SOLUTION PREPARED?

Darío Barona

By mixing compounds that contain the essential nutrients, dissolved in water, so that the plants can absorb them through their roots and utilize them.

Plants in aeroponic modules don’t need soil for nourishment; they are fed by a nutrient solution that is supplied to them in the right quantities to ensure their growth47.

The implementing technical staff is responsible for preparing the nutrient solutions, although the greenhouse operators may also do it, providing that they have been trained and are working under the technician’s supervision.

The steps for preparing the nutrient solution are as follows:

1. Chemical analysis of the water
2. Selection of the formula and of the fertilizers for the nutrient solution
3. Preparation of the nutrient solution

1. Chemical analysis of the water

Before starting the preparation of the nutrient solution, we need to determine the quality of the water we will be using, to know its content of salts and nutrients. Based on these data, we can cover the nutritional requirements of the plant, and prepare the nutrient solution.

A full chemical analysis of the water enables us to obtain the values of macronutrients, micronutrients, electrical conductivity (EC), potential of hydrogen (pH), hardness (quantity of minerals, in particular salts of magnesium and calcium), total solids, chlorides, sulfides, and nitrates, which will make it possible to decide how to use this water.

After the analysis, its characteristics can be identified, and you must evaluate whether it is prudent to use it. If the results reveal a very hard type of water (more than 120 mg of calcium carbonate, CaCO$_3$, per liter), there could be problems with nutrient fixation. For example, when phosphorous reacts with magnesium or calcium creates insoluble compounds (phosphates).

On the other hand, if, the water is soft, it has minimal quantities of dissolved salts. In this case, there could be pH stability problems, if there is an insufficient quantity of salts (carbonates) to buffer the nutrient solution.

The following table shows the main criteria for evaluating the water before using it to prepare...
Referring to the table above, it is ideal to have values between None and Moderate, because if we have values in the Severe degree of restriction, there can be problems, both with the stability of the nutrient solution, and with clogging of the micro sprinklers.

The iron available in the water source should not be taken into account because it can precipitate.

Likewise, copper and other metals can be immobilized in complex compounds, becoming scantily available for the plants.

The water source must also be considered. If it is well water or water from irrigation ditches, it could have microorganisms (fungi, bacteria, etc.) that can cause diseases in the plants.

This type of water must be treated to disinfect it before using it in the preparation of the nutrient solution.

---

### Criteria for evaluating the water before preparing the nutrient solution

<table>
<thead>
<tr>
<th>Potential problem*</th>
<th>Unit</th>
<th>Degree of restriction in use</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>None</td>
<td>Moderate</td>
</tr>
<tr>
<td><strong>EC</strong></td>
<td>&lt;0.7</td>
<td>0.7 to 3</td>
</tr>
<tr>
<td><strong>TDS</strong></td>
<td>&lt;450</td>
<td>450 to 2000</td>
</tr>
<tr>
<td><strong>Sodium (Na⁺)</strong></td>
<td>&lt;3</td>
<td>&gt;3</td>
</tr>
<tr>
<td><strong>Chlorides (Cl)</strong></td>
<td>&lt;3</td>
<td>&gt;3</td>
</tr>
<tr>
<td><strong>Boron (B)</strong></td>
<td>&lt;0.7</td>
<td>0.7 to 3</td>
</tr>
<tr>
<td><strong>Nitrates (N-NO₃⁻)</strong></td>
<td>&lt;5</td>
<td>5 to 30</td>
</tr>
<tr>
<td><strong>Bicarbonates (HCO₃⁻)</strong></td>
<td>&lt;1.5</td>
<td>1.5 to 8.5</td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td></td>
<td>Normal range 6.5 to 8.4</td>
</tr>
</tbody>
</table>

* EC: electrical conductivity; TDS: total dissolved solids; pH: potential of hydrogen

Salinity affects the availability of water for the plants. The EC is reported in terms of decisiemens per meter at 25°C (dS m⁻¹) or in milimhos per centimeter (mmho cm⁻¹). Both measurements are equivalent, the former being the unit adopted by the International System of Units. TDS is the total solids in solution, and it is expressed in mg l⁻¹.

Nitrates (N-NO₃⁻) refer to the nitric nitrogen reported in terms of elementary nitrogen.

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For example, by chlorination: that is, the application of 2 to 5 ppm of sodium or calcium hypochlorite some days prior to preparation of the nutrient solution, which gives a residual concentration of chlorine of 0.5 to 1 ppm. Microbiological filters may also be used, or other methods for disinfecting the water⁴⁹.

2. Selection of the formula and fertilizers for the nutrient solution

In aeroponics, two nutrient solutions are normally used:

- **The initial solution**, which is maintained from transplantation until the lowering of stems (hilling up), that is, for the first 35 or 40 days.

- **The final solution**, which is used after lowering of stems (hilling up) until cultivation is completed.

There are many formulae for seed potato production by hydroponic methods that have been tried around the world. In the following chart, we present formulae of nutrient solutions that have been tested and used for aeroponic potato production in different systems in the Andean region.

### Nutrient solutions used in aeroponic potato cultivation

<table>
<thead>
<tr>
<th>Nutrient solution</th>
<th>Milligrams per liter (= ppmᵃ)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>UNALMb</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>150</td>
</tr>
<tr>
<td>CIP-Lima</td>
<td>191</td>
</tr>
<tr>
<td></td>
<td>155</td>
</tr>
<tr>
<td>INIAP, CIP-Quito</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>150</td>
</tr>
<tr>
<td>CORPOICA</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>150</td>
</tr>
</tbody>
</table>

ᵃ Parts per million.
ᵇ Universidad Nacional Agraria La Molina, Lima, Peru.
ᶜ Solution used from transplantation to lowering of stems (hilling up).
ᵈ Solution used from lowering of stems (hilling up) to completion of harvest.

The original solution with which aeroponic work began at CIP-Lima, in 2005, was the solution developed by Universidad Nacional Agraria La Molina (UNALM) in Lima, Peru, to be used on different crops⁵⁰. This solution was subsequently adjusted by CIP, INIAP, and CORPOICA, as part of the aeroponics validation process, that is, its adaptation to local conditions.
During this trial period, the support of plant nutrition experts or people with experience in aeroponics is recommended.

For example, it will probably be necessary to do analyses of the nutrient concentration in leaves and other parts of the plant. These analyses should be interpreted by specialists in plant nutrition, who will suggest any corrective measures that may be required in the nutrient solution.

**What fertilizers should we use in aeroponics?**

Not all the fertilizers used in conventional agriculture are suitable for preparing nutrient solutions for aeroponics.

Aeroponics requires fertilizers with rapid and high solubility in water, and which contain levels of insoluble residues, contaminating heavy metals, or other components that are toxic for plants, for example chlorides, lower than the maximum tolerance specified in the regulations in force in each country.

Some fertilizers contribute —to a greater or lesser degree— to the alkalinity or acidity of the solution, so it is good to have that information.

- Acidifying fertilizers include:
  - ammonium phosphate
  - ammonium sulfate
  - urea
  - ammonium nitrate

- And neutral fertilizers include:
  - potassium chloride
  - potassium nitrate
  - potassium sulfate

The selection of fertilizers will also depend on their availability. The following table shows the fertilizers and acids most commonly used in the preparation of nutrient solutions for aeroponics.
For the macronutrients, diammonium phosphate, monoammonium phosphate, potassium nitrate, potassium sulfate and others that have a high percentage of macronutrients in their composition may be used.

For the micronutrients, compound fertilizers may be used, which are highly soluble and which will be sufficient to cover the nutritional needs of the plants.

---

**Fertilizers and acids used for the formulation of nutrient solutions**

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Chemical composition</th>
<th>Molecular weight (g/mol)</th>
<th>Nutrients</th>
<th>Concentración (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boric acid</td>
<td>H₃BO₃</td>
<td>61.83</td>
<td>B</td>
<td>17</td>
</tr>
<tr>
<td>Phosphoric acid</td>
<td>H₃PO₄</td>
<td>98</td>
<td>P₂O₅</td>
<td>61</td>
</tr>
<tr>
<td>Molybdic acid</td>
<td>H₂MoO₄H₂O</td>
<td>180</td>
<td>Mo</td>
<td>47.5</td>
</tr>
<tr>
<td>Nitric acid</td>
<td>HNO₃</td>
<td>63</td>
<td>N</td>
<td>22</td>
</tr>
<tr>
<td>Borax</td>
<td>Na₂B₄O₇10H₂O</td>
<td>381.2</td>
<td>B</td>
<td>11.3</td>
</tr>
<tr>
<td>Potassium chloride</td>
<td>KCl</td>
<td>74.55</td>
<td>K₂O</td>
<td>60</td>
</tr>
<tr>
<td>Zinc chloride</td>
<td>ZnCl₂</td>
<td>136</td>
<td>Zn</td>
<td>45</td>
</tr>
<tr>
<td>Diammonium phosphate (DAP)</td>
<td>(NH₄)₂H₂PO₄</td>
<td>132.1</td>
<td>P₂O₅</td>
<td>18-37</td>
</tr>
<tr>
<td>Monoammonium phosphate (MAP)</td>
<td>(NH₄)₂H₂PO₄</td>
<td>115</td>
<td>P₂O₅</td>
<td>12-61</td>
</tr>
<tr>
<td>Monopotassium phosphate</td>
<td>KH₂PO₄</td>
<td>136.1</td>
<td>K₂O</td>
<td>52-34</td>
</tr>
<tr>
<td>Sodium molybdate</td>
<td>Na₂MoO₄.2H₂O</td>
<td>241.9</td>
<td>Mo</td>
<td>40</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>NH₄NO₃</td>
<td>80</td>
<td>N</td>
<td>34</td>
</tr>
<tr>
<td>Calcium nitrate</td>
<td>(Ca(NO₃)₂·2H₂O)NH₄NO₃</td>
<td>1080.5</td>
<td>CaO/N</td>
<td>17/15.5</td>
</tr>
<tr>
<td>Magnesium nitrate</td>
<td>Mg(NO₃)₂·6H₂O</td>
<td>256.3</td>
<td>MgO/N</td>
<td>16/11</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>KNO₃</td>
<td>101.1</td>
<td>K₂O/N</td>
<td>44/13</td>
</tr>
<tr>
<td>6% Iron chelate</td>
<td>Fe-DTPA</td>
<td>932</td>
<td>Fe</td>
<td>6</td>
</tr>
<tr>
<td>5% Iron chelate</td>
<td>Fe-EDDHA</td>
<td>1118</td>
<td>Fe</td>
<td>5</td>
</tr>
<tr>
<td>13% Iron chelate</td>
<td>Fe-EDTA</td>
<td>430</td>
<td>Fe</td>
<td>13</td>
</tr>
<tr>
<td>Manganese chelate</td>
<td>Mn-EDTA</td>
<td>366</td>
<td>Mn</td>
<td>15</td>
</tr>
<tr>
<td>Ammonium sulphate</td>
<td>(NH₄)₂SO₄</td>
<td>132.14</td>
<td>N S</td>
<td>21/24</td>
</tr>
<tr>
<td>Copper(II) sulphate</td>
<td>CuSO₄.5H₂O</td>
<td>249.7</td>
<td>S Cu</td>
<td>13/25</td>
</tr>
<tr>
<td>Iron sulfate</td>
<td>FeSO₄·7H₂O</td>
<td>277.8</td>
<td>S Fe</td>
<td>11/20</td>
</tr>
<tr>
<td>Magnesium sulfate</td>
<td>MgSO₄·7H₂O</td>
<td>246.3</td>
<td>MgO/S</td>
<td>16/13</td>
</tr>
<tr>
<td>Manganese sulfate</td>
<td>MnSO₄·5H₂O</td>
<td>169</td>
<td>S Mn</td>
<td>18/31</td>
</tr>
<tr>
<td>Potassium sulfate</td>
<td>K₂SO₄</td>
<td>174.3</td>
<td>K₂O/S</td>
<td>50/18</td>
</tr>
<tr>
<td>Zinc sulfate</td>
<td>ZnSO₄·7H₂O</td>
<td>287.5</td>
<td>S Zn</td>
<td>11/22</td>
</tr>
<tr>
<td>Urea</td>
<td>CO(NH)₃</td>
<td>60</td>
<td>N</td>
<td>46</td>
</tr>
</tbody>
</table>
An experience:

At present, there are companies that market fertilizers and nutrient solutions with which agreements can be made for them to do the physical mixes of simple fertilizers, which facilitates the preparation of the nutrient solution.

For example, CIP-Lima came to an agreement with a private company to prepare and sell a physical mix of several soluble fertilizers for use in aeroponics, which facilitated the nutritional management of the plants.

3. Preparation of the nutrient solution

We can use the following example to determine the required formulation of a nutrient solution (both initial and final) that will be prepared using as reference the UNALM solution, taking into account the characteristics of the water, whose chemical analysis is known. The volume required is 250 l.

### Chemical composition of water, initial UNALM solution and final adjustment

<table>
<thead>
<tr>
<th></th>
<th>Milligrams per liter (= ppm$^*$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
</tr>
<tr>
<td>Water</td>
<td>UND</td>
</tr>
<tr>
<td>UNALM initial</td>
<td>190</td>
</tr>
<tr>
<td>UNALM final</td>
<td>150</td>
</tr>
<tr>
<td>Adjustment initial</td>
<td>190</td>
</tr>
<tr>
<td>Adjustment final</td>
<td>150</td>
</tr>
</tbody>
</table>

$^*$ Parts per million  
| b Undetermined |

After making the adjustment of the nutrient solution (both for the initial and for the final solution), the fertilizers available in the market need to be identified.

The following chart gives the quantities of fertilizers that should be used to prepare 250 l of the UNALM initial and final solutions, as indicated in the previous chart. The fertilizers used are those normally found in Peru, since this example is based on an experience at CIP-Lima.
Fertilizers required for 250 liters of nutrient solution

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Unit</th>
<th>Initial solution 1 l</th>
<th>Initial solution 250 l</th>
<th>Final solution 1 l</th>
<th>Final solution 250 l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium nitrate</td>
<td>g</td>
<td>0.63156</td>
<td>157.9</td>
<td>0.63156</td>
<td>157.9</td>
</tr>
<tr>
<td>Magnesium sulfate</td>
<td>g</td>
<td>0.45684</td>
<td>114.2</td>
<td>0.45684</td>
<td>114.2</td>
</tr>
<tr>
<td>Potassium sulfate</td>
<td>g</td>
<td>0.3292</td>
<td>82.3</td>
<td>0.43364</td>
<td>108.4</td>
</tr>
<tr>
<td>Potassium nitrate</td>
<td>g</td>
<td>0.32304</td>
<td>80.8</td>
<td>0.03352</td>
<td>8.4</td>
</tr>
<tr>
<td>Ammonium nitrate</td>
<td>g</td>
<td>0.03448</td>
<td>8.6</td>
<td>0.25856</td>
<td>64.6</td>
</tr>
<tr>
<td>10% Iron chelate</td>
<td>ml</td>
<td>0.03</td>
<td>7.5</td>
<td>0.06</td>
<td>15.0</td>
</tr>
<tr>
<td>Phosphoric acid, 85%</td>
<td>ml</td>
<td>0.0992</td>
<td>24.8</td>
<td>0.088</td>
<td>22.0</td>
</tr>
<tr>
<td>Foliar fertilizer(^a)</td>
<td>g</td>
<td>0.012</td>
<td>3.0</td>
<td>0.012</td>
<td>3.0</td>
</tr>
</tbody>
</table>

\(^a\) Commercial foliar fertilizer: 4.0% (Mn); 4.0% (Fe); 1.5% (Cu); 1.5% (Zn); 0.5% (B); 0.1% (Mo); 3.3% (MgO); 3.0% (S). All the metallic micronutrients are in chelated form EDTA. Chelates are complexes formed by the union of a metal and a compound that contains two or more potential ligands.

**Materials**

- Weighing scales with at least 0.1 g precision.
- Plates for weighing the fertilizers. Plastic plates are recommended to prevent them from rusting and reacting with the fertilizers.
- Plastic spoon.
- 3 ten-liter plastic buckets.
- 2 graduated test tubes, 25 ml.
- Rod or other tool to stir the solution, preferably plastic.
- Portable pH-meter and conductivity meter.

**Important!**

When preparing nutrient solutions, wear gloves and a facemask at all times and avoid direct contact with the fertilizers.
**Procedure (for a 250 liter tank)**

**First.** Weigh (with the scales) or measure (with the graduated test tube) the required quantities of each fertilizer.

**Second.** Dissolve each fertilizer separately in recipients containing half a liter of water. To dissolve the potassium sulfate, hot water is recommended.

**Third.** Half-fill the 250-liter tank with water and incorporate the dissolved fertilizers one by one, stirring the solution with clean, disinfected utensils.

**Fourth.** Fill the tank with water, to complete the 250 liters. Stir the solution so that the nutrients are evenly distributed. Mix and oxygenate the nutrient solution.

---

**PRECAUTIONS FOR PREPARING THE NUTRIENT SOLUTION**

- Review the solubility and compatibility of fertilizers with the supplier/s.
- Add liquid fertilizers to the water in the tank before adding solid fertilizers.
- Add the fertilizers slowly, while stirring to prevent insoluble compounds from forming.
- Place the acid in the water, NOT the water in the acid.
- When adding chlorine, always add the chlorine to the water, not the water to the chlorine.
- Never mix an acid or acid fertilizer with chlorine (sodium hypochlorite will form, which is a toxic gas).
- Do not mix anhydrous ammonium ($\text{NH}_3$) or ammonia water directly with any acid. The reaction is violent and immediate.
- Do not mix concentrated fertilizer solutions directly with other concentrated fertilizer solutions.
- Do not mix compounds containing sulfate with compounds containing calcium (it will result in insoluble gypsum).
- Do not mix fertilizers that have a strongly acid reaction with others that have a strongly alkaline reaction.
- Do not mix phosphate fertilizers with fertilizers containing calcium. Extremely hard waters will combine with the phosphorous or sulfates and form insoluble substances.
**Storage**

The fertilizers should be stored in a cool place, free from humidity. Fertilizer handling indications given on the manufacturer’s fact sheets and safety data sheets should be followed. Never store acids and chlorine in the same place.

