



植物工場運営 超入門

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PFBoost

Running a Vertical Farm: A Beginner's Guide

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Preface

A vertical farm is not a business you can win just by putting the equipment in place. Since entering this industry in 2011, I have seen more than ten sites, large and small. Some major companies with financial strength withdrew after only a few years, while other farms stabilized their earnings by steadily accumulating modest improvements. The difference is almost entirely concentrated in "how the site is run."

Running a Vertical Farm: A Beginner's Guide is an introductory book for helping you grasp that on-site sense in a short time.

- You have just entered a vertical farm and cannot see the overall picture of the work
- You first want to cover the basics needed for a manager
- Even with limited experience, you want a foundation that lets you make judgments on-site

For readers like this, I have organized only the knowledge you need, using "understand the basics of vertical farm in three hours" as the guide. Broadly and shallowly, but in a form you can actually use on-site.

Because this is for beginners, there is less in-depth content for experienced practitioners.

Content that goes further into profitability is handled separately on the site

(<https://pfboost.com/en/>). I have prepared farm operations management templates, nutrient program tools, and articles specialized in profitability, so please take a look after you finish Running a Vertical Farm: A Beginner's Guide.

How to Use This Book

The intended reader is someone who has just entered a vertical farm. I would be grateful if you used it as introductory material to hand to someone new on-site and say, "Read this first." You are free to copy and redistribute it. However, I have not abandoned the copyright, so please refrain from modifying the content.



Author

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Entered the vertical farm industry in 2011. As an on-site worker and support team manager, he has been involved in launching and operating more than ten vertical farms, large and small. He has trained more than 600 staff members in total. From that experience, he became convinced that what determines the profitability of a vertical farm is not the equipment or systems, but the skills and knowledge of the people who use them. He is now independent and provides profitability improvement consulting, support, and content for vertical farms.

Chapter 1: The Future and Outlook of Vertical Farms

Knowing the "Now" of Vertical Farming

I entered the vertical farm industry in 2011, during what was called the "vertical farm boom." Major companies entered one after another, new farms were built in many places, and the media covered them as "the agriculture of the future."

However, what followed did not go as expected. Even major companies with financial strength and brand power withdrew one after another after only a few years. Simply installing cutting-edge equipment did not mean success. In recent years, construction of new farms has also decreased considerably.

What Changed, and What Did Not

Over these more than ten years, some things have certainly changed. The performance of LED lighting has improved greatly. When I first entered the field, some farms were still using fluorescent lights. Management of cultivation data and system efficiency have also advanced. There has been steady progress on the technical side.

Some things have not changed. What I strongly feel after more than ten years in this industry is that **what determines the profitability of a vertical farm is not the equipment or systems, but the "people" who operate them.** Alongside the latest IoT sensors, staff check the condition of leaves by hand. Alongside AI environmental control, the "instinct" of veterans is still alive. That is what a vertical farm is.

Still, vertical farms have potential

Honestly, I do not think the situation is one we can view optimistically. However, even in a difficult environment, there are certainly farms that generate earnings. What they have in common is that they know "how to run the site." It is not whether the equipment is good or bad. It is how well the on-site staff understand cultivation and how much they can build up daily judgment. I have seen many farms change greatly because of one very small improvement. Stable production unaffected by weather, high productivity on limited land, and a major reduction in pesticide use. These strengths have value in every region of the world. In *Running a Vertical Farm: A Beginner's Guide*, I will explain the basic knowledge that forms that

foundation as an overall picture.

Why Do Vertical Farms Fall Into the Red?

Even though there is potential, the reality is that many farms are forced into difficult management.

- "The capital investment cost too much"
- "The vegetables do not grow the way we expected"
- "We managed to produce them, but they do not sell"

These are voices I often hear on-site. Why do so many farms struggle with losses?

The Harsh Reality Told by Data

The profitability problem in vertical farms is not limited to Japan. Similar issues are reported around the world. Here, let us look at survey data from Japan, a leading market. Around 2010, many companies in Japan entered vertical farming and experienced both success and failure. Those lessons apply to any region that will take on vertical farming from here on. In a survey by the Japan Greenhouse Horticulture Association, when operators are classified by yield per unit area, there is a clear trend: the higher the yield, the larger the share of operators in the black.

- Greenhouse, high yield: 46% in the black, 31% in the red
- Greenhouse, low yield: 25% in the black, 58% in the red
- PFAL, high yield: 27% in the black, 27% in the red
- PFAL, low yield: 6% in the black, 83% in the red

In particular, among PFAL operators with low yield, the share in the red reaches 83%. How many vegetables you can produce from the same area has a major impact on profitability.