**How do we manage the pH and electrical conductivity (EC) of the solution?**

The addition of the nutrients to the nutrient solution directly affects the osmotic potential and pH.

Osmotic potential is the concentration of mineral salts in the nutrient solution and it is measured by electrical conductivity (EC). There is a linear relationship between the osmotic potential and the EC. The potential of hydrogen (pH) is a measurement of the acidity or alkalinity of the nutrient solution.

The pH in the environment of the roots is important because very low values are toxic for the plants. However, in practice, the pH is important for its effects on the availability of many nutrients, especially the micronutrients.

**Important!**

The pH of the nutrient solution must be managed with great care. High pH values can lead to deficiencies of micronutrients such as iron. With low pH values, there can be a deficiency of macronutrients, such as phosphorous.

It is advisable to measure the pH and EC first thing every day, since these data tell us how the nutrient solution is behaving. We can then make any correction that may be needed.

To take these measurements, you will need portable measuring instruments: a pH-meter and a conductivity meter. Careful handling and cleanliness of the instruments are indispensable for accurate measurements, as is following the manufacturer’s instructions.

**Important!**

The ideal EC for an aeroponics system is 1.5 to 2.5 dS.m\(^{-1}\).

High EC values hinder nutrient absorption due to the increase in osmotic pressure, while low EC values can severely affect the plant’s growth and its yield, due to the deficiency of nutrients.
The reduction in water absorption correlates in a linear way with the EC. It is, therefore, recommended to maintain an average EC of 2.0 dS m\(^{-1}\) in an aeroponic potato production system. We can reduce the EC by adding pure water to the nutrient solution. If, on the other hand, we have EC values of less than 1.5 dS m\(^{-1}\) fertilizers can be added to the nutrient solution.

When it comes to the pH, variations observed in a nutrient solution respond to the difference, in magnitude, of the plants' absorption of nutrients, in terms of the balance of anions over cations. When anions are absorbed in higher concentrations than cations—for example, in the case of nitrate—the plants excrete OH or HCO\(^{-3}\) as anions to balance the electrical charges in the solution, thereby producing an increase in the pH value. This process is called physiological alkalinity.

Regulating the pH is normally done with acids: nitric, sulfuric or phosphoric. These acids can be used individually or in combination. If you need to raise the pH, it is best to use hydroxides, especially potassium hydroxide.

**Important!**

The ideal pH for an aeroponic system is slightly acid, between 6.5 and 6.8.

**How often should we change the nutrient solution?**

It should be changed every 7 to 15 days, since the solution's pH and EC change over time as it is recycled and its nutrients are absorbed by the plants. At the same time, the plants' roots release different types of organic substances into the nutrient solution that cause issues of pH and EC instability. The presence of those organic substances in the nutrient solution may or may not be harmful for the growth and production of plants in the aeroponic system.

In addition, as the nutrient concentration in the solution becomes reduced, there is a possibility of problems of toxicity or deficiency in the plants, and a decrease in yields.

How often the nutrient solution needs to be changed also depends on the stage of growth the plants are in, because if they are at an early stage, with small plants, water consumption is very low, so you can wait longer to make changes. On the other hand, if the plants are at the height of their growth and production, water consumption is high, so it is recommended that you change the solution more frequently.

The decision of when to change the solution also depends on environmental conditions. If there are high temperatures, the plants will consume more solution, and evaporation of the nutrient solution can also occur, which cause the pH and the EC to vary. In such cases, it is advisable to change the solution at shorter intervals.
What can we do with the remaining solution?

This solution contains nutrients that can be used by plants. Therefore, it can be used in family gardens or vegetable gardens near the aeroponic system, preferably on crops that don't require intensive agronomic management and that are not Solanaceae, in order to prevent potential spreading of diseases.

Before using this nutrient solution in an intensive cropping system, it is best to do an analysis of the nutrient content. If the concentration is found to be low, it could be advisable to increase the fertilizer dosage to complement it. However, more research is needed on this issue.

EXPERIENCES AND LESSONS LEARNED

What does experience tell us?

About reutilizing the used solution

IN ECUADOR

At CIP-Quito, a greenhouse was implemented for tomato production with a drip irrigation system and fertigation, which is a practical example of reusing the nutrient solution. But the results were very poor, which confirms that it is inappropriate to rely on the used nutrient solution as the only source of fertilization for Solanaceae or intensive cropping.

IN PERU AND KENYA

At CIP-Huancayo and at the Tigoni Station (Kenya), ornamental plants on the research stations' grounds are fertilized with the used solution.

About managing phytotoxicity

IN ECUADOR

Even though the necessary precautions are taken, cases of phytotoxicity will probably appear due to errors in the preparation of the nutrient solution, especially during the validation stage of aeroponics.
IN PERU
At CIP-Lima, deficiency problems were detected, mainly of calcium and manganese. This was possibly because the water used for the nutrient solution was very hard, which caused the plants to assimilate lower levels of nutrients. This illustrated the importance of analyzing the water before preparing the nutrient solution.

About controlling excessive foliage and prolongation of the crop cycle
IN PERU AND ECUADOR
Excessive plant growth and a longer duration of the crop cycle are problems found in aeroponics. This, apparently, is due to an excess of nitrogen and other nutrients in the solution. The excessive growth of the plants has been managed with pruning, but the long duration of the crop cycle hasn’t been controlled. This points to the need for research into doses and sources of nutrients to control these problems.

IN COLOMBIA
At CORPOICA-Tibaitatá, where researchers used a final nutrient solution with lower levels of macro nutrients than the solutions used in other countries, there have been no excesses in plant height.

IN ETHIOPIA
At the Holetta Experimental Station, exceptional foliage growth was observed on the plants, but they produced few minitubers. Upon reviewing the fertilizers being used, it was discovered that they were pure laboratory compounds rather than field fertilizers, which have less concentrated nutrients.

About managing nutrient deficiencies
IN PERU
At CIP-Lima, deficiency problems were detected, mainly of calcium and manganese. This was possibly because the water used for the nutrient solution was very hard, which caused the plants to assimilate lower levels of nutrients. This illustrated the importance of analyzing the water before preparing the nutrient solution.
About fertilizing with magnesium sulfate

IN ECUADOR, COLOMBIA AND PERU

Following a recommendation from the Universidad Nacional Agraria La Molina (Lima, Peru), CIP-Lima, CIP-Quito and CORPOICA-Tibaitatá have used a concentration of 0.457 g of magnesium sulfate per liter—higher than that recommended by Otazú (2010): 0.247 g per liter—with good results. In contrast, doses lower than that recommended by Otazú (2010), are used in several African countries: 0.1 g per liter.

Lessons learned:

The nutrient solution is an important factor in aeroponics. The plants' nutrition depends solely on the fertilizers used, together with management of the pH and EC. Because it is a recirculating solution, its nutrient concentrations, pH and EC vary over the course of time, from when it is prepared to when it is replaced 7 to 15 days later. As you can see, the management of the nutrient solution is complex.

In fact, at the initial stage of validation of aeroponics, you frequently encounter problems of deficiency, moderate phytotoxicity and, in some cases, acute phytotoxicity, which can cause total loss of production.

However, once this stage has been resolved, once the sources of nutrients, the concentrations and the optimal management for local conditions have been determined, management of the nutrient solution becomes a routine task.

Finally, it has been shown that when a standard hydroponics nutrient solution (such as the UNALM solution) is used, the yields obtained are acceptable. This indicates that, even though the nutrient solution is important in aeroponics, there are other factors that affect the yield and that require even greater attention: the environmental conditions (defined by the location of the net house and the quality of the infrastructure), the potato variety, and the agronomic management (the quality and acclimatization of planting material, density, lowering of stems [=hilling up], pruning, training, and integrated pest and disease management).
Important

Once the nutrient solution has been prepared, we can start working with the plantlets that will serve as planting material for the aeroponic crop.

It is important to keep the hygiene standards for handling plants in mind. They must be strictly followed, since the health of the minitubers will depend, to a large extent, on them.

Remember that the minitubers will be planted in the field to obtain basic seed, registered and certified, and a contaminated minituber runs the risk of spreading a pest or disease to many farms.

HYGIENE STANDARDS FOR HANDLING PLANTS DURING ACCUMULATION, TRANSPLANT, STEM LOWERING, PRUNING AND HARVEST

- Disinfect the tools that will be used (tweezers, scalpels, etc.) with a 1% sodium or calcium hypochlorite solution.

  - **Always use gloves when handling the sodium or calcium hypochlorite solution.**

- Wash your hands with soap and water before handling the plants.

- Place your hands in a 70% antiseptic alcohol solution. Disposable latex gloves with frequent applications of antiseptic alcohol (70%) may also be used.

- After making cuts in each plant, disinfect the blade of the scalpel with antiseptic alcohol (70%) and pass it over a flame to prevent the propagation of pathogens.

- Always wear a clean apron that is used exclusively for working in the greenhouse.

- When pruning, gather up the plant material (leaves, stems) in plastic bags and dispose of it appropriately, for example on a compost heap far from the net house.
Because it needs to be adapted to the conditions of the net house. The plantlets used for aeroponics usually come from a laboratory (in vitro) or from cuttings obtained from mother plants. In both cases, it is advisable to acclimatize them.

**Acclimatizing in vitro plantlets**

Unquestionably, the laboratory environment is different from the net house environment, so the material to be transplanted requires a process of adaptation, which consists in providing the ideal environmental factors for a gradual transition from the in vitro environment to the ex vitro environment.

When the in vitro plantlets arrive from the laboratory in tubes or magenta boxes, they need to be acclimatized to adapt them to the net house environment and to allow them to grow their root system and harden their stems before being transplanted. At this point, the most vigorous plants can be selected.

There are different options for acclimatizing the plantlets:

- In sand trays
- In small modules
- In floating root trays

**Acclimatization in sand trays**

**What will we need?**

- In vitro plantlets
- Plastic trays (approximately 6 cm deep, with holes in the base)
- Anti-aphid net
- Sand
- Potable water
- Containers for washing the plantlets’ roots
- Initial nutrient solution (at 50% concentration)
- Paper towels

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Magenta boxes: transparent plastic boxes used for the in vitro cultivation of plants, under aseptic conditions.
Make sure that the sand is from an uncontaminated source. River sand is nearly always contaminated with chemical residues, so it must be washed several times with potable water before being disinfected. It is not advisable to use sand from mine tailings or from the sea.

The sand should have an irregular, angular surface, and it should be 1 to 2 mm in size: this is the sand that gives the best results as rooting substrate. If larger than 2 mm, it provides little contact with the roots. On the other hand, sand that is too fine retains a great deal of humidity, which displaces the oxygen and inhibits root formation.

To disinfect the sand, use sodium hypochlorite, boiled water or moist heat.

**Disinfecting with sodium hypochlorite**

- Distribute a 0.35% sodium hypochlorite solution uniformly over the sand. Ten liters of this solution can be used for 300 kg of sand.

- Soak for ten minutes, and then wash the sand five times with potable water to remove the sodium hypochlorite.

- Dry the sand at ambient temperature in a clean place, protected from rain, for four or five days, to allow the hypochlorite to evaporate.

- Store the sand in clean 15-kg sacks to facilitate transportation.

**Disinfecting with boiled water**

- Boil the sand with water for ten minutes or wash it several times with boiled water.

- Dry the sand at ambient temperature in a clean place, protected from the rain, for one or two days.

- Store the sand in clean 15-kg sacks to facilitate transportation.

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- Anatomical tweezers
- Wash bottle or hand sprinkler
- Disposable latex gloves
- Antiseptic alcohol (70%)
Disinfecting with moist heat

This can be done with portable steam-producing equipment or with autoclaves. The temperature required ranges from 70 to 82°C, for 30 minutes. Temperatures of more than 85°C can cause sand to release manganese or toxic salts (in the case of soil).

How are the trays prepared?

- Make holes in the base of the tray to allow excess water to drain.
- Disinfect the trays with a 0.25% sodium or calcium hypochlorite solution.
- Place anti-aphid net at the bottom of the tray to prevent sand from washing out when irrigating.
- Place the disinfected sand in the trays in a layer approximately 5 cm deep.

How do we transplant the plantlets to the sand tray?

The day for transplanting should be cloudy and cool, because brightness and high temperatures are stress factors for the plantlets.

Transplantation should preferably take place early in the morning or at dusk, following these steps:

- Follow the standards of hygiene for handling plants.
• Make sure that the test tubes or magenta boxes are properly identified with the name of the variety to be transplanted.

• Prepare a container with potable water and a tray with damp paper towels, on which the plantlets will be placed before transplanting.

• Moisten and compact the sand.

• Make holes with your finger or with a test tube, leaving 3 to 4 cm between plants. The holes should be 4 cm deep.
Wash the roots of the plants carefully with potable water. A wash bottle or hand sprinkler can also be used to remove all of the agar that may be adhering to the roots.

Very carefully remove the in vitro plantlets from the tubes or magenta boxes, one by one, with the help of tweezers, without breaking leaves or roots.

Wash the roots of the plants carefully with potable water. A wash bottle or hand sprinkler can also be used to remove all of the agar that may be adhering to the roots.

Transplant the plantlets into the holes, making sure that there is good contact between the plantlet and the sand.

Water the sand lightly with the initial nutrient solution used in aeroponics, at 50%, without removing the sand near the plantlets. Irrigation should be light and frequent, depending on the temperature and the evaporation.
• Provide shade for the plantlets to prevent excessive evapotranspiration and wilting, during the first two or three days. Then, gradually, submit them to the conditions of the net house where they will be finally transplanted.

• Wait for approximately 21 days, and then transplant the plantlets into the aeroponics module.

**Acclimatization in small modules**

This acclimatization is done in disposable micropipette tip boxes.

![Small modules (TipOne® box).](image)

**What will we need?**

- In vitro plantlets
- Small modules
- Containers for washing the plantlets' roots
- Distilled water
- Initial nutrient solution, at 50%
- Air compressor (air pump for aquarium)
- Timer
- Hose, 5 mm in diameter
- Disposable latex gloves
- Antiseptic alcohol (70%)
How is it done?

- Follow the standards of hygiene for handling plants.
- Check the identity of the in vitro plantlets, and clean them following the instructions given for acclimatization in sand trays.
- Remove the in vitro plantlets from the tubes or magentas and wash their roots carefully.
- Transplant the plantlets to the small module.
- Connect the air compressor to the small module using a 5 mm hose.
- Oxygenate the solution, setting the timer to switch the pump on every four hours for 15 minutes. Use the initial nutrient solution for aeroponics, at 50%.
- Provide shade for the plantlets, to prevent excessive evapotranspiration and wilting, during the first two or three days. Then, gradually, submit them to the conditions of the net house where they will be finally transplanted.
Acclimatization in floating root trays

What are we going to need?

- In vitro plantlets
- Initial nutrient solution, at 50%
- Containers for cleaning the roots of the plantlets
- Plastic propagation trays with holes
- Potable water
- Pool-type tray, 5 cm deep, on a table, into which the planting trays with holes holding the in vitro plantlets will be placed. The length and width will depend on the number and size of the trays to be used
- Frame for creating a wet chamber, closed and covered with transparent plastic
- Shade net, 35%
- Air compressor (submersible pump or for aquarium)
- Timer
- 12 mm hose and siphon for recirculating the nutrient solution
- Large container for nutrient solution

- Wait 12 to 15 days and transplant the rooted plantlets to the aeroponics module.
What do we have to do?

- Construct a wet chamber inside the net house and cover it with shading net. Inside, place the pool-type recipient on a table and connect it to the nutrient solution tank with a hose.

- Install a pump to recirculate the nutrient solution.

- Fill the pool-type recipient with the initial nutrient solution at 50% concentration, not allowing it to overflow.

- Follow the standards of hygiene for handling plants.

- Check the identity of the in vitro plantlets, and clean them following the instruction given for acclimatization in sand trays.

- Place the plantlets in the plastic trays, one plant in each hole.
- Place the trays with the plantlets in the pool-type recipient, making sure that the nutrient solution enters the trays through the holes and that the roots remain submerged.

- Wait 10 to 12 days and transplant the plantlets into the aeroponic module.

**Acclimatization of cuttings**

Cuttings are an alternative to using in vitro plants for transplantation. Among the types of cutting used for aeroponics, we have lateral stem cuttings from mother plants\(^5^4\); and, recently, sprout cuttings from pre-basic minitubers, although more research is needed on the latter.

Detailed methods for obtaining potato cuttings, from different parts of the plant, can be found in other publications\(^5^5\).

**What are we going to need?**

- Lateral stem cuttings
- Paper towel
- Initial nutrient solution, at 50%
- Disposable latex gloves
- Antiseptic alcohol (70%)
- Trays with drainage holes

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\(^{5^4}\) Barona, 2012.

\(^{5^5}\) For example, Hidalgo et al., 1999.
What do we have to do?

- Follow the hygiene standards for handling plants.

Once the cuttings have been harvested, cover them with moistened paper towel and place them in the shade to prevent wilting. The cuttings can be maintained for two days in a refrigerator at a temperature of 4 to 6°C. Prepare the sand trays following the instructions given for in vitro plants.

Dip the base of the cutting slightly into the rooting hormone. With this hormone, rooting is obtained in a shorter period: 2 to 3 days.
Transplant the cuttings into the holes, taking care that the first node is above the surface of the sand. Make sure that the cutting makes good contact with the sand.

Water lightly after planting, without removing the sand near to the cuttings. If hormones have been used, you need to wait at least two hours before watering, to allow the tissues to absorb the hormone. Irrigation after this should be light and frequent, in accordance with the temperature and the evaporation. For the first three or four days use pure water, then irrigate with the initial nutrient solution at 50%.

Provide shade for the transplanted cuttings to prevent excessive evapotranspiration and wilting.

Transplant into the aeroponic modules once the cuttings have rooted (about 15 days). Remove any lateral stem cutting that has not rooted properly. Select only the cuttings that have a good quantity of roots.
**Some additional considerations:**

- Select cuttings that are from a physiologically young mother plant. Avoid using very mature cuttings, because they form tubers too soon and have low production.

- If cuttings appear to be rotting because of pathogens, improve the drainage of the substrate and use fungicides preventively.

**Environment for acclimatization**

Whichever acclimatization method is used, both in vitro plantlets and cuttings must be in the net house for a period of 10 to 21 days before final transplanting, protected under shade for the first few days, with a temperature of 15 to 20°C and a relative humidity of 80 to 90% (a tent may be used to maintain this humidity).

Several days before the definitive transplantation, the plants should be exposed to the net house environment without any protection.

Irrigate with the initial nutrient solution used in aeroponics at 50%, except in the case of cuttings, where irrigation will be with water alone for three to four days, after which the initial solution is used at 50%.

Since low temperatures are required for the acclimatization and transplantation, it is best not to do the acclimatization work during the sunniest, hottest times of the year.

**HOW DO WE TRANSPLANT INTO THE AEROPONIC MODULES?**

By placing the rooted in vitro plantlets or cuttings—which have already been acclimatized—into the aeroponic modules.

**What do we need for transplanting?**

- Rooted in vitro plantlets or plantlets from rooted cuttings
- 0.1% sodium or calcium hypochlorite
- Disposable latex gloves
- 70% antiseptic alcohol
- Wash bottle or atomizer with potable water
- Paper towel
- Anatomical tweezers
How do we transplant the plantlets?

The day when we are going to transplant should not be too bright or too hot, since these are stress factors for the plantlets. It is best to transplant on cloudy days with temperatures of 16 to 18°C and relative humidity of 80%, preferably early in the morning or in the afternoon.

Before transplanting, we need to define the plant density, which can be 15 to 30 plants per m². The transplantation density will vary depending on the characteristics of the growth of foliage, stolons, and roots of the potato variety we are to transplant.

Examples of transplantation density:

<table>
<thead>
<tr>
<th>Variety</th>
<th>Type</th>
<th>Characteristics</th>
<th>Density (plants per m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ecuador</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>INIAP-Fripapa</td>
<td>Improved (andigena x tuberosum type)</td>
<td>Does not develop abundant foliage or stolons.</td>
<td>20 - 25</td>
</tr>
<tr>
<td>INIAP-Libertad</td>
<td>Improved (S. tuberosum ssp. tuberosum)</td>
<td>Limited development of foliage. Little branching of stolons.</td>
<td>25 - 30</td>
</tr>
<tr>
<td>INIAP-Victoria</td>
<td>Improved (andigena x tuberosum type)</td>
<td>Does not develop abundant foliage. Abundant stolons.</td>
<td>15 - 20</td>
</tr>
<tr>
<td>Superchola</td>
<td>Improved (S. tuberosum ssp. andigena)</td>
<td>Abundant development of foliage and stolons.</td>
<td>15 - 20</td>
</tr>
</tbody>
</table>
First, make sure that the net house has shade.

Follow the standards of hygiene for handling plants.

Carefully remove the plantlets (whether in vitro or from cuttings) from the acclimatization trays. Large tweezers are of great help for this. A fine paintbrush is useful for cleaning the roots that contain sand. A hand atomizer can also be used to clean off the sand without damaging the rootlets.

### What do we do during transplantation?

- First, make sure that the net house has shade.

- Follow the standards of hygiene for handling plants.

- Carefully remove the plantlets (whether in vitro or from cuttings) from the acclimatization trays. Large tweezers are of great help for this. A fine paintbrush is useful for cleaning the roots that contain sand. A hand atomizer can also be used to clean off the sand without damaging the rootlets.

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56 See procedure in Chapter 4.
• Disinfect the roots of the plantlets using 0.1% sodium or calcium hypochlorite.

• Then wash them with potable water. For this procedure, we need two 15-liter buckets: one with potable water, and the other with the calcium or sodium hypochlorite solution.

• Place the disinfected plantlets in a tray with moist paper towel, while the transplantation is carried out.

• Transplant to the aeroponic module, using sponges or drinking straws.

  - **Use of sponge.** Sponge is used to give initial support to the plantlets on the lid of the module, inside the hose. A piece of moistened new sponge is wrapped around the neck of each plantlet.

Before placing the plantlets in the hoses, we need to make cuts, in the form of a cross (using a stiletto), on the white plastic and above each hose hole, to introduce the plantlets.

When the plantlets are placed with the sponge in the holes, the roots should be carefully pushed into the module with a pair of tweezers, leaving the foliage outside.

Afterwards, by lifting up the lid of the module, check that the roots are not rolled up in the hose. On the days following transplantation, the sponge can be moistened to give moisture to the plant.
• **Use of drinking straw**: The straws are small plastic tubes 15 to 25 cm long and 5 mm to 1 cm in diameter. It is better to use the 15 x 1 cm straws because it is easier to introduce the root portion.

Before transplanting, cut the straw open lengthwise and place the roots and part of the stem inside it.

• Then place them into a cup filled with potable water while waiting for transplantation.

• Use a pointed object to make a hole in the plastic, over the hose.
Introduce the straw with the plantlet into the hole with the roots towards the inside of the module. Once inserted, remove the straw very carefully from inside the module. The plantlet remains suspended thanks to the pressure exercised by the plastic.

What do we do after transplanting?

- Program the timer to switch on the irrigation system for approximately 15 seconds every 15 minutes, 24 hours a day, or as per the requirements of the crop. During cold days and when the plantlets are small, the irrigation requirement is less than on warmer days and for large plants.

- During the first three days, the plants should be nebulized with the nutrient solution, at 50% concentration. Afterwards, the nutrient solution should be used in its normal dose.

- Place small transparent or white plastic glasses over the plantlets that have just been transplanted to prevent them from transpiring excessively and to maintain a relative humidity of 80 to 90%.

- Make sure that the roots are exposed to the nebulized solution and cover any point of entry of light into the modules.

- Avoid direct exposure to sunlight during the first few days after transplantation. Use the shade net on the roof of the net house.

- Two weeks after transplantation, when the plantlets are adapted and have reached a good size, remove the small plastic glasses.
WHAT DO STEM LOWERING, TRAINING AND PRUNING CONSIST OF, AND WHY ARE THEY DONE?

**Stem Lowering (equivalent of hilling up)**

Stem lowering, the process of lowering the stems, is done in order to induce the greatest number of stolons, and therefore a larger number of tubers. It is the equivalent of hilling up in the field.

**When should we do this?**

When the stolons appear at the top of the root system. Then, the plants should immediately be lowered, introducing a portion of stem with the lower leaves removed.

In most potato varieties, the stolons appear 30 to 40 days after transplantation. Plantlets from cuttings develop faster, so the time for stem lowering (hilling up) may be earlier.

Some varieties tend to form superficial stolons that may be inside the hosepipe. If you don’t lower the sponge below the lid, one or more minitubers may form inside the hose, which could squeeze and strangle the plant’s stem and possibly kill it. Be careful not to lower the sponge too much, however, to ensure that no light enters inside the module.

**What are we going to need?**

- Disposable latex gloves
- Scalpel
- 1% sodium or calcium hypochlorite
- Candle or burner
- 70% antiseptic alcohol
- Recipients for chlorine and alcohol

**What do we do?**

- Follow the standards of hygiene for handling plants.
Training or support

The plants can hold themselves upright for three or four weeks. After that, and after the stem lowering, they grow quickly and require support, such as: bamboo stakes, wire mesh, agricultural nylon or raffia, depending on the method to be used, the funds and materials available locally.

Important!

For training, use materials that won’t damage the plant and that won’t be a source of inoculum or host of pests and diseases.

- Cut 3 or 4 lower leaves off each plant, using a scalpel.
- Allow the wounds to heal for 2 or 3 days.
- Introduce 8 to 12 cm of stem into the module, remembering to follow the hygiene measures.
What are we going to need?

- Disposable latex gloves
- Antiseptic alcohol (70%)
- Bamboo stakes, nylon netting or agricultural raffia
- Twists, string or raffia

What do we do? (depending on the method to be used)

**With bamboo stakes:**

- If you use bamboo stakes, disinfect them first with a 1% sodium or calcium hypochlorite solution.
- Follow the hygiene standards for handling plants.
- Install lines of white string over the module where the plants are growing in order to provide support for the bamboo stakes.
- Hang the stakes vertically.
- Attach the plants to the bamboo stakes with twist ties or string as they grow.

**With nylon mesh:**

- Follow the hygiene standards for handling plants.
- Place the nylon netting 30 cm above the aeroponic module, fixed to the training posts.
As the plants grow, more netting should be added higher up to direct their growth.

**Pruning**

Management of seed potato production in aeroponics should include two types of pruning, in order to:

- Control the height of the plants, and
- Remove old or sick plant tissue (sanitary pruning)

**Pruning to control the height of the plants**

This pruning consists in cutting the apical sprouts, and it is done at tuber initiation. The pruning reduces the size of the plant, which facilitates its management without significantly reducing the production of minitubers.

This procedure is recommended for the varieties of the andigena type, but not for the varieties of the andigena x tuberosum and spp. tuberosum, because they don’t develop abundant foliage.

**What are we going to need?**

- Disposable latex gloves
- 70% antiseptic alcohol
- Scalpel
- Burner or candle
- 1% sodium or calcium hypochlorite solution
What do we do?

- Follow the hygiene standards for handling plants.

- Using a scalpel, cut the apical sprouts after the first minituber harvest, leaving the plants with an average height of 80 cm. The scalpel is placed at right angles to make a clean, firm cut. A solid support, such as folded paper towel, helps to obtain this kind of cut. Be careful not to cut your fingers.

Sanitary pruning

This pruning consists in cutting lateral sprouts and diseased leaves. It is done at any time during vegetative growth, whenever it is necessary to remove diseased leaves.

This pruning is also recommended in varieties that develop abundant foliage, to ensure good ventilation between the lid of the module and the foliage. In this case, the lateral stems and lower leaves should be removed.

What are we going to use?

- Scalpel
- 70% antiseptic alcohol
- Burner or candle
- Disposable latex gloves
- 1% sodium or calcium hypochlorite

What do we do?

- Follow the hygiene standards for handling plants.

- Remove the lower lateral stems and the diseased leaves with the scalpel, at any time during the vegetative cycle.

- Place the pruned leaves directly into a plastic bag, to dispose of them at a distance from the net house, thereby preventing them from contaminating the aeroponic crop.
EXPERIENCES AND LESSONS LEARNED

What does experience tell us?

IN ECUADOR

About acclimatizing in vitro plants

In the case of CIP-Quito, the acclimatization was done by leaving the plantlets for two to four days in the uncapped test tubes under shade in the net house. After this period, they were transplanted into the module, without submitting the plants to any other acclimatization processes for the roots to develop. Although the period of adaptation was long (more than three weeks), the plants grew with no major difficulties.

However, it is necessary to compare this with the procedures used in Peru and Colombia (acclimatization in sand trays, in small modules, and in floating root trays) to determine which of them is the most suitable.

About the irrigation system

At CIP-Quito the irrigation times were modified depending on the crop conditions, with good results. For example, irrigation time was reduced from 15 to 10 seconds every 15 minutes from transplantation to the lowering of the stems. In addition, the irrigation system was switched off during the night, from 10 p.m. to 4 a.m., because of the low temperatures.

IN COLOMBIA

About the use of the floating root technique

At CORPOICA, the plantlets have shown good adaptation with the use of the floating root technique. This is true of all the varieties tested: Diacol Capiro, Parda Pastusa, Pastusa Suprema, Roja Nariño, and ICA Única.

IN PERU

About the use of cuttings as material for transplant

In the aeroponic system at CIP-Lima, cuttings have been found to produce a larger total weight of tubers and larger number of tubers weighing more than 5 g; while the in vitro plants produce a larger total number of tubers, but most of them weigh less than 5 g. However, this depends on the variety. Therefore, if you wish to use cuttings rather than in vitro plants, you will have to compare the two types of planting material in the potato variety you intend to plant.
For disease and pest management, we need to define which agents are causing the diseases, and which pests are causing the damage. We must also rule out that the symptoms are being caused by nutritional imbalances or adverse environmental conditions.

Hygiene and other preventive measures, which reduce the predisposing factors for diseases and for the growth of pest populations, are the basis of integrated management.

Diseases and pests produce symptoms that are usually clearly visible. The challenge is to diagnose the causal agents and identify the pathogens and pests that could enter the net house.

The next thing is to implement the appropriate management measures, such as: modification of the environmental conditions to delay multiplication of the pathogens and pests; use of physical and biological control methods; and selection and use of suitable pesticides for the control of each of the potato pests and diseases in the aeroponic system.

For having an infectious disease (caused by a microorganism: for example, a fungus), three factors have to be present at the same time. They are represented with the disease triangle:

### Disease Triangle

- **Favorable environment**
- **Susceptible plant or host**
- **Aggressive pathogen**
An example?

Potato late blight appears in the aeroponic crop when: there are infected potatoes in surrounding areas; we are cultivating a susceptible potato variety; and, at the same time, there is water condensing on the plant’s leaves.

In potato late blight, the three disease factors are present:

- **Aggressive pathogen:** spores of Phytophthora infestans that entered the net house wind-borne, passing through the anti-aphid net.

- **Susceptible plant or host:** potato plant of a variety that can become infected with P. infestans.

- **Favorable environment:** water on the foliage for a little more than one hour—it may be the morning dew—which permits the germination of the spores and the consequent infection of the plant.

**Pathogen**

This is the disease-causing microorganism. It may be present in the water, soil, dust, contaminated plants, insect vectors or other means of transmission, such as the clothing and footwear of greenhouse operators or technicians.
The forms of dispersal of bacteria and fungi include:

- the wind, which transports spores
- rain, which disperses pathogens when it splashes, so leaks in the net house must be prevented
- irrigation
- contaminated plantlets
- people, on their boots, clothes, hands, etc.
- insects
- tools

Important!

The first measure for disease management is to prevent pathogens from entering the net house, for example, through human activities.

Host

This is the plant susceptible to the pathogen. Normally, all the potato varieties are compatible with the pathogens that affect them, at different levels of susceptibility.

Environment

The optimal conditions of the environment, which favor the development and reproduction of pathogens, vary. For many pathogens, heat and high humidity are excellent conditions for developing and causing the plant disease. The water of the nutrient solution can also be a medium conducive to the survival and spreading of pathogens.

In addition to the three factors of the disease triangle, there is the “human” factor. The people who manage the aeroponic crop can have a great deal of influence on those factors when, for example, they carry out tasks such as: deciding the transplant density, applying pesticides, and controlling the humidity and temperature in the net house, among others. If we act as indicated, we can reduce the probability of a disease developing.

Which pathogens and pests can enter the net house?

Pathogens and pests grouped under the following categories:

- Bacterial diseases
- Diseases caused by fungi and oomycetes.
- Potato viruses
- Potato insect pests
Bacterial diseases

**Black Leg and Soft Rot** *(Erwinia o Pectobacterium spp.)*

Black leg can appear at any stage of the plant’s development. Necrotic lesions often extend up the stem from the base of the plant, which shows bacterial soft rot. Young tubers sometimes rot at the stolon end. Wilting and death of the plant can ensue.

The bacteria that cause soft rot can infect the lenticels if the tuber surface is moist, producing concave circular lesions from which the soft rot can rapidly expand. Soft rot usually has a foul smell.
**Common Scab** (*Streptomyces spp.*)  
Several types of lesions develop on the tubers: they may be superficial or deep, concave, protuberant, or reticular. In many cases, most of the surface of the tubers is affected. The fibrous roots can also be damaged, but the foliage is not affected.

This can be verified by observing a milky white filamentous fluid emanates from the vascular bundles upon cutting a piece of stem and submerging it in clean water.

**Bacterial Wilt** (*Ralstonia solanacearum*)  
The initial symptom is a slight yellowing, at first seen only on one side of the leaf or on one branch and not on the next.

The advanced symptoms are:

- severe wilting,
- darkening of the vascular bundles, and
- exuding of a brownish gray mucilage if the stem or tuber is cut through (not seen in mild cases).

This can be verified by observing a milky white filamentous fluid emanates from the vascular bundles upon cutting a piece of stem and submerging it in clean water. Bacterial wilt is a very dangerous disease—subject to quarantine in most countries—found in Bolivia, Colombia, and Peru, but it has not been reported in Ecuador.
Diseases caused by fungi and oomycetes

Late blight (Phytophthora infestans)
Late blight is known as “gota” in Colombia, “rancha” in Peru and “lancha” in Ecuador. The symptoms are moist-looking lesions on the foliage, which become necrotic in a few days. These lesions are brown when they are dry and black when they are wet.

Under conditions of high humidity, we may see a white fuzz, especially on the underside of the leaves. Often a pale green border forms around the lesions on the leaves. It can affect the stems and the tubers. If we cut through the affected tubers, we can see brown necrotic tissues, not very distinguishable from the healthy parts.

The blight is diagnosed through the “wet box” method. The part of the plant with symptoms is placed in a closed box, with moisture (closed plastic container, with a damp piece of paper towel inside it). If the infection is caused by P. infestans, in three or four days a white fuzz is formed by the pathogen’s mycelia and spores.