Cost Structure

Let us also look at the cost structure from the same survey.

- Greenhouse: labor costs 34-37%, depreciation 10-11%, utilities 12-16%, materials 15-16%
- PFAL: labor costs 29-34%, depreciation 14-17%, utilities 29-31%, materials 7-9%

In both cultivation formats, labor costs account for the largest share of total costs. This is not limited to vertical farm; it is a common issue for agriculture around the world. In PFAL, utilities are about 30%, reaching roughly twice the Greenhouse level. Air-conditioning costs for keeping temperature and humidity constant in an enclosed space cannot be ignored. In my experience, there is a limit to reducing utilities. They are essentially the inputs the crop depends on, and if you reduce them, yield also drops.

Causes of Falling into the Red

The causes of losses in vertical farms are not only costs. The causes commonly seen in vertical farms around the world are as follows.

Lack of Cultivation Technology

- Failure in environmental control: Unable to properly control temperature, humidity, light, carbon dioxide concentration, and other factors, leading to poor growth and disease.
- Mistakes in nutrient solution management: Concentration (EC) and component management of the nutrient solution in hydroponics are not appropriate, leading to poor growth and lower quality.
- Insufficient hygiene management: Unable to prevent pests and diseases, resulting in severe damage.

Errors in Sales Strategy

- Insufficient sales channel development: Unable to find stable buyers and struggling with sales.
- Getting caught in price competition: Drawn into competition with low-priced vegetables from open-field farming and unable to secure enough profit.
- Mismatch between demand and supply: Unable to understand market demand, resulting in unsold products.

Pressure from Initial Investment and Running Costs

- Failure in equipment investment: Introducing more equipment than necessary, causing initial costs to swell.
- Insufficient fundraising: In many countries and regions, subsidies and grant systems for vertical farms exist, but there are many cases where they are not used sufficiently.

Shortage of Human Resources

- Difficulty securing personnel: People with specialized knowledge and skills are needed, but securing experienced personnel is not easy.
- Insufficient human resource development: Employee education is inadequate, so skills and knowledge do not take root, and productivity and quality do not rise.

These factors become tangled together and lead to unprofitable management.

The Reality of a Profitable Vertical Farm

We have looked at the harsh reality, but even within it, there are certainly farms that generate earnings. Where is the difference between farms in the red and profitable ones?

Scale Is Not a Cure-All

"Scale" is one factor that affects profitability. In large-scale facilities, cost reductions through economies of scale and stronger sales power through stable supply can be expected.

However, when we look at the relationship between area size and profitability in the Japanese survey, the results are unexpected.

- Greenhouse, small area: 50% in the black, 23% in the red
- Greenhouse, large area: 41% in the black, 50% in the red
- PFAL, small area: 6% in the black, 78% in the red
- PFAL, large area: 19% in the black, 50% in the red

In Greenhouse, the share of operators in the black is actually higher for smaller areas. We cannot say that profitability is always higher if the scale is large. As scale increases, initial investment and the burden of personnel management also increase. How well fixed costs such as labor costs and utilities can be held down has a major impact on profitability. Expanding scale is only one means of improving profitability.

What Profitable Vertical Farms Have in Common

After being involved in many different sites, large and small, what I feel is that what profitable farms have in common is neither new equipment nor scale.

- They understand the basics of cultivation and steadily accumulate daily environmental management

- They have people who can trace the cause of a problem from both data and observation when something happens
- They find waste in operations and continue improving little by little

In one phrase, it is whether there are people who can run the site. This is the biggest difference. Even if cutting-edge equipment is installed, it will not lead to profitability if there are no people who can use it well. Many cases of major companies withdrawing have their cause here.



Vertical Farm: What Is the Decisive Difference from Open-Field Farming and Protected Cultivation?

How is vertical farming different from other forms of agriculture? Let us organize this together with an on-site sense.

Environmental Control: From Leaving It to Nature to Full Control

The environment for growing crops is very different.

- Open-field farming: Relies on natural forces such as rain, wind, and sunlight. Requires vast land and heavy labor such as soil management and watering. Easily affected by weather and always next to the risk of typhoons and drought.
- Protected cultivation: Uses plastic greenhouses or glass greenhouses and protects crops from weather to a certain extent. Temperature and humidity can be adjusted, and production can be more stable than open-field farming. Facility construction and maintenance, fuel costs, and other costs are required.

- Vertical farm: Cultivates in an indoor enclosed space. Artificially controls temperature, humidity, light, carbon dioxide concentration, and other factors to create an optimal environment for growth. Stable production throughout the year is possible without being affected by weather. Equipment investment and electricity costs are required, and advanced technology and knowledge are demanded.