If the net house is in a potato-producing area, it is almost certain that the spores of this microorganism will enter through the net, air-borne from nearby crops, during humid and rainy seasons.

The necrotic spots develop on the plants when the water condenses on their foliage for more than an hour. These spots start at the edges of the leaflets and in places where the drops of water accumulate.
Important!

If late blight is not controlled, it can infect all the plants in the net house and cause their death in two or three weeks, depending on the environmental conditions.

**Oidiosis Powdery mildew** (Erysiphe / Oidium spp.)

This is a disease typical of greenhouse potatoes, under high temperature conditions.

The main symptoms are seen on the leaves, which become covered with cottony layer of whitish gray mycelium, which at first sight looks like remnants of powder or the remains of something that has been sprinkled on the plant.

**Alternaria spots** (Alternaria solani)

Alternaria forms small necrotic spots on the leaves, marked internally by concentric rings. Large lesions on the leaves are seldom circular because they are restricted by the main veins.
The spots nearly always appear at flowering time and increase in number as the plants mature. The lesions are formed first on the lower leaves. Alternaria is more severe when the weather is hot.

**Stem rot, minituber rot and wilt** (complex of fungi and oomycetes: Rhizoctonia, Fusarium, Sclerotium, Pythium, Phytophthora)

A complex of fungi can affect the potato plants in the aeroponic system, causing lesions on stems, stolons, minitubers and roots. Wilt, also known as “damping-off”, causes disintegration of the tissues near the base of the stem and strangulation at the base of the plantlets, root necrosis and wilting, and even the death of the plantlets.

In large plants the lesions typically start on the stolons and spread to the minitubers, where they cause rotting in combination with a brown necrosis on the stolons and roots.

Rots due to fungi and oomycetes do not cause a bad smell. The pathogens that cause rots of minitubers and stolons spread easily through the water of the nutrient solution. The diagnosis of the causal pathogens is made with the help of laboratory methods.
Wilt due to Verticillium spp.
This is characterized by the yellowing and wilting of the leaf, which begins at the base of the plant and develops, limiting the symptoms to one side of the main vein of the leaves, or one side of the stem or the plant. These symptoms are caused by the blockage of the vascular system on one side of the leaf or plant.

Verticillium Wilt is more severe when there are high temperatures and low humidity in the air.

Powdery scab (Spongospora subterránea)
Normally there are no signs of the scab on the aerial part of the plant. The first symptoms manifest themselves with the appearance of small, pale blisters on the surface of the tubers.

At an advanced stage, these blisters become dark open pustules, with a diameter of 2 to 10 mm, or even larger, containing a powdery mass of dark brown spores.

The roots can form galls of up to 15 mm. The color of the galls, when recently formed, is similar to that of a normal root. As the galls disintegrate, the color quickly becomes darker. The pathogen is easily spread through the water of the nutrient solution.

Important!

It is always necessary to watch how the plants are developing, to identify any cause of abnormal growth, because fungi and pathogen bacteria are able to enter the aeroponic system.
**Potato viruses**

Viruses are too small to be seen with an optical microscope. They are acellular organisms, transmissible parasites that consist of nucleic acids (RNA or DNA) surrounded by a protein coat.

Viruses do not feed; they merely reproduce. Because of their transmission potential and their negative effect on production (they cause degeneration) it is important to avoid them in seed production. Some varieties can be infected without showing any symptoms.

The most important viruses affecting the potato are:

**Potato Virus Y (PVY)**

- Symptoms vary a lot depending on the virus variant, the potato variety and the environment. Typical symptoms are: necrosis of veins, rough mosaics, twisting of the leaves and plant dwarfism.

- Form of transmission: by aphids (not persistent).

**Potato Leafroll Virus (PLRV)**

- Symptoms: Rolling of the leaves. These leaves tend to grow upright and stiff. They also show marginal and interveinal chlorosis (yellowing), especially on the upper leaves. And the plant is severely stunted.

- Form of transmission: by aphids (persistent).
Potato Virus X (PVX)

- Symptoms: mosaics on the leaves. The infection can be slight in some crops and it is often latent (without symptoms).

- Form of transmission: by contact among plants, by machinery and by chewing insects.

Potato Virus S (PVS)

- Symptoms: mosaics on the leaves. The infection can be slight in some crops and it is often latent (without symptoms).

- Form of transmission: by contact, by machinery, and by aphids.
**Potato Yellow Vein Virus (PYVV)**

- Symptoms: bright yellowing on the veins and blade of the leaves.
- Form of transmission: mainly by whitefly.

**Potato insect pests**

*Potato flea beetle* (*Epitrix* spp.)

The adult is black and shiny, approximately 3 mm long. In the mornings it is found at the base of the leaflets, and as it feeds it leaves a round hole that grows with the growth of the leaf.

In net houses with aeroponics, only the adult insects are found, because the female needs soil to lay its eggs and the larva doesn’t have a chance to develop. Therefore, the population observed will be those beetles that reach the net house from the outside.
In aeroponics we need to monitor the level of the population. Control measures, such as the application of insecticide, are required only if there is more than one adult per five plants. When the plants are big —50 days after transplantation— this pest is no longer significant.

**Potato tuber moths** (Phthorimaea operculella, Symmetrischema tangolias, Tecia solanivora)

The *P. operculella* adults are 5 mm long. Their fore wings have various dark spots distributed all over their surface. The larvae of this species are cream-colored, long, and they develop in the leaves forming round leaf mines. They also bore the stem.
The adults of *S. tangolias* are gray with a triangular mark on the front marginal part of the first pair of wings. The body is 1 cm long. The larvae show green stripes alternating with pink stripes the whole length of their body. They bore the stem, which wilts. To pupate, they leave the tunnels.

The Guatemalan potato moth (*Tecia solanivora*) is not regarded as a potato pest in the aeroponic system, because the adults do not damage the potato plant and the larvae feed only on tubers. The adult has a black line the length of each wing.

It is assumed that the larvae of these moths do not have access to tubers in the aeroponic modules.
**Thrips** (Frankliniella spp.)

Thrips are tiny, elongated insects, measuring 2 mm. Fringe-like wings emerge from a central stump. These insects scratch the surface of the leaf and suck the sap they need for food. The internal part of the cells, emptied by the thrips, becomes oxidized, producing silvery marks. The adults are black or coffee-colored; they are migrant individuals that arrive from outside the net house. Later, they will give rise to immature insects, cream or yellow in color, and wingless.

**Whitefly** (Trialeurodes vaporariorum and others)

The common name of “fly” is not accurate, because it corresponds to an insect of a different order (Homoptera). The adults are 2 mm long. The female lays eggs on the underside of the leaves, where they do not receive the sun’s radiation directly. The eggs are laid perpendicular to the leaf surface, and they are barrel-shaped.
There are winged populations and others without wings. The winged individuals have little capacity for moving great distances, so they make use of the wind to colonize new places. The winged aphids enter the net house through any openings there may be in the infrastructure, or by means of infested material. The favorite places for the aphids are: the underside of lower leaves and tender sprouts.

**Aphids or greenfly** (*Macroshipun euforbiae* and *Myzus persicae*)

These are globe-shaped insects of a soft consistency, 3 to 5 mm long. They live in colonies around a mother. At one point, these colonies join together, giving the appearance of a single population. They are black or green, depending on the species.
The larvae are a problem, in particular for the recently transplanted plants. When the plants are big, 50 days after transplantation, the damage that the insect larva could cause becomes negligible.

**Bud Midge** (*Prodiplosis* spp.)
This small fly is one of the main pests of tomato crops and it can also be a problem for the potato crop. In the Andean countries, it is a significant pest in at altitudes below 2,000 m.a.s.l., for example in the coastal region of Peru. It is a tiny, yellowish white insect with a large dark head, black eyes, long legs and antennae, and large wings. The adults grow to approximately 2 mm. The larvae, from 0.5 to 2 mm, are white or yellowish. Typically, they are found at the base of the leaflets.

The larvae are a problem, in particular for the recently transplanted plants. When the plants are big, 50 days after transplantation, the damage that the insect larva could cause becomes negligible.

**Broad mite** (*Polyphagotarsonemus latus*)
These are very small, almost microscopic insects, 0.15 mm in size. They are barely visible to the naked eye. They are nearly always found on the underside of young leaves at the upper part of the crop, so in an aeroponic crop it is necessary to use a ladder to examine the foliage closely.

Diseases caused by adverse environmental conditions

Adverse environmental conditions can trigger alterations in the plant tissues and hinder normal plant development. In the net house, these conditions can be: frost, heat waves, sudden temperature changes, excess humidity, lack of light or sun-scorch.

Young, newly transplanted plants are highly susceptible to sun scorch and sudden temperature changes, which can produce lesions similar to those caused by pathogens such as late blight.

High temperatures can also cause excessive transpiration and wilting in the young, recently transplanted plants.

To prevent damage to the plants from adverse environmental conditions, it is necessary to protect them, for example, by using shade nets, or placing white plastic cups on recently transplanted plantlets to protect them from low humidity, strong sunlight and sudden temperature changes.

That is why it is important to control the high temperatures at noon and in the afternoon, and the low temperatures in the early hours of the morning.

In the minitubers, you may see the lenticels swell and lesions appear in a net-like pattern. This is apparently due to excess humidity, lack of oxygen and an excess of carbon dioxide, rather than being caused by pathogens.
Appropriate measures for disease and pest management

The minitubers produced by aeroponics should have “zero tolerance” for diseases caused by pathogens and damage caused by pests. Management should guarantee the “zero tolerance” criterion and be based on preventive measures that:

- Prevent pests and pathogens from entering the net house.
- Prevent any that manage to enter from developing.

How can we prevent pests and pathogens from entering the net house?

When it come to insect management, it is important to take precautions regarding the degree of isolation the net house offers in terms of them entering from outside.

Important!

The anti-aphid net is crucial for protecting the plants from the entry of insects. It needs to be examined regularly to ensure that it hasn’t been damaged.

In addition, the entrance to the net house must have double doors, and one of them must always be closed to prevent direct airflow that can carry insects in.

Measures to prevent pests and diseases from entering the net house include the following:

- Pay attention to the design of the infrastructure, because it can help in keeping out pests and diseases. For example, the location of the net house itself and its entrances can prevent dust and water, which can carry pathogens, from entering.
• Disinfect the net house and the irrigation system.  

• Cover the floors with cement, pumice stone, or any other material that will prevent the growth of weeds or creation of dust when one walks on it. The floor should be disinfected regularly (especially after receiving visitors) by spraying it with a 0.25% sodium or calcium hypochlorite solution.  

• **ALWAYS use gloves when handling sodium or calcium hypochlorite.**  

• Disinfect the water for the nutrient solution.  

• Use anti-pathogen additives, such as chlorine or isopropyl alcohol (less toxic than sodium hypochlorite) in the nutrient solution. In the case of chlorine, we can apply 0.5 to 2 ppm of sodium or calcium hypochlorite.  

• Transplant healthy planting material from a reliable source, free from viruses and other pathogens and pests.  

• Keep the space adjacent to the net house free from weeds and crops that could be host plants to potato pests and diseases. There should be no potato crops nearer to the net house than 300 m away.  

• Remember that people can introduce pathogens and pests into the net house, because they can carry microorganisms on their hands, and especially on their shoes, and they can bring insects in on their clothes.  

• Make sure that all the material entering the net house is clean and free from pathogens or pests. All tools (scalpels, tweezers, etc.) must be disinfected with a 1% sodium or calcium hypochlorite solution.  

• Mix and oxygenate the nutrient solution with clean, disinfected hands and tools.  

• Wear clothes and boots that are exclusively for use in the net house. Every time people enter the net house, they must disinfect their boots in the trays containing chlorine and lime in the pre-chamber.  

**Important!**  

Follow all the hygiene standards to prevent the entry of pests and diseases into the net house.
How can we disinfect the water for the nutrient solution?

The water source may be contaminated with pathogens and potato pests.

Deep well water is not normally contaminated. But water from shallow wells is quite likely to be contaminated with bacteria, including Pectobacterium, or pathogenic fungi and oomycetes.

Water from suspicious sources should undergo microbiological analysis. Filters and other treatments can reduce the risk of entry of pathogens via the irrigation water to a minimum. The water must be treated before entering the nutrient solution tank.

There are several types of treatment for disinfecting water:

- **Chlorination**: or application of chlorine. For example, 2 to 5 ppm of sodium or calcium hypochlorite gives a residual concentration of chlorine of 0.5 to 1 ppm.

- **Filtration**: either using physical filters (sand, for example), or biological filters (micro-organisms).

- **Ultraviolet radiation**: ultraviolet radiation (UV-C) is an electromagnetic radiation, with a wavelength between 100 and 400 nm; the wavelength that is effective as a germicide is 254 nm. Its disinfecting action is due to the fact that it alters the DNA of microorganisms, causing their death.

- **Heat**: the water can be passed through a heat exchanger. It is recommended that the water reach 95°C for 30 seconds to guarantee the removal of pathogens.

How can we prevent pathogens and pests from surviving in the greenhouse?

- **Cleaning**: Cleanliness is very important in an aeroponic system. If everything is not regularly cleaned —the modules, anti-aphid nets, walls, cover, pre-chamber, floors, etc.— with water and then 0.25% sodium or calcium hypochlorite, and if sanitary pruning is not done, the plants can become infected, since diseases and pests spread rapidly throughout the system. This can cause total loss of the crop, because in the net house —a closed system— the conditions are favorable for the development of pests and diseases.

- **Using independent irrigation systems**: It is important to isolate the systems with independent tanks and irrigation systems to minimize the risk of total loss. For example, an independent irrigation system can be used for every 40 m² of production modules.
• **Adding sodium or calcium hypochlorite directly to the nutrient solution.** 0.5 to 2 ppm of sodium or calcium hypochlorite is added to the nutrient solution. Residual concentration in the nutrient solution should not exceed 1 ppm.

• **Changing the nutrient solution frequently.** It should be changed at least every 7 to 15 days. The nutrient solution can very quickly develop a micro flora (potentially with pathogens) even though, in principle, it should be free from microorganisms.

• **Removing plant remains or diseased parts.** This material must be removed in plastic bags and disposed of at a distance from the net house.

**Monitoring and control of insect pests using traps**

For the potato moths, pheromone traps must be used to detect the pests (*Phthorimaea operculella*, *Symmetrischema tangolias*), and to be sure that the net house has no openings. There should be a trap with a pheromone for each species.

Yellow containers with soapy water, or traps consisting of sticky yellow card (with glue), can be used to monitor the entry of insects, such as winged aphids, whitefly, and bud midges, and to control their populations.

Traps made of blue or white card with glue are used to monitor the entry of thrips.

![Photo: Peter Kromann.](image)

From left to right: pheromone traps for moths, aphids (yellow), and thrips (blue). CIP-Quito.
There should be a trap of each type for more or less every 50 m² of the greenhouse for monitoring. If you want to use the traps as control tools, you will need to use more of them.

If you detect the presence of pest insects in the traps in numbers above the economic damage threshold, you will need to use other physical methods (for example, light traps); biological controls (predatory mites, wasps, fungi, etc.); biological insecticides (for example Bacillus thuringiensis or neem); or, as a last resort, synthetic insecticides (for example imidacloprid), or others of low toxicity both for human beings and for other living creatures.

**Monitoring for potential virus infections**

To monitor latent virus infections, we have to take samples of leaflets when the plants are flowering: one sample per 1 to 5 m² of production.

The technique most frequently used to diagnose viruses is DAS-ELISA. However, there are certain viruses, such as PYVV, that cannot be detected with DAS-ELISA and in those cases other techniques must be used.

**Important!**

Virus tolerance in potato plants in the aeroponic system is “0” – zero. If virus infections are detected, all the plants must be removed from the module.

It is, therefore, indispensable that the planting material be virus-free, that there be no plants infected with virus in the vicinity of the net house, and that insect vectors be prevented from entering.

**Management of environmental conditions inside the net house**

The temperature has to be regulated. The potato is adapted to cold tropical climates, with temperatures that can vary between 18 and 25°C in the daytime, and between 8 and 15°C at night. However, this range is also ideal for the development of many pests and pathogens. When the temperature rises above 25°C, the growth of the plants is affected, while the development of many pests and pathogens is favored.

Therefore, the temperature of the air in the greenhouse must be kept below 25°C. The temperature can be lowered using anti-aphid net walls, zenithal openings, electric fans, roof sprinklers, shade net and ventilation ducts, among other methods.
Regulating solar radiation

Sunlight is indispensable for plant growth. However, optimal plant growth requires a balance between the temperature, the RH, and the light. If the sunlight increases, the plant grows better, but if a lot of sunlight enters, it can raise the temperature and reduce the RH inside the net house to a point that causes the plants to suffer and can predispose them to attacks by pathogens and pests.

Solar radiation therefore needs to be regulated through the correct placement (orientation) of the net house and the use of shade nets. The use of these nets is especially important at the time of transplantation, since the plantlets are prone to sun scorch.

There is a new generation of plastics, called “anti-vector plastic sheeting.” This plastic is able to filter all the UV radiation and hence alter the behavior of virus-transmitting insects.

The UV filter also inhibits the formation of spores of certain fungi, for example Alternaria.

Regulating the humidity and hours of wet foliage

Air with high relative humidity (RH) is conducive to the development of pathogens that attack the foliage of the potato crop, especially Phytophthora and Oidium, which are two very common pathogens in aeroponic systems for potato.

The growth of these pathogens can be limited by keeping RH in the net house below 70 to 80%. An excessive RH can be reduced by means of ventilation, an increase in temperature, and also by avoiding excessive moisture on the floor.

Low RH levels prevent water condensation (dew) resulting from the sudden drop in temperature during the night and dawn.

Water condensation or dew on the foliage creates optimal conditions for the development of late blight and other diseases.

To aerate the crop and lower the RH, we can:

- Ventilate the net house well,
- Reduce the plant density, and
- Remove excess foliage, lateral stems, and old lower leaves.

CHAPTER 6: MANAGING THE AEROPONIC POTATO CROP
**Biological controls**

There is currently a range of biological products for disease and pest control in greenhouses that is growing every year. One of the agents most frequently used as an insecticide is the Bacillus thuringiensis bacterium.

In some countries, there are already entomopathogens on the market such as the fungus Verticillium lecanii, to control flea beeldes, and parasitoid insects such as Encarsia formosa that are released for whitefly control, or predatory mites to control thrips.

In countries with a floricultural and horticultural industry, access to biological controllers has advanced. We recommend that you find out about locally available biological controllers with which to improve integrated pest and disease management.

**Control with pesticides**

If the management options described above have been exhausted and if diseases and pests have exceeded the economic damage thresholds (in aeroponics they are low because of the high cost of the crop!), then you should consider using pesticides.

Pesticides are applied when the risk of damage from pests or disease has risen to critical levels, identified by means of monitoring or risky environmental circumstances (for example, the formation of dew in the case of late blight).

Generally speaking, in aeroponics it is advisable to manage low damage thresholds and a prevention strategy, because the production cost is high.

**Selecting appropriate pesticides**

- Before selecting a pesticide, we need to identify:
  - Whether the problem is caused by a pathogen or pest rather than by abiotic factors (for example, adverse environmental conditions or nutritional imbalance).
  - The causal agent.
  - The active ingredient that controls the identified pathogen or pest.

- Always use active ingredients of low toxicity to reduce the risks of intoxication of the greenhouse operators, technicians, visitors and other living beings.
• Apply pesticides by spraying the foliage. If you want to mix pesticides with the nutrient solution, be careful: you run the risk of intoxicating the plants. It is recommended to conduct trials on a small scale. Systemic pesticides protect the root system as well as the foliage.

Examples of contact fungicides, systemic fungicides, insecticides and information to support the selection of appropriate pesticides are found in Annex 5.

The right time to apply pesticides

• Preventive, or when the first symptoms are detected.

• It is advisable to apply the pesticides at the end of the afternoon, to avoid too much sun and heat, which can scorch the plants, and also for the safety of the greenhouse operators.

• The period of time for reentering the net house after pesticide spraying must be respected. It is normally 12 to 24 hours. This is why it is best to apply the pesticides at the end of the day, and preferably on a Friday, avoiding reentry until the following Monday.

Proper procedure for applying pesticides

• Make sure that the application equipment is in good condition.

• Use low doses to prevent adverse effects in the plants and for the safety of the greenhouse operators. In the aeroponic system, plants have a fast metabolism due to the ideal conditions for growth. The absorption and distribution of systemic pesticides inside the plants is also fast, so it is recommended to use low doses to avoid adverse effects. When the plants are small and attacks of pests are not severe, we can use 50 to 75% of the dose recommended for use in the field. If the plants are big, the recommended dose can be used (100%).

Preparing the pesticide-and-water mix for spraying

• Mixing pesticides can be a hazardous job, especially because we are working with the concentrated, undiluted product. There is great risk of splashing, spilling, or accidental inhalation of particles of dust, mists or fumes. Exposure to a quantity—albeit very small—of undiluted pesticide can cause serious damage to a greenhouse operators’ health.

• It is thus advisable to use liquid pesticides only.
A practical example

Calculate the dose of the fungicide propineb for 10 liters of water to be used for controlling late blight and alternaria leaf spot.

- On the label, the manufacturer recommends the following dose: 500 ml/200 l = 2.5 ml/l. **The dose recommended for aeroponics is 2 ml/l** (75% of the dose recommended is equal to 1.9 ml/l, which can be rounded up to approximately 2 ml/l).

- So, for 10 liters we need: 10 x 2 ml/l = 20 ml of the propineb commercial fungicide.

- A good mix is obtained by diluting the 20 ml in 2 liters of water, in a bucket or other recipient, until a homogenous suspension is obtained. This pre-mix is then deposited in the tank of the equipment that is to be used, with 8 liters of water.

Handling resistance

Bear in mind that the indiscriminate use of pesticides can result in the appearance of populations of pathogens that are resistant to those pesticides, as in the cases of P. infestans and the fungicide metalaxil, and whitefly with the insecticide imidacloprid. To prevent this, it is important to alternate the active ingredients and take other preventive measures, following the recommendations found in specialized publications.

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Important!

ALWAYS use personal protection equipment when mixing and applying pesticides, and strictly observe the regulations in force in your country for their use.

- The best place for preparing pesticide mixes is in the open air, on a concrete surface. If it has to be done in an enclosed place, there must be good ventilation and light.

- When only a small quantity is to be applied (two or three backpack sprayers), the mix required for each of these sprayers should be prepared. A pre-mix should be prepared in a small recipient, stirring it with a wooden stick, and then it should be added to the sprayer, which already has water in it. Make sure that the preparation is fully mixed in the sprayer.

- Always check that the dosage has been accurately calculated. It is preferable to calculate the weight or volume to be used per liter of water and afterwards multiply by the quantity of liters that you plan to use.

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60 For example, FRAG-UK, 2007.
What does experience tell us?

Recently transplanted plantlets are often seen to have scorched or necrotic leaves or borders. In the great majority of such cases, the scorching has been caused by sudden temperature changes, and only seldom by pathogens.

Chlorotic or slightly scorched roots have also been seen. The cause of this is nearly always nutritional imbalances (variation in electrical conductivity or pH) rather than pathogens in the nutrient solution.

IN ECUADOR

At CIP-Quito they worked with water from nearby paramo wetlands, which the initial microbiological analyses had shown to be clean. For this reason it was disinfected with only 1 ppm of sodium hypochlorite, and no other treatment was given.

In early crop cycles, Fusarium and Verticillum entered the system and affected two plants, which were immediately removed when the first symptoms were seen. Then it was possible to prevent the infection of other plants, by immediately changing the nutrient solutions and using systemic fungicides (azoxystrobin and dimetomorf) applied to the foliage.

However, in one crop cycle, Spongospora subterranean was detected, which entered the aeroponic modules, and which could not be controlled by changing the nutrient solution, so all the contaminated modules had to be eliminated. In the following crop cycle, a microbiological filter was implemented to rule out contamination from the water source, which solved the problem.

Nevertheless, despite the microbiological filter, necrosis was observed in the roots and stolons, possibly caused by an excess of humidity and lack of oxygen. To solve this problem, 5000 ppm of oxygenated water (3% hydrogen peroxide) was placed in the nutrient solution, with which the necrosis was successfully reduced.

Experience has shown that with good insulation of the inside environment of the net house from the outside environment, mainly with anti-aphid nets, the problems with insect pests at CIP-Quito (3,058 m.a.s.l.) have been minimal.

IN PERU

One of the partners that routinely works with aeroponics in Peru used a mix of the fungicides carboxin and captan in the nutrient solution, to control a disease caused by Fusarium in the root system. The result was an acute toxicity of the plants, which led to the total loss of the crop. Therefore, it is not recommended to mix fungicides with the nutrient solution without previous trials.
Once the minitubers reach the appropriate weight and size (8 to 10 g), they should be harvested; and they need suitable storage conditions to promote the physiological change that will enable them to be used as planting material.

Harvests take place sequentially, at one- to two-week intervals. The number of harvests varies from three to ten.

It is recommended that you reread Chapter 5 to review the process of physiological change in the minituber, from the time it is harvested to the time it sprouts, so that it can be managed properly.

**Procedure for the sequential harvests**

To harvest minitubers grown aeroponically, we need:

- Soapy solution
- 1% sodium or calcium hypochlorite
- Disposable latex gloves
- 70% antiseptic alcohol
- Buckets
- Trays
- Clean water

**Procedure**

**Before**

- Review the standards of hygiene for handling plants, and prepare the materials for the harvest.

- Identify the best time to start harvesting: when the minitubers reach a weight of 8 to 10 g and a diameter of 2 to 3 cm. This weight and size are ideal for using them as planting material in the field.
Follow the standards of hygiene for handling plants. Change gloves or apply 70% antiseptic alcohol on your hands each time you are going to harvest from a new aeroponic module, to minimize the risk of contamination.

Harvest the minitubers through the side windows of the aeroponic modules with great care, to avoid causing damage to the roots or causing other small minitubers to fall from the same plant or nearby plants.

Remove any minitubers that fall from the aeroponic modules.

Once they have been harvested, the minitubers should be washed with a 1% sodium or calcium hypochlorite solution, then rinsed them three or four times with clean water. Let them dry at ambient temperature for a few hours. Then you should classify the minitubers according to their weight, discarding any that show deformities or any kind of physiological damage.

Afterwards they need to be “cured”, that is, placed in environmental conditions that will allow their skin to harden and let any injuries heal that may have occurred during harvesting. These conditions are: temperature of 15 to 20°C, relative humidity of 80 to 90%, low diffused light, on clean, dry trays, for 7 to 10 days. During this process, you can also remove any minitubers that show deformities or symptoms of physiological damage.

Subsequent harvests are done in the same way, after about one or two weeks, when there are minitubers of the right weight and size.

In some varieties, the skin of the minitubers can be very thin, so the hypochlorite can damage it. In such cases, the disinfection of the minitubers can be done after “curing” them.
Classification of minitubers

After every harvest, the minitubers are classified by weight, to facilitate their management. They are divided into the following classes:

<table>
<thead>
<tr>
<th>Classes of minitubers</th>
<th>Weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>Above 10 g</td>
</tr>
<tr>
<td>Second</td>
<td>Above 5 and up to 10 g</td>
</tr>
<tr>
<td>Third</td>
<td>Above 2 and up to 5 g</td>
</tr>
<tr>
<td>Fourth</td>
<td>Up to 2 g</td>
</tr>
</tbody>
</table>

Minitubers range from 0.5 to 30 g, although it is occasionally possible to get minitubers of up to 60 g. Quite often, the greatest percentage of minitubers weigh less than 5 g, although this depends on the variety, the environmental conditions, and the management, as we see in the following chart of data from four cycles of evaluation at CIP-Quito.

<table>
<thead>
<tr>
<th>Variety</th>
<th>Year</th>
<th>Average minitubers per m²</th>
<th>Classes of minitubers (%)</th>
<th>1st.</th>
<th>2nd.</th>
<th>3rd.</th>
<th>4th.</th>
</tr>
</thead>
<tbody>
<tr>
<td>INIAP-Fripapa</td>
<td>2009, 2010</td>
<td>997</td>
<td></td>
<td>21.2</td>
<td>27.0</td>
<td>23.7</td>
<td>28.2</td>
</tr>
<tr>
<td>INIAP-Puca Shungo</td>
<td>2012</td>
<td>940</td>
<td></td>
<td>18.5</td>
<td>43.5</td>
<td>24.4</td>
<td>13.6</td>
</tr>
<tr>
<td>INIAP-Victoria</td>
<td>2012</td>
<td>3105</td>
<td></td>
<td>2.0</td>
<td>12.4</td>
<td>28.4</td>
<td>57.2</td>
</tr>
<tr>
<td>INIAP-Yana Shungo</td>
<td>2012</td>
<td>1023</td>
<td></td>
<td>24.9</td>
<td>58.1</td>
<td>12.8</td>
<td>4.2</td>
</tr>
<tr>
<td>Superchola</td>
<td>2008-2010, 2012</td>
<td>1960</td>
<td></td>
<td>10.4</td>
<td>26.3</td>
<td>34.7</td>
<td>28.6</td>
</tr>
</tbody>
</table>

Important!

The best period of time between harvests depends on the development of the minitubers, and therefore on the potato variety and the environmental conditions.
Storage

A significant difference between minitubers produced with conventional or semi-hydroponic technologies (Annex 1) and those obtained by aeroponics is that the latter have different physiological ages, due to the fact that they have been harvested on different dates (sometimes more than ten). The minitubers produced with other technologies have the same physiological age, since they are harvested at the end of the plants’ vegetative cycle.

In the case of aeroponics, at the end of the crop cycle, the first minitubers are already sprouting, while the last minitubers harvested are still without sprouts.

One way of counteracting the effects of the different physiological ages is by placing the minitubers from the early harvests in refrigerated storage rooms or cold rooms. The other way is to treat the minitubers of the last harvests with hormones to accelerate sprouting.

In both cases, the idea is to combine the minitubers from several harvests and to ensure uniform sprouting. Nevertheless, despite these treatments, it is quite likely that there will be some minitubers with well-developed sprouts and others with sprouts that are just beginning to develop. This causes emergence in the field to be uneven, but the size of the plants usually evens out by the time they are flowering.

For storage of the minitubers, we need to consider the following factors:

- Temperature and light
- Humidity
- Ventilation
Temperature and light. The temperature and light of the storage place depend on when the minitubers are to be used:

- If we need to store them for relatively long periods (weeks or months) or if we want to group the minitubers from several harvests to obtain uniform sprouting, then the storage temperature should be 4 to 5°C, and for this purpose we need to use cold rooms, without light.

- If the minitubers are to be used in the short term, that is, if we want to allow sprouting so that they will be ready for planting, we should store them at an ambient temperature (12 to 18°C). If we wish to accelerate sprouting, we can store the minitubers in places with higher temperatures. **That is, the higher the temperature, the faster the sprouting**. In any case, the storage place should have diffused light, because it promotes the greening of the minitubers' skin, facilitates the breaking of apical dominance, and favors the production of good quality sprouts (short and strong) and the appearance of root primordials.

**Important!**

We must prevent sunlight from shining directly onto the minitubers, because this causes dehydration and cellular death.

Humidity. Minitubers are very susceptible to dehydration, because their skin is thin and their surface-area-to-volume ratio is high. For this reason, a relative humidity of 90 to 95% must be maintained in the storage place. However, higher humidity may cause condensation of water on the surface of the minitubers, which favors the development of pathogens.

Ventilation. Heat and gases such as CO$_2$ produced by the respiration of the stored minitubers must be permanently extracted via natural or forced ventilation, to minimize losses and favor optimal sprouting. Excess ventilation, however, produces excessive water losses, so that minitubers become dehydrated and their quality deteriorates.

Storage place

There are two types of infrastructure:

- **Cold room.** This is used to store the minitubers for a short time (one to two months) and then put them to sprout under the required conditions. The minitubers are stored at a temperature of 4 to 5°C, humidity of 90 to 95%, and without light.
**Storehouse.** To enable the minitubers to sprout, the storehouse must have the following characteristics:

- Secure, to prevent theft.
- Clean.
- With shelves where trays containing the minitubers can be placed.
- With a temperature that will permit proper sprouting of the tubers (between 12 and 18°C). If we wish to accelerate the sprouting, the temperatures will need to be higher.
- With ambient humidity of 90 to 95%. To ensure this, recipients with clean water, or humidifiers should be placed on the floor.
- With diffused light.
- With anti-aphid net and protection against rodents.

**Other standards for handling minitubers during storage**

- To prevent rot and the development of long, whitish sprouts, minitubers should be placed on trays with a maximum of three layers. They should never be stored in sacks or piles.

- In the sprouting storehouse, the minitubers must be moved every two or three weeks to make sure that they all receive diffused light and to obtain even sprouting.
If minitubers show apical dominance during storage, we need to remove the sprouts and place the minitubers in an environment with temperatures of 15 to 20°C and 90 to 95% relative humidity, with diffused light and good ventilation, to stimulate the development of the rest of the sprouts. Do no remove sprouts from minitubers weighing less than 8 g because they will lose vigor.

**Waste management**

At the end of the harvests, a large quantity of plant material—stems, leaves, and roots—needs to be managed as waste. These remains can be used to make compost in a site far away from the net house. As in the case of the nutrient solution, it is best not to use the compost on Solanaceae to avoid the potential spreading of diseases.
EXPERIENCES AND LESSONS LEARNED

What does experience tell us?

Potato minituber production in aeroponics depends on the variety cultivated, on the environmental factors and on the management given to the crop: quality of the material to be transplanted, application of hygiene standards, timeliness and quality of stem-lowering, pruning, and training, nutrient solution management, pest and disease management, harvesting and storage of the minitubers.

IN ECUADOR

In Ecuador, different varieties of potato were planted to verify their yields: Superchola (Solanum tuberosum ssp. andigena), INIAP-Fripapa (tuberosum x andigena type, with tuberosum characteristics), INIAP-Victoria (tuberosum x andigena type with andigena characteristics), INIAP-Libertad (ssp. tuberosum) and chauchas: INIAP-Yana Shungo and INIAP-Puca Shungo (andigenum x phureja).

Lesson learned:

The variety, management and environmental conditions can result in great differences in production from one cycle to another:

- The crop cycle in aeroponics is lengthy in comparison with a crop cycle in the field. Up to 10 harvests per cycle have been obtained.

- With the Superchola variety, 23 to 193 minitubers per plant were harvested; in some cases, up to 294 days after transplantation.

- With the INIAP-Fripapa variety, 10 to 63 minitubers per plant were harvested, up to 204 days after transplantation.

- The andigena types (Superchola and INIAP-Victoria) always produced more minitubers than the INIAP-Fripapa variety (tuberosum type), mostly weighing less than 5 g. The chauchas (andigena x phureja) behaved more or less like the INIAP-Fripapa, producing a majority of tubers that weighed more than 5 g.

A high transplantation density can make harvesting difficult. Manipulation by the greenhouse operators during harvesting can cause minitubers to fall and can damage the stolons.