In a vertical farm, the environment is created by human hands instead of borrowing the power of nature. Managers adjust temperature, humidity, light, CO₂, and other factors to manage plant growth.

Work Content: From Instinct and Experience to Data-Based Judgment

Cultivation methods and work content are also different.

- Open-field farming: From soil preparation to harvest, many years of experience and instinct matter. There is a lot of heavy labor, and workloads fluctuate greatly from season to season.
- Protected cultivation: In addition to experience in open-field farming, technology for environmental control inside the facility is needed. Temperature management, ventilation, irrigation, and other tasks require frequent observation and adjustment.
- Vertical farm: Automation through computer control has advanced, and there is less heavy labor than in conventional agriculture. The work centers on data-based environmental control and growth management, and analytical ability and IT skills are required. A management perspective that sees the whole farm, from production planning to shipment management, is also necessary.

In a vertical farm, you grasp growth conditions through data and respond quickly if there is a problem. Knowledge of plant growth, environmental control technology, data analysis ability, and the management ability to bring a team together are required. Then, what roles does a manager who leads such a site have?

The Three Roles of a Vertical Farm Manager

The roles required of a vertical farm manager can be divided broadly into three.

1. Protect Stable Production and Quality

In a vertical farm, every environmental factor, including temperature, humidity, light, and CO2 concentration, is managed by human hands. Because these factors affect one another, changing one factor affects the others. In that complex environment, continuing to ship vegetables of stable quality every day is the most basic role of a manager.

2. Bring the Team Together

A vertical farm cannot run with one person. Most daily work is carried out by on-site staff. It is the manager's job to bring out the abilities of each staff member and keep daily work moving. This also includes communicating knowledge of environmental control and cultivation to staff and increasing the number of people who can make judgments on their own.

3. Secure Profitability

Create a production plan, manage costs, and build a sales strategy. Read market needs and continue taking on new challenges. A vertical farm cannot continue on dreams and ideals alone. If profitability cannot be secured, the site cannot continue either.

Chapter 1 Summary

- Vertical farming is a difficult environment, but farms with people who can run the site are generating earnings
- The main causes of losses are lack of cultivation technology, errors in sales strategy, and shortage of human resources
- Unlike conventional agriculture, vertical farming requires data analysis ability and management ability
- The manager's roles are three: "stable production," "team building," and "securing profitability"
- More than equipment, "the power of people" determines profitability

In the next chapter, we will look at the basics of cultivation technology needed on-site.

Chapter 2: The Basics of Crop Management

What Are the Key Points in Choosing the Best Crops for a Vertical Farm?

From here, we will move into the know-how for actually growing vegetables. Because a vertical farm can artificially control the environment, in theory it can grow any crop. However, when you try to actually generate profit on-site, the crops you can choose from become narrower.

Point 1. Market Needs and Profitability

The first thing to keep in mind is that "a vertical farm is a business." This is probably the point that causes the most difficulty in operation. The crops you grow should be chosen after identifying market needs.

- What kinds of vegetables are in demand?
- What are consumers' preferences and trends?
- At what price can they be sold?

Conduct market research in advance and choose crops with profitability in mind.

Crops Often Grown

- Leafy greens: lettuce, Korean lettuce, komatsuna, spinach, and others
- Herbs: basil, parsley, mint, cilantro, and others
- Baby leaf: a mix of young leaves from various vegetables. Popular for its color and nutritional value
- High-value crops: rare varieties, crops with enhanced functional components, highly convenient products, and others

These are suited to vertical farms because the cultivation period is short and the turnover rate is high.

Point 2. Ease of Cultivation

Even though the environment can be artificially controlled, that does not mean any crop can be grown easily.

- Cultivation period: the shorter it is, the higher the turnover rate becomes, and the higher profitability becomes
- Growing environment: the optimal values for temperature, humidity, light, and other factors differ by crop
- Cultivation technology: even with varieties that are easy to grow, a minimum level of knowledge and skill is necessary

When you have little experience, I recommend starting with crops that have a short cultivation period and are relatively easy to manage environmentally. When people think of vertical farms, many facilities are growing leafy greens, especially lettuce.

Point 3. Compatibility with the Equipment

"What you want to grow" and "what you can grow" do not always match. Check the constraints on the equipment side first.

- Equipment height: tall crops require extra height in the equipment
- Lighting: the light intensity and wavelengths that can be delivered differ depending on the type of LED, and the suitable crops also change
- Temperature control: if proper temperature control is difficult, choose crops that are resistant to temperature changes

Many facilities that produce leafy greens use equipment designed specifically for leafy vegetables. To raise production efficiency, it is necessary to specialize in specific items.