- Thus, in the INIAP-Victoria variety, despite initially applying 1 ppm of sodium hypochlorite in the nutrient solution, rot was seen on stolons and tubers, caused by Phytophthora infestans. It is probable that these rots resulted from damage to the stolons caused when harvesting.
IN PERU

Researchers at the CIP-Huancayo Station found that production of minitubers per plant is always better in the summer (rainy season: January to June) than in the winter (dry season: May to October):

<table>
<thead>
<tr>
<th>Variety</th>
<th>Rainy season (January to June)</th>
<th>Dry season (May to October)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Average</td>
<td>sd*</td>
</tr>
<tr>
<td>Canchan</td>
<td>185.9</td>
<td>69.1</td>
</tr>
<tr>
<td>Perricholi</td>
<td>129.9</td>
<td>23.7</td>
</tr>
<tr>
<td>Yungay</td>
<td>138.4</td>
<td>31.3</td>
</tr>
</tbody>
</table>

*Standard deviation

The *tuberosum* type varieties were found to develop and produce less than the *andigena* type varieties or native potatoes.

In an experiment at CIP-Huancayo, it was found that the Dutch variety, Desiree, substantially improved its production: from 3.2 minitubers per plant on average without additional light, to 25.6 with four hours of additional light per day.

In aeroponics, the minitubers develop hanging from the plants through the stolons, which causes them to lengthen, apparently from the effect of gravity. This lengthening is more noticeable in certain varieties, but does not affect the quality of the minitubers.

- It is important to renew the nutrient solution to reduce the risk of contamination by pathogens. Bear in mind, too, that sodium hypochlorite applied to the nutrient solution (0.5 to 2 ppm) decomposes in time.

- It has been common that small minitubers fall from roots of the ssp. *andigena* varieties, resulting in a high production of minitubers weighing less than 5 g.
**In a few words...**

During the implementation and management of the aeroponic crop, following hygiene standards is fundamental for maintaining a healthy, high quality crop. However, these standards are not easy to implement with staff that is not used to taking those kinds of precautions, so special training and follow-up are needed to ensure their implementation.

The steps for the preparation of the nutrient solution are: chemical analysis of the water supply, selection of the formula for the nutrient solution, selection and calculation of fertilizers, and preparation of the solution.

You can work with different formulae for the nutrient solution, depending on the sources of fertilizers available. However, great care must be taken to manage the solution’s pH and electrical conductivity.

Managing an aeroponic crop demands daily, ongoing monitoring. The steps involved in implementation and care of the crop include: acclimatizing planting material for transplantation, transplanting it into the aeroponic module, stem lowering (equivalent of hilling up), pruning, training, integrated pest and disease management, harvesting, and storage. Each task calls for special precautions and the work must always be adapted to local conditions.

Experience shows that the period of the potato cultivation cycle in aeroponics is longer than a cultivation cycle in the field.

The production of potato minitubers in aeroponics varies from one cycle to another, depending on the variety, environmental factors and management of the crop.

There is always a great risk of losing the entire production in modules, primarily because the nutrient solution is recirculated, so any mistake in its preparation, or the entry of a pathogen into the system, can cause serious damage.

Nevertheless, with appropriate management, production can be more than 50 minitubers per plant in most varieties and production cycles.

Since several harvests are made in one aeroponic cycle, minitubers of different physiological ages are obtained and thus require differentiated storage.

Proper storage is important; it consists of keeping the minitubers in conditions that permit their physiological change (from dormancy to multiple sprouting) before planting.
CHAPTER 7

MANAGING MINITUBERS IN THE FIELD

Víctor Otazá
WHAT DO WE PLAN TO DO IN THIS CHAPTER?

- Describe the optimal physiological status of minitubers for use as planting material.
- Indicate the characteristics of minitubers produced with aeroponics that influence their management in the field.
- Explain how to manage them in the field.
- Compare their yield with that of minitubers produced using other multiplication techniques.
Once the minitubers have been harvested and stored correctly, —at temperatures of 12 to 18°C, with 90 to 95% relative humidity, with diffused light, good ventilation, and for a period that permits sprouting (from a few days to three months or more, depending on the variety)— then they can be used as planting material, either in the field or in a greenhouse.

What is the optimal physiological state of minitubers for use as planting material?

The most suitable is the physiological state of multiple sprouting, that is, with at least three strong, short sprouts (1 to 2 cm).

Minitubers with multiple sprouting:

- Ensure rapid, even emergence, and

- Guarantee an abundant production, because they produce vigorous plants. From each sprout, a stem will be formed; and from each of these, two to eight tubers will emerge, depending on the variety, the management and the environmental conditions.

Minitubers that are at other physiological states (dormancy, apical dominance or senescence) must not be used as seed because:

- In the state of dormancy, the period of cultivation is longer,

- In the state of apical dominance, plants are formed with only one stem, so the yields will be low, and

- In the state of senescence, emergence isn’t uniform, the plants are weak, susceptible to pests, and their production is low.

Important!

Planting minitubers that are not at the right physiological stage (multiple sprouting) is a great risk, since the plants can emerge unevenly and with a single stem. The minitubers can also rot or dry up in the soil before emerging, causing crop failure.
What are the characteristics of minitubers produced with aeroponics that influence their management in the field?

Minitubers produced with aeroponics have two important characteristics that influence their management in the field:

1. Physiological age
2. Weight

Physiological age

Since there are several harvests in aeroponics, the physiological ages of the minitubers are different. One way of counteracting the effects of these differences is by placing the minitubers from the early harvests in refrigerated storehouses or cold rooms. Another way is by treating the minitubers of the last harvests with hormones, to accelerate sprouting and to even out the physiological status of the seed lot.

Despite these treatments, it is very likely that, when planting, there will be some minitubers with well-developed sprouts and others with smaller ones.

This is why at the start, there is little uniformity in the emergence of the plants in the field, but eventually their size tends to even out, as seen in the following pictures of a field of potato planted with minitubers obtained from aeroponics, of the Tigoni variety, at Kisima Farm (Kenya):

Weight

Minitubers produced by aeroponics range in weight from 0.5 to 30 g, though they can sometimes be as heavy as 60 g. However, the majority of minitubers often weigh less than 5 g.

64 See Chapter 6: Storage.
65 This also occurs in other production systems (conventional or semi-hydroponics) when in vitro plants are used.
This is a contrast to what is customary for seed producers in the Andes, particularly commercial potato producers, who use seed potatoes weighing between 30 and 60 g.

**Important!**

Specialized seed producers must multiply minitubers produced with aeroponics in order to produce basic seed. The use of minitubers is not recommended for the production of commercial potatoes because of their high cost and the special management conditions.

The management of minitubers produced with aeroponics in the field depends on their class (weight). As a rule, the heavier the minitubers, the less specialized the seed producer that multiplies will need to be, and the less demanding the conditions for their multiplication will be, as is illustrated by the following chart:

<table>
<thead>
<tr>
<th>Class of minituber</th>
<th>Weight (g)</th>
<th>Seed producer</th>
<th>Pre-emergence treatment</th>
<th>Destination: field or greenhouse</th>
</tr>
</thead>
<tbody>
<tr>
<td>First</td>
<td>Above 10 g</td>
<td>Moderately specialized</td>
<td>No</td>
<td>Field with average characteristics</td>
</tr>
<tr>
<td>Second</td>
<td>Above 5 g up to 10 g</td>
<td>Moderately specialized</td>
<td>No</td>
<td>Field with characteristics above the average</td>
</tr>
<tr>
<td>Third</td>
<td>Above 2 g up to 5 g</td>
<td>Highly specialized</td>
<td>Yes</td>
<td>Field with characteristics above the average</td>
</tr>
<tr>
<td>Fourth</td>
<td>2 g or below</td>
<td>Highly specialized</td>
<td>Yes</td>
<td>Field with characteristics above the average, or greenhouse</td>
</tr>
</tbody>
</table>

Let’s take a closer look at the terms used in the chart:

**Seed producer**

Producers who multiply seed produced with aeroponics must be registered with the pertinent authorities.

- **Moderately specialized producer**: A person who produces seed potato with a performance within the average and an acceptable degree of reliability. This kind of seed producer is recommended for multiplying minitubers produced with aeroponics that weigh more than 5 g.
Minitubers with a weight of more than 5 g don’t normally require pre-emergence treatment, whereas minitubers weighing 5 g or less do need it.

Pre-emergence treatment consists in planting the minitubers in pre-germination trays used for horticultural production, with a disinfected substrate.

Some recommendations are given below:

- Planting depth should be two or three times the diameter of the minituber.
- Ideally, these trays should remain in a greenhouse, but they can also be placed in other places protected from the rain.
- Irrigation should be light, to prevent rotting.
- Depending on the sprouting status of the minitubers, the resulting plantlets should be ready after two to four weeks from transplantation to a:
  - **field**: plantlets from minitubers that weigh more than 2 g (up to 5 g), or
  - **greenhouse** (conventional systems, semi-hydroponics or aeroponics66): plantlets from minitubers that weigh 2 g or less. These plantlets may also be transplanted into the field, depending on their conditions.

If the conditions are not available for applying pre-emergence treatment, two to four minitubers at the multiple sprouting stage with weights of 5 g or less may be planted, per planting site, directly in the field.

**Destination of the minitubers**

Depending on their weight, minitubers produced with aeroponics can be used in two types of agricultural fields:

---

66 See Annex 2.
• **Fields with average characteristics:** that is, fields that comply with current regulations, but which occasionally present some kind of problem. For example, sporadic lack of irrigation, frosts, etc. In this type of field, it is recommended to use the minitubers that weigh above 10 g, because in extreme weather events (for example, a drought or frosts), they can sprout again and recover.

• **Fields with characteristics above the average:** that is, fields that comply with current regulations and which present extraordinary characteristics for seed production. These fields are often used for horticultural production with high market value. In this type of field, it is recommended to use the minitubers that weigh 10 g or less.

### How do we manage minitubers in the field?

#### Characteristics of the field

The fields where the minitubers are to be planted must comply with the regulations in force for the production of basic seed, specific to each country (Colombia\(^67\), Ecuador\(^68\) and Peru\(^69\)).

• Be isolated from commercial potato crops.

• Be located at a certain altitude or in a geographic zone with a relatively low risk of viral insect vectors, frost, hail and flooding.

• Comply with the standards of soil rotation.

• Have access roads to facilitate the transportation of people, inputs, and production.

• Have access to irrigation water.

• Have security to prevent theft.

• Have an ideal soil for potato production.

---

68 MAGAP, 2013.
69 INIA, 2009.
Agronomic management

The minitubers or plantlets that are used as planting material must be given careful agronomic management.

The main recommendations are as follows:

- **Preparing the soil:** good soil preparation will favor fast emergence of the minitubers or quick rooting of the plantlets. Good soil management practices must be used to prevent erosion.

- **Planting depth:** minitubers should be planted at a lower depth than is customary for large tubers. A good guideline is to plant them at a depth of two to three times the diameter of the minituber. In the case of plantlets, transplantation involves burying the roots up to the neck of the plant, taking care not to damage the roots, and conserving the soil adhered to them.

- **Planting density:** this depends on the variety (varieties of the andigena type require more space than those of the tuberosum type), but basically, the same spacing should be used as for producing seed. The most frequently used spacing is 0.25 m between plants and 0.80 m between furrows.

- **Pest and disease management:** insofar as is possible, conduct preventive controls. At least twice during the crop cycle, the entire field should be inspected and plants that are of a different variety, or which show symptoms of diseases that are under regulation by the competent authorities, should be removed. This work is known as “roguing.”

- **Cultivation work:** weeding, hilling up and irrigation must be done carefully and at the appropriate time.

- **Harvest:** the time for harvesting is when the tuber is physiologically mature. The foliage can be eliminated (chemically or manually) to hasten maturity and prevent the tubers from growing too much.

**What does the yield of minitubers produced with aeroponics depend on?**

On the variety, the management and environmental conditions, so it can vary significantly. In experiments in Ecuador and Peru, yields have varied between 0.29 and 1.46 kg per plant.
Do the minitubers produced by aeroponics yield the same as minitubers produced with other technologies?

Yes. Field trials in Ecuador and Peru showed that the yields of minitubers produced with aeroponics are similar to the yields of minitubers produced with conventional technology or semi-hydroponics.

These trials were conducted with six potato varieties. In Peru, they were done at CIP-Huancayo (3,259 m.a.s.l.) and at CIP-Lima (250 m.a.s.l.). In Ecuador, the trials were carried out at Salcedo, in the province of Cotopaxi (3,110 m.a.s.l.):

<table>
<thead>
<tr>
<th>Locality</th>
<th>Variety</th>
<th>Minitubers (kg per plant)</th>
<th>Statistical significance (P = 0.05)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lima</td>
<td>Perricholi</td>
<td>1.09</td>
<td>1.46</td>
</tr>
<tr>
<td>Lima</td>
<td>Yungay</td>
<td>1.17</td>
<td>0.92</td>
</tr>
<tr>
<td>Huancayo</td>
<td>Maria Reiche</td>
<td>0.88</td>
<td>0.88</td>
</tr>
<tr>
<td>Huancayo</td>
<td>Desiree</td>
<td>0.66</td>
<td>0.83</td>
</tr>
<tr>
<td>Huancayo</td>
<td>Canchán</td>
<td>1.04</td>
<td>0.92</td>
</tr>
<tr>
<td>Salcedo</td>
<td>Superchola</td>
<td>0.27</td>
<td>0.53</td>
</tr>
</tbody>
</table>

\(^\text{n.s.}: \text{not significant.}\)
EXPERIENCES AND LESSONS LEARNED

What does experience tell us?

About managing the minitubers of different weights obtained with aeroponics

IN ECUADOR

Some trials have shown that minitubers heavier than 5 g are suitable for planting directly in the field. The weight of the minituber did not influence the number of stems or the number or weight of tubers harvested, although to a certain extent, it influenced the vigor of the plants (minitubers of greater weight resulted in more vigorous plants).

IN KENYA

In one field at Kisima Farm, two sizes of seed were used (more than 10 g and less than 5 g), and several differences were noted: in emergence, foliage development and yield, to the advantage of the larger seed:

About managing minitubers of different physiological ages obtained by aeroponics

IN ECUADOR

The time during which minitubers remain in storage before being planted had a negative influence on yields in the field: the greater the time, the lower the yield. Therefore, in places where potato can be planted in the field year-round (as in some areas of Ecuador), avoiding storing the minitubers in cold rooms for long periods and planting minitubers on successive dates is recommended —as soon as they reach the multiple sprouting stage— rather than keeping them for too long in cold rooms and planting all the minitubers on the same date.
In a few words...

Once the minitubers have been harvested and stored correctly, they can be used as planting material in either the field or a greenhouse.

The best physiological state for minitubers to be used as planting material is that of multiple sprouting. This ensures fast, even emergence, vigorous plants and good yields.

Physiological age and weight are the main characteristics that influence the field management of minitubers obtained from aeroponics:

- The **physiological age** of the minitubers is variable because in aeroponics there are sequential harvests. This can be managed by using cold rooms that delay sprouting, or hormones that induce faster sprouting. Nevertheless, there is often a lack of uniformity in the emergence of the plants, though their sizes tend to even out as the plants grow.

- The **weight** of a minituber produced with aeroponics largely defines its management in the field. As a rule, minitubers that weigh more are going to require a lesser degree of specialization on the part of the seed producer, as well as less demanding conditions for their multiplication.

The field management of minitubers produced with aeroponics must be carried out with great care and it must comply with the current regulations for basic seed production.

No significant differences have been found between the yield of minitubers produced with conventional technology or semi-hydroponics and the yield of those produced by aeroponics.

In Ecuador, it was found that the time during which minitubers remain in storage before being planted had a negative influence on yields. The longer the period, the lower the yield.
CHAPTER 8

PRODUCTION COSTS

Julián Mateus-Rodríguez
Fabían Montesdeoca
WHAT DO WE PLAN TO DO IN THIS CHAPTER?

- Explain how to estimate production costs, income and economic profitability in the production of potato minitubers using aeroponics.
Aeroponics has two main uses:

- as a commercial rapid seed multiplication technology,
- as a research tool.

To be a commercially viable rapid seed multiplication technology, aeroponics must meet the needs of the market and generate profits. In this context, the person or institution wishing to implement aeroponics must have detailed knowledge of how to estimate the production costs, income and economic profitability.\(^\text{71}\)

**What are production costs?**

The production costs are the expenditures required to launch and keep an enterprise working, in this case the production of pre-basic seed using aeroponics. They constitute the best way to back up a productive business.

It is thus essential to keep an accurate record of production costs, since they will allow you to value the product properly and to ensure that the difference between income and costs is as high as possible.\(^\text{72}\)

Some of the benefits of keeping a record of production costs are listed below:

- To determine the fixed, variable and total costs of the activity, in order to know the financial status of the enterprise.
- To determine the real cost of the products sold, in order to calculate profit or loss from the activity.
- To have a useful management tool for planning and controlling production costs.
- To have a source of information for making decisions about capital investments, machinery replacement, establishing prices, increasing production volume and other issues.

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\(^{71}\) Detailed examples and an extensive discussion on this topic can be found in Mateus-Rodríguez et al., 2013.

\(^{72}\) Machón, 2000.
How are production costs classified?

They are classified as:\[3\]:

- Fixed or investment costs
- Variable or operating costs
- Total costs
- Unit costs

**Fixed or investment costs (FC)**

These refer to the capital needed for the construction of the infrastructure and the purchase of equipment.

These costs include:

- Net house, machinery room, cold room,
- Storehouse, aeroponic modules,
- Irrigation system,
- Equipment for measuring environmental conditions and nutrient solution, and
- Material that can be used during several seasons or crop cycles, such as shade net to mitigate the effect of high temperatures and high luminosity, buckets, hoses, etc.

Each of these investments has a specific **useful lifetime**, usually estimated in years, which can be used to calculate depreciation, that is, the periodic reduction in the value of a tangible or intangible asset. This depreciation can be the result of three factors:

- wear and tear,
- the passing of time
- obsolescence, that is, premature aging due to change in technology.
The fixed cost (FC) of a specific item per crop cycle is calculated with the following formula:

\[
FC = \frac{C}{(UL \times CY)}
\]

where:

- **C**: cost of item (USD)
- **UL**: useful life (years)
- **CY**: crop cycles per year

### An example:

The cost (C) of the construction of a net house is **4720 USD** and its useful life (UL) is 7 years. In this net house, there is 1 crop cycle per year (CY).

The fixed cost of the net house per each crop cycle, that is, its depreciation, is **674 USD**:

\[
FC = \frac{4720}{(7 \times 1)} = 674 \text{ USD}
\]

### Variable or operating costs (VC)

These are the costs involved directly in the production activity, in this case, the production of minitubers using aeroponics.

The variable costs include:

- Material and inputs used during each crop cycle: plantlets or cuttings, fertilizers, pesticides, disinfecting material, etc.

- Services: electricity, water, security, virus diagnosis, testing of water or foliage, among other things; maintenance of equipment and infrastructure; consultation with specialized technicians, etc.

- Salaries of implementing technicians, greenhouse operators and administrative staff.

### Total costs (TC)

Calculated by adding together the fixed and variable costs.

\[
TC = FC + VC
\]
Unit costs (UC)

The unit costs are those that correspond to each unit of product obtained, in this case, potato minitubers. It is obtained by dividing the total production cost (TC) by the number of units produced (Q).

\[ UC = \frac{TC}{Q} \]

What is the income?

The financial resources from the sale of goods or services produced by a company. It is divided into:

- Gross, and
- Net.

Gross or total income (GI)

This is the overall income obtained from the sale of a commercial product. It is calculated by multiplying the unit-selling price (SP) by the quantity sold (Q).

\[ GI = SP \times Q \]

Net income or profit (NI)

This is the gross income (GI) minus total costs (TC)

\[ NI = GI - TC \]

How do we calculate profitability (P)?

The profitability (%) can be calculated by dividing the net income (NI) by the total cost (TC) multiplied by 100:

\[ P = \frac{NI}{TC} \times 100 \]
AN EXAMPLE

As an example, we present data from a net house built of wood, cement, anti-aphid net and a polycarbonate roof (8 x 16 m and 4 m, at the highest part), located at CIP’s Santa Ana Station (3259 m.a.s.l.) in Huancayo, Peru. The data are from experiments carried out between 2008 and 2010. The effective production area of the aeroponic modules was 42 m².

The fixed production costs are shown in Table A, the variable costs in Table B, and total costs, production, unit cost, selling prices, income and profitability in Table C.

Table A. Fixed or investment costs for the production of potato minitubers using aeroponics at CIP-Huancayo (Peru) in an effective production area of 42 m².

<table>
<thead>
<tr>
<th>Item</th>
<th>Quantity</th>
<th>Unit price (USD)</th>
<th>Total price (USD)</th>
<th>Years of useful life</th>
<th>Crop cycle per year</th>
<th>Cost per crop cycle (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Infrastructure</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Net house</td>
<td>1</td>
<td>4720</td>
<td>4720</td>
<td>7</td>
<td>1</td>
<td>674.3</td>
</tr>
<tr>
<td>Aeroponic modules</td>
<td>7</td>
<td>262</td>
<td>1834</td>
<td>7</td>
<td>1</td>
<td>262.0</td>
</tr>
<tr>
<td>Irrigation system</td>
<td>1</td>
<td>380</td>
<td>380</td>
<td>7</td>
<td>1</td>
<td>54.3</td>
</tr>
<tr>
<td>Machinery house</td>
<td>1</td>
<td>330</td>
<td>330</td>
<td>7</td>
<td>1</td>
<td>47.1</td>
</tr>
<tr>
<td>Irrigation head</td>
<td>1</td>
<td>1121</td>
<td>1121</td>
<td>7</td>
<td>1</td>
<td>160.1</td>
</tr>
<tr>
<td>Installation</td>
<td>1</td>
<td>682</td>
<td>682</td>
<td>7</td>
<td>1</td>
<td>97.4</td>
</tr>
<tr>
<td><strong>Equipment</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sensors of CE&lt;sup&gt;a&lt;/sup&gt;, pH&lt;sup&gt;b&lt;/sup&gt;</td>
<td>1</td>
<td>177</td>
<td>177</td>
<td>7</td>
<td>1</td>
<td>25.3</td>
</tr>
<tr>
<td>Sensors of T&lt;sup&gt;c&lt;/sup&gt; and RH&lt;sup&gt;d&lt;/sup&gt;</td>
<td>1</td>
<td>177</td>
<td>177</td>
<td>7</td>
<td>1</td>
<td>25.3</td>
</tr>
<tr>
<td>Pesticide sprayer</td>
<td>1</td>
<td>103</td>
<td>103</td>
<td>7</td>
<td>1</td>
<td>14.7</td>
</tr>
<tr>
<td>Thermometer</td>
<td>1</td>
<td>13</td>
<td>13</td>
<td>7</td>
<td>1</td>
<td>1.9</td>
</tr>
<tr>
<td><strong>Materials</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Shade net</td>
<td>1</td>
<td>300</td>
<td>300</td>
<td>7</td>
<td>1</td>
<td>42.9</td>
</tr>
<tr>
<td>Bucket</td>
<td>1</td>
<td>6</td>
<td>6</td>
<td>7</td>
<td>1</td>
<td>0.9</td>
</tr>
<tr>
<td>Graduated test tubes</td>
<td>1</td>
<td>22</td>
<td>22</td>
<td>7</td>
<td>1</td>
<td>3.1</td>
</tr>
<tr>
<td>Plastic containers</td>
<td>5</td>
<td>2</td>
<td>10</td>
<td>7</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>Hose</td>
<td>1</td>
<td>17</td>
<td>17</td>
<td>7</td>
<td>1</td>
<td>2.4</td>
</tr>
<tr>
<td>Plastic wash bottle</td>
<td>1</td>
<td>9</td>
<td>9</td>
<td>7</td>
<td>1</td>
<td>1.3</td>
</tr>
<tr>
<td><strong>Total fixed costs (USD)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td><strong>1414.4</strong></td>
</tr>
</tbody>
</table>

<sup>a</sup> Electrical conductivity  
<sup>b</sup> Potential of hydrogen  
<sup>c</sup> Temperature  
<sup>d</sup> Relative humidity
Table B. Variable or operating costs for the production of potato minitubers using aeroponics, at CIP-Huancayo (Peru) in an effective production area of 42 m².

<table>
<thead>
<tr>
<th>Item</th>
<th>Unit</th>
<th>Quantity</th>
<th>Unit value (USD)</th>
<th>Cost crop cycle (USD)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Inputs</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In vitro plantlets</td>
<td>Plantlet</td>
<td>700</td>
<td>0.27</td>
<td>189</td>
</tr>
<tr>
<td>Commercial nutrient solutions</td>
<td>Misc.</td>
<td>1</td>
<td>99</td>
<td>99</td>
</tr>
<tr>
<td>Commercial simple fertilizers</td>
<td>Misc.</td>
<td>1</td>
<td>157</td>
<td>157</td>
</tr>
<tr>
<td>Products for pest control</td>
<td>Misc.</td>
<td>1</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Disinfecting inputs</td>
<td>Misc.</td>
<td>1</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>Other inputs</td>
<td>Misc.</td>
<td>1</td>
<td>102</td>
<td>102</td>
</tr>
<tr>
<td><strong>Services</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electric power</td>
<td>Consump.</td>
<td>1</td>
<td>186</td>
<td>186</td>
</tr>
<tr>
<td>Water</td>
<td>Consump.</td>
<td>1</td>
<td>36</td>
<td>36</td>
</tr>
<tr>
<td>Virus test</td>
<td>Test</td>
<td>30</td>
<td>2</td>
<td>60</td>
</tr>
<tr>
<td>Water test</td>
<td>Test</td>
<td>1</td>
<td>17</td>
<td>17</td>
</tr>
<tr>
<td>Foliage test</td>
<td>Test</td>
<td>1</td>
<td>33</td>
<td>33</td>
</tr>
<tr>
<td>Maintenance of equipment</td>
<td>Service</td>
<td>3</td>
<td>28</td>
<td>84</td>
</tr>
<tr>
<td>Maintenance of infrastructure</td>
<td>Service</td>
<td>3</td>
<td>28</td>
<td>84</td>
</tr>
<tr>
<td><strong>Staff</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Implementing technician</td>
<td>Person</td>
<td>25% in 6 months a</td>
<td>1100 p. month</td>
<td>1650 a</td>
</tr>
<tr>
<td>Greenhouse operator</td>
<td>Person</td>
<td>60% in 6 months</td>
<td>310 p. month</td>
<td>1116</td>
</tr>
<tr>
<td><strong>Total fixed costs (USD)</strong></td>
<td></td>
<td></td>
<td></td>
<td>3845</td>
</tr>
</tbody>
</table>

a Meaning that the implementing technician dedicates 25% of her/his time in 6 months of duration of the crop cycle.

b Calculated thus: USD1100 per month x 25% dedication x 6 months = USD 1650.
The costs of infrastructure, equipment and inputs listed will vary depending on the country and locality.

Fixed costs accounted for 27% of the total costs, whereas variable costs constituted 73% of total costs. In the variable cost category, staff wages were the largest expense (53%), which reflects the importance of human resources.

The production was 35 minitubers per plant with a density of 16 plants per m². This is a relatively low yield, because yields of more than 100 minitubers per plant have been recorded. Remember that the yield depends on the variety, the management and the environment.

Profitability was 40%, a far lower figure than that presented by Maldonado et al. (2007), who reported a profitability of 545%. These authors considered a yield of 45 minitubers per plant, with twice the plant density per m² used in this example.

Aeroponics was in the stage of adaptation to local conditions (validation) for this example, which explains the relatively low yield and high costs. As the technique becomes better adapted to local conditions, and production processes are improved, it should be possible to reduce costs and raise the yield.

---

**Table C. Total costs, production, unit cost, income, and profitability for potato minituber production using aeroponics, at CIP-Huancayo (Peru) in an effective production area of 42 m².**

<table>
<thead>
<tr>
<th>Detail</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total costs (TC)</td>
<td>5259 USD</td>
</tr>
<tr>
<td>Fixed costs (FC)</td>
<td>1414 USD</td>
</tr>
<tr>
<td>Variable costs (VC)</td>
<td>3845 USD</td>
</tr>
<tr>
<td>Production (Q)</td>
<td>24,500 minitubers</td>
</tr>
<tr>
<td>Unit cost (UC)</td>
<td>0.26 USD per minituber</td>
</tr>
<tr>
<td>Selling price (SP)</td>
<td>0.30 USD per minituber</td>
</tr>
<tr>
<td>Gross income (GI)</td>
<td>7350 USD</td>
</tr>
<tr>
<td>Net income (NI)</td>
<td>2091 USD</td>
</tr>
<tr>
<td>Profitability (P)</td>
<td>40%</td>
</tr>
</tbody>
</table>

Some points to bear in mind regarding this example:

- The costs of infrastructure, equipment and inputs listed will vary depending on the country and locality.

- Fixed costs accounted for 27% of the total costs, whereas variable costs constituted 73% of total costs. In the variable cost category, staff wages were the largest expense (53%), which reflects the importance of human resources.

- The production was 35 minitubers per plant with a density of 16 plants per m². This is a relatively low yield, because yields of more than 100 minitubers per plant have been recorded. Remember that the yield depends on the variety, the management and the environment.

- Profitability was 40%, a far lower figure than that presented by Maldonado et al. (2007), who reported a profitability of 545%. These authors considered a yield of 45 minitubers per plant, with twice the plant density per m² used in this example.

- Aeroponics was in the stage of adaptation to local conditions (validation) for this example, which explains the relatively low yield and high costs. As the technique becomes better adapted to local conditions, and production processes are improved, it should be possible to reduce costs and raise the yield.

---

74 Mateus-Rodriguez et al., 2012.
As already mentioned, there are several risks that can cause total loss of the modules\textsuperscript{75}, especially during the initial cycles of adaptation of aeroponics to local conditions.

Therefore, the possibility of having total or very high losses during these early cycles must be taken into account when making economic projections.

**Important!**

The first crop cycle, and even the second, can be regarded as trials, to adapt the aeroponics to local conditions (validation). In these cycles, low productive yields should be expected, as well as low or even zero profits.

\textsuperscript{75} For example: contamination of the irrigation system by pathogens that affect the plant’s vascular or root system, intoxication of the plants due to inadequate dosage of pesticides or fertilizers, or a poor logistics and administrative capacity to respond to emergency situations, such as damage to the irrigation system.
In a few words ...

If aeroponics is to be used for rapid seed multiplication commercially, knowing how to estimate production costs, income and economic profitability is indispensable.

Production costs are the expenses required to keep the project working. Those costs include: fixed, variable, total and per unit.

Fixed costs refer to the capital used for the construction of the infrastructure and for equipping the facilities; variable costs are those directly involved in the production activity; total costs are the sum of the fixed and variable costs; and unit costs are the costs of each unit of product obtained, in this case potato minitubers.

Income is the financial resources obtained from the sale of goods or services produced by companies, in this case potato minitubers. It is classified as gross and net income. The gross income is the total income obtained from the sale of the minitubers, and net income is the result we obtain when we subtract total costs from total income.

Profitability is calculated by dividing the net income by the total cost multiplied by 100. In the case of the CIP-Huancayo example, the profitability was 40% per crop cycle. The possibility of having total or very high losses must be taken into account when making economic projections, especially in the early crop cycles, when the aeroponic system is being adapted to local conditions.
Based on the different uses of aeroponics—for rapid seed multiplication, research or communication and political advocacy—it is possible to predict some of the prospects for this technology.

Considering that aeroponics is a rapid seed multiplication technology, and bearing in mind its complexity, CIP, CORPOICA and INIAP expect that it will be adopted for commercial purposes by private companies, governmental organizations (GOs) or non-governmental organizations (NGOs) with sufficient administrative and financial capacity to:

- hire specialized staff,
- construct a relatively complex infrastructure,
- address unexpected situations promptly, and
- develop a profitable business through the sale of minitubers and/or certified seed.

Experiences in Africa and Asia indicate that private companies have the best possibilities of success with aeroponics, as is the case of companies in Kenya and India. At the same time, CIP has witnessed failures by some GOs and NGOs, although this is not always the case, as demonstrated by several success stories of GOs in different countries.

In all successful cases—whether private companies, GOs or NGOs—aeroponics has been implemented with a focus on producing minitubers from a few potato varieties for which there is ample market demand. Recently, aeroponics has also been used by CIP in partnership with a private company to multiply elite potato clones for international distribution.

It should be noted that aeroponics does not seem to be suitable for rapid multiplication of potato genotypes at initial stages of breeding. This is because there is a high variability in the behavior of these genotypes when propagated using aeroponics, and therefore a period of adjustment is needed to determine their requirements (such as planting density, nutrient solution, etc.).

We expect that aeroponics will be used as part of integrated minituber production systems in which several technologies are combined. For example, the use of mother plants, cuttings, hydroponics on solid substrates and aeroponics can be combined. This will make it possible to reduce the risk of losses and to maximize production, taking advantage of the complementary contributions of the different technologies, as shown by the experience of INIAP in Ecuador.
Looking to the future, and based on the experiences of CIP, CORPOICA and INIAP, we propose the following topics as areas that need more research in order to improve the performance of aeroponics as a rapid seed-multiplication technology in highland tropical zones (> 2600 m.a.s.l.):

- Adjustment of the nutrient solution or other measures to shorten the vegetative cycle and reduce the size of the plants, especially in andigena type varieties, which usually tend to develop abundant foliage.

- Effects of stressing nutrient solutions, or of other measures to promote tuber formation.

- Effects of harvesting intervals on minituber production.

- Adjustment of irrigation according to the variety, age of plants and environment.

- Control of fungi, oomycetes and bacteria by means of commercial pesticides or other substances applied in the nutrient solution.

- Use of alternative energies for supply the electricity for irrigation pumps.

- Searching for biodegradable materials to replace those that are non-degradable.

- Use of tomato grafts on potato stems for the simultaneous production of the two crops.

Aeroponics can also be considered a research tool. In this case, some topics that could be studied using aeroponics are:

- Root architecture and tuber development in varieties tolerant to abiotic stress.

- Effects of growth-promoting organisms.

- Effects of chemical elements on plant nutrition.

- Selection of potato genotypes according to root characteristics.

---

76 Such as plastic that should be replaced every other crop cycle, and insulation boards that should be replaced every 4 or 5 crop cycles.

77 Preliminary experiments at CIP-Lima show that this can be an interesting option, especially in places where the value of land is very high and there is a need to optimize the use of the space in the net houses.
The difference between the proposed research topics is subtle and calls for an additional explanation. While on the one hand we propose topics for research needed to improve the performance of aeroponics as a seed multiplication technique, on the other hand, we propose topics that generate research questions where aeroponics is used as a tool.

For example: adjusting the nutrient solution to reduce the size of the plants is a topic of research that could help improve agronomic management, and therefore commercial production using aeroponics. On the other hand, studying the root architecture of varieties tolerant to abiotic stress is a research topic that uses aeroponics as a tool, without immediate commercial implications.

Finally, aeroponics can also be a tool for communication and political advocacy. As already mentioned, one of its important characteristics is that it is a very attractive technology. Organizations have taken advantage of this to position and promote the potato, which has made it possible to attract funds to implement research and development activities around the subject of seed.

A clear example of this effect was seen in Ecuador, where the Ministry of Agriculture decided to make a large investment in formal seed potato systems in 2012, partly as a result of successful experiments with aeroponics conducted by CIP and INIAP.

In this sense, the prospect will be to explore, at greater depth, the role of aeroponics as a tool for communicating the advantages of potatoes. Aeroponic modules (with transparent walls that allow the roots and tubers to be observed) located, in addition to research centers, in restaurants, fairs, and other public places, could be an interesting option in the future.
MANUAL PARA LA PRODUCCIÓN DE SEMILLA DE PATATAS USANDO AEROPONÍCOS

Thomas-Sharma, S., Abdurahman, A., Ali, S., Andrade-Piedra, J.L., Bao, S., Charkowski, A.O., Crook, D., Kadian, M., Sun, H.S., y Yang, Y.J.

Sonneveld, C, y Voogt, W.

Sensi, A., Brandenberg, O., Ghosh, K., y Sonnino, A.

Schulte-Geldermann, E., Gildemacher, P.R., y Struik, P.C.


Orrego, R., Manrique, K., Quevedo, M., y Ortiz, O.

Nichols, M.A.

NASA (National Aeronautics and Space Administration).

Naik, P., y Karihaloo J.L.


Muro, J., Díaz, V., Goñi, J.L., y Lamsfus, C.

Montesdeoca, F., Panchi, N., Pallo, E., Yumisaca, F., Taipe, A., Mera, X., Espinoza, S., y Andrade-Piedra, J.


Raggi, P., y Casadesus, M.


Kim, K.T., Kim, S.B., Ko, S.B., y Park, Y.B.


Monteith, J.


Medina, S.


MAGAP (Ministerio de Agricultura, Ganadería, Acuacultura y Pesca).


INPOFOS (Instituto de la Potasa y el Fósforo).


ANNEXES

ANNEX 1  Alternative technologies to aeroponics for potato minituber production.

ANNEX 2  Integrated potato minituber production system.

ANNEX 3  Examples of how to prepare sodium or calcium hypochlorite solutions.

ANNEX 4  Infrastructure for aeroponics used in Colombia, Ecuador, and Peru.

ANNEX 5  Examples of contact fungicides, systemic fungicides and insecticides.
ANNEX 1: ALTERNATIVE TECHNOLOGIES TO AEROPONICS FOR POTATO MINITUBER PRODUCTION

The table gives a brief description of four technologies for potato minituber production, listing their advantages and disadvantages: conventional, semi-hydroponics, aeroponics, and nutrient film technique.

A detailed comparison of these technologies can be found in Mateus-Rodríguez et al. (2013).

<table>
<thead>
<tr>
<th>Technology</th>
<th>Brief description</th>
<th>Advantages</th>
<th>Disadvantages</th>
<th>Additional Information</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conventional</td>
<td>Uses solid substrate: (soil mixed with different proportions of sand, moss, compost, etc.) in seedbeds or pots; disinfected by pasteurization, water vapor, hot water or chemical products, most of which are very toxic. Generally, solid fertilizers are used at planting or hilling.</td>
<td>• Generally low production. Semi-hydroponics has higher production than conventional technology.</td>
<td>• Low risk of total losses since it doesn’t depend on electricity and pathogens can be controlled and eliminated in affected sections.</td>
<td>Hidalgo et al., 1999.</td>
</tr>
<tr>
<td>Semi-hydroponics</td>
<td>Use of inert solid substrate: in which roots are sustained. Those substrates must be washed and/or disinfected. Nutrients are provided through a solution that isn’t recirculated.</td>
<td>• Easy implementation; doesn’t require specialized staff. • Simple infrastructure</td>
<td>• In the case of semi-hydroponics, the majority of tubers weigh &gt;20 g, which means they can be planted directly in the field. This isn’t the case with conventional technology, in which most tubers are &lt;20 g.</td>
<td>Muro et al., 1997; Ranoil, 1997; Ritter et al., 2001.</td>
</tr>
<tr>
<td>Technology</td>
<td>Brief description</td>
<td>Advantages</td>
<td>Disadvantages</td>
<td>Additional information</td>
</tr>
<tr>
<td>--------------------------</td>
<td>-----------------------------------------------------------------------------------</td>
<td>-----------------------------------------------------------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-----------------------------------------------</td>
</tr>
</tbody>
</table>
| Aeroponics               | Plant roots grow suspended in the air inside closed boxes, or modules, and are fed a nutrient solution that is nebulized and recirculated. | - High production: high multiplication level per plant and high productive efficiency per area.  
- High profitability.  
- Minitubers have high phytosanitary levels.  
- Low environmental impact since solid substrates aren’t used and there is consequently no need for disinfection.  
- Low water consumption because nutrient solution is recycled.  
- Technology is novel and can be used to attract donors. | - Expensive infrastructure.  
- Requires specialized staff.  
- High risk of total loss of production due to a loss of power or the presence of pathogens in the irrigation system, or problems with the nutrient solution.  
- The majority of minitubers are ≤5 g and require a special treatment (planting in trays to produce plantlets) before they can be planted in the field.  
- Minitubers of different physiological ages which can complicate planting in the field.  
- Requires a very efficient logistical and administrative arrangement for dealing with emergency situations (for example, a broken pump, etc.). | Mateus-Rodríguez et al., 2013. |
| Nutrient Film Technique (NFT) | Plant roots grow in a series of canals covered with plastic film supported by a hard structure through which a nutrient solution is recirculated. | - High production, although lower than aeroponics.  
- Very profitable; even more than aeroponics.  
- Minitubers have high phytosanitary levels.  
- Low environmental impact since solid substrates aren’t used.  
- Low water consumption since nutrient solution is recirculated. | - Expensive infrastructure.  
- Requires specialized staff.  
- Limited space for root development.  
- The black plastic covering absorbs heat.  
- High risk of total loss of production due to a loss of power or the presence of pathogens in the irrigation system, or problems with the nutrient solution.  
- Minitubers produced have different physiological ages, which can complicate planting in the field.  
- Requires a very efficient logistical and administrative arrangement for dealing with emergency situations (for example, a broken pump, etc.). | Boesieg & Wagner, 1988; Naik & Karihaloo, 2007; Chuquillanqui et al., 2008. |
ANNEX 2: INTEGRATED POTATO MINITUBER PRODUCTION SYSTEM

To limit the high risk of aeroponic production, while at the same time taking advantage of the smallest minitubers, we recommend using aeroponics as part of an integrated minituber production system that combines several technologies.

An integrated minituber production system can combine the use of in vitro plants, mother plants, cuttings, semi-hydroponics and aeroponics:

This integrated minituber production system works as follows:

- The system begins with the production of in vitro plants: see (a) above.
- If the in vitro plants can be obtained easily and their cost is reasonable, they can be transplanted directly into semi-hydroponics and/or aeroponics (b).
- If, on the other hand, in vitro plants are not easily obtained and/or they have a high cost, they can be used to produce mother plants (c).
- From these mother plants, cuttings can be harvested (d), which will be rooted in trays to produce plantlets (e). Some of these plantlets can be transplanted directly to the field (f), and others can be used as starting material for semi-hydroponics and/or aeroponics (g). Great care must be taken with the pest and disease management of the mother plants and the cuttings, because any infection can jeopardize the whole production system.
- In semi-hydroponics and aeroponics, tubers of different sizes are produced: ≥ 5 g (h) and < 5 g (i).
- In addition, as a by-product, cuttings can be harvested (j) which, once they have been rooted in trays to produce plantlets (k), can be transplanted to the field (l). In principle, this practice should be carried out following strict standards of hygiene, to prevent contamination by pathogens; and in moderation, so as not to drastically reduce the leaf area and affect the yields of minitubers. However, the practice of harvesting cuttings from plants in semi-hydroponics and/or aeroponics needs to be validated.
- Minitubers weighing ≥ 5 g can be planted directly in the field (m), while those weighing < 5 g can be planted in trays to produce plantlets (n) that can be transplanted to the field (o).
Minitubers harvested from mother plants (or from conventional technologies) can carry pathogens that multiply in the organic matter of the substrate. These can cause serious problems if they are used in aeroponics or semi-hydroponics.

As a general rule:

- Minitubers from a conventional system can be used to continue multiplying in another conventional system.

- Do not use minitubers obtained from a conventional system in aeroponics or semi-hydroponics.

- The number of times we can continue multiplying this material in the greenhouse will depend on whether or not the material is contaminated. Quality tests should be used to determine this.
ANNEX 3: EXAMPLES OF HOW TO PREPARE SODIUM OR CALCIUM HYPOCHLORITE SOLUTIONS

Sodium hypochlorite (NaClO) is a commercially available liquid with a chlorine concentration of 5 to 15%.

Calcium hypochlorite (Ca(ClO)₂) is more stable than sodium hypochlorite, and it contains a higher chlorine concentration (30 to 75%). It is commercially available in powder or tablet form, so it first has to be diluted to the required concentration. For example, to prepare a 5% calcium hypochlorite solution, 77 g of calcium hypochlorite (65%) is mixed in 1 liter of water.

* 5% sodium or calcium hypochlorite
** In practice, these decimals are rounded off to the nearest whole number (1000 l)

Although this Manual recommends the use of chlorine-based disinfectants, it is important to find out whether there are less toxic disinfectants on the local market, to lower the environmental impact: for example, isopropyl alcohol.
### ANNEX 4: INFRASTRUCTURE FOR AEROPONICS USED IN COLOMBIA, ECUADOR AND PERU

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Quito</th>
<th>Lima</th>
<th>Huancayo</th>
<th>Tíbaitá</th>
</tr>
</thead>
<tbody>
<tr>
<td>Institution</td>
<td>CIP-INIAP</td>
<td>CIP</td>
<td>CIP</td>
<td>CORPOICA</td>
</tr>
<tr>
<td>Latitude</td>
<td>0° 22' S</td>
<td>12° 42' S</td>
<td>12° 04' S</td>
<td>4° 42' N</td>
</tr>
<tr>
<td>Longitude</td>
<td>78° 33' O</td>
<td>76° 57' O</td>
<td>75° 14' O</td>
<td>74° 12' O</td>
</tr>
<tr>
<td>Altitude (m. a.s.l.)</td>
<td>3,058</td>
<td>244</td>
<td>3,250</td>
<td>2,543</td>
</tr>
<tr>
<td><strong>Net house</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Orientation</td>
<td>North-south</td>
<td>East-west</td>
<td>East-west</td>
<td>East-west</td>
</tr>
<tr>
<td>Width (m)</td>
<td>8</td>
<td>12</td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>Length (m)</td>
<td>20</td>
<td>30</td>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>Height (m)</td>
<td>4</td>
<td>8</td>
<td>3.5</td>
<td>4</td>
</tr>
<tr>
<td>Height (m)</td>
<td>2.7</td>
<td>4</td>
<td>2.6</td>
<td>2.7</td>
</tr>
<tr>
<td>Structure</td>
<td>Metal</td>
<td>Wood</td>
<td>Wood</td>
<td>Metal</td>
</tr>
<tr>
<td>Walls</td>
<td>Anti-aphid net</td>
<td>Anti-aphid net</td>
<td>Anti-aphid net</td>
<td>Anti-aphid net</td>
</tr>
<tr>
<td>Roof</td>
<td>Gabled glass without zenithal opening</td>
<td>Gabled fiberglass with zenithal opening</td>
<td>Gabled polycarbonate without zenithal opening</td>
<td>Gabled polycarbonate without zenithal opening</td>
</tr>
<tr>
<td>Floor</td>
<td>Dirt covered with pumice stone</td>
<td>Dirt covered with gravel and central walkway with cement</td>
<td>Dirt covered with gravel</td>
<td>Concrete</td>
</tr>
<tr>
<td>Temperature control</td>
<td>Lateral ventilators, wind extractors, sprinklers and shade nets on roof</td>
<td>Shade net</td>
<td>Shade net</td>
<td>Shade net and ventilation duct</td>
</tr>
<tr>
<td>Pre-chamber</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Attached storeroom</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Machinery house</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Emergency generator</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Number of aeroponic modules</td>
<td>8</td>
<td>14</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>Module dimensions</td>
<td>5 x 1 m</td>
<td>4.8 x 1.2 m</td>
<td>1 x 1 m</td>
<td>5.0 x 1.2 m</td>
</tr>
<tr>
<td>Number of independent irrigation systems</td>
<td>8</td>
<td>2</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Water filtration</td>
<td>Microbiological filter, ring filter</td>
<td>Ring filter</td>
<td>Ring filter</td>
<td>Ring filter</td>
</tr>
</tbody>
</table>

¹ At the highest part; ² at the lowest part.
### Annex 5: Examples of Contact Fungicides, Systemic Fungicides, and Insecticides

<table>
<thead>
<tr>
<th>Active Ingredient</th>
<th>Toxicological classification</th>
<th>EIQ&lt;sup&gt;2&lt;/sup&gt; (Environmental Impact Quotient)</th>
<th>Dosage for potato in an aeroponic system</th>
<th>Diseases or pests that it can be used to control</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Contact fungicides</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sulfur</td>
<td>IV</td>
<td>32.66</td>
<td>150 - 200 g / 20 L</td>
<td>Oidium, rust, (mites)&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Copper</td>
<td>III</td>
<td>33.20 - 67.67</td>
<td>20 - 100 g / 20 L</td>
<td>Late blight, alternaria, septoria and others</td>
</tr>
<tr>
<td>Propineb</td>
<td>IV</td>
<td>16.90</td>
<td>25 - 50 g / 20 L</td>
<td>Late blight, alternaria, septoria and others</td>
</tr>
<tr>
<td>Chlorothalonil</td>
<td>IV</td>
<td>37.42</td>
<td>20 - 40 ml / 20 L</td>
<td>Late blight, alternaria, septoria and others</td>
</tr>
<tr>
<td>Mandipropamid</td>
<td>III</td>
<td>27.14</td>
<td>15 - 30 ml / 20 L</td>
<td>Late blight, (oidium)&lt;sup&gt;3&lt;/sup&gt;</td>
</tr>
<tr>
<td>Mancozeb</td>
<td>IV</td>
<td>25.72</td>
<td>25 - 50 g / 20 L</td>
<td>Late blight, alternaria, septoria and others</td>
</tr>
<tr>
<td><strong>Systemic fungicides</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Azoxystrobin (maximum of 2 applications per growing cycle)</td>
<td>IV</td>
<td>26.92</td>
<td>10 - 15 g / 20 L</td>
<td>Wilting caused by Verticillium, Pythium, Fusarium and others; late blight, oidium and others</td>
</tr>
<tr>
<td>Bupirimate</td>
<td>IV</td>
<td>30</td>
<td>5 - 10 ml / 20 L</td>
<td>Oidium</td>
</tr>
<tr>
<td>Cymoxanil + mancozeb</td>
<td>III</td>
<td>35.48 + 25.72</td>
<td>25 - 50 g / 20 L</td>
<td>Late blight, alternaria, septoria and others</td>
</tr>
<tr>
<td>Dimethomorph + mancozeb</td>
<td>III</td>
<td>24.01 + 25.72</td>
<td>40 - 75 g / 20 L</td>
<td>Wilting caused by Verticillium, Pythium, Fusarium and others; late blight, oidium and others</td>
</tr>
<tr>
<td>Phosphites</td>
<td>IV</td>
<td>7.33 a 12.0</td>
<td>20 - 40 g / 20 L</td>
<td>Wilting caused by Verticillium, Pythium, Fusarium and others; late blight, oidium and others</td>
</tr>
<tr>
<td>Metalaxyl-M + mancozeb</td>
<td>III</td>
<td>19.07 + 25.72</td>
<td>15 - 30 g / 20 L</td>
<td>Wilting caused by Verticillium, Pythium, Fusarium and others; late blight, oidium and others</td>
</tr>
<tr>
<td>Propamocarb</td>
<td>IV</td>
<td>23.89</td>
<td>30 - 50 ml / 20 L</td>
<td>Wilting caused by Verticillium, Pythium, Fusarium and others; late blight, oidiosis and others</td>
</tr>
<tr>
<td><strong>Insecticides</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacillus thuringiensis</td>
<td>U</td>
<td>32.66</td>
<td>40 g / 20 L</td>
<td>Potato flea beetle, tuber moths/worms, aphids, whiteflies, bud midges, thrips</td>
</tr>
<tr>
<td>Berliner, var. Kurstaki</td>
<td>(biological)</td>
<td>Doesn’t apply</td>
<td>Doesn’t apply</td>
<td>Potato flea beetle, tuber moths/worms, aphids, whiteflies, bud midges, thrips</td>
</tr>
<tr>
<td>Neem (biological)</td>
<td>Doesn’t apply</td>
<td>Doesn’t apply</td>
<td>20 - 60 ml / 20 L</td>
<td>Potato flea beetle, tuber moths/worms, aphids, whiteflies, bud midges, thrips</td>
</tr>
<tr>
<td>Lambda-cyhalothrin (contact)</td>
<td>II</td>
<td>44.17</td>
<td>4 ml / 20 L</td>
<td>Potato flea beetle, tuber moths/worms, aphids, whiteflies, bud midges, thrips, mites</td>
</tr>
<tr>
<td>Imidacloprid (systemic)</td>
<td>II</td>
<td>36.71</td>
<td>6 ml / 20 L</td>
<td>Potato flea beetle, aphids, whitefly, bud midge, thrips, mites</td>
</tr>
</tbody>
</table>
CIP, INIAP and CORPOICA neither endorse nor recommend the use of specific pesticides. The appropriate use of pesticides is the full responsibility of the users of this Manual.

Very important!
ACKNOWLEDGMENTS

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CIP is a research-for-development organization with a focus on potato, sweetpotato and Andean roots and tubers. It delivers innovative science-based solutions to enhance access to affordable nutritious food, foster inclusive sustainable business and employment growth, and drive the climate resilience of root and tuber agri-food systems. Headquartered in Lima, Peru, CIP has a research presence in more than 20 countries in Africa, Asia and Latin America.

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