Three Types

Vertical farms can be broadly divided into three types.

- Greenhouse type: makes maximum use of sunlight. Initial costs can be kept down, but it is easily affected by weather. Many crops can be grown, including leafy vegetables and fruiting vegetables.
- Greenhouse with supplemental artificial lighting: uses both sunlight and artificial light. It can aim to balance stable production with lower running costs. Many crops can be grown, including leafy vegetables and fruiting vegetables.
- PFAL: grows crops using only artificial light. Stable production unaffected by weather is possible, but operating costs are high. Production centers on leafy vegetables, and some

fruiting vegetables can also be grown.

The crops that can be grown change depending on which type it is and what equipment has been introduced. Crop selection is decided by balancing the three points of "profitability," "ease of cultivation," and "compatibility with the equipment."

From here, let us look one by one at the technologies and equipment used in vertical farm cultivation.

Using LED Lighting



The most symbolic equipment in a vertical farm is the rows of LED lighting. In conventional agriculture, there was no choice but to rely on sunlight, but in a vertical farm, LEDs can artificially create a light environment optimized for growth.

Three Benefits LED Lighting Brings to a Vertical Farm

1. Cost Reduction Through Energy Savings

Electricity costs are a cost that a vertical farm cannot ignore. Because LED lighting has excellent energy efficiency, a major reduction in electricity costs can be expected.

2. Long Service Life and Lower Maintenance

Fluorescent lights need regular replacement, and each replacement costs money and labor. LEDs have a much longer life and can reduce replacement frequency. In a vertical farm that uses a large amount of lighting, this cost difference is large.

3. The Light Color Can Be Chosen to Match the Plant

Plants need different light wavelengths (colors) depending on the species and growth stage. LEDs come in products with various wavelengths, such as red, blue, and white, and can be chosen to match the crop being grown. In conventional vertical farms, LED lighting that combined red light and blue light was mainstream, but in recent years, white LEDs close to sunlight have also become widespread.

Adjustments in Installation and Operation

To get the most out of LEDs, detailed adjustments such as installation method and irradiation time are also important.

- Multi-tier cultivation: to make effective use of limited space, "multi-tier cultivation," in which cultivation racks are stacked in many layers, is common.
- Irradiation angle and distance: photosynthetic efficiency can be increased by adjusting the irradiation angle of the LEDs and the distance to the plants.
- Irradiation time: plants grow by repeating the "light period," when they carry out photosynthesis, and the "dark period," when they carry out respiration and nutrient translocation.

Light

LEDs are only tools for creating the light environment. What matters is how plants receive that light. Here, let us cover the basics of light itself.

Light Intensity: Stronger Is Not Always Better

Light is essential for plant growth, but if it is too strong, it causes damage instead. The basic approach is to install LEDs with an intensity that matches the crop being grown. Fruiting vegetables and similar crops need strong light, but leafy vegetables can be grown even under relatively weak light. This is one reason leafy vegetables are favored in vertical farms.

Light Wavelength: Plants Have Preferred Colors

Light differs in color depending on its wavelength, and plants use each wavelength for different purposes.

- Red light (600-700 nm): one of the most effective wavelengths for photosynthesis. It promotes growth and also has the effect of promoting flowering and fruiting
- Blue light (400-500 nm): effective for photosynthesis, promotes chloroplast development, and also has the effect of thickening stems
- Green light (500-600 nm): contributes less to photosynthesis, but is considered to be involved in plant morphogenesis and stress responses

In recent years, LED lighting with various wavelengths, such as green light and white light, has appeared. I have used many kinds of LEDs, and I feel that types with green light added, or types close to sunlight, give better growth than types with only red and blue.

Uneven Lighting: Delivering Light Evenly to Every Crop

In multi-tier cultivation, places that receive less light inevitably appear, and uneven growth occurs. There are adjustments that can be made on-site to prevent unevenness.

- Installation of reflective material: installing reflective material on cultivation racks prevents light from leaking toward the aisle side and being wasted, and also delivers light to places that are hard to reach
- Adjusting lighting arrangement: install multiple LED lighting units or adjust the irradiation angle so that light hits evenly
- Do not increase the number of crops too much: when planting becomes excessively dense, light does not reach each crop easily. Be careful not to pack in too many crops in pursuit of productivity

Hydroponics Systems



Alongside lighting, one of the defining features of a vertical farm is hydroponics.

Why Hydroponics Is Chosen in Vertical Farms

The biggest advantage of hydroponics is that it does not use soil.

- Space saving and freedom of location: because soil is unnecessary, cultivation is possible even in urban areas and regions with difficult land conditions
- Improved growth speed: because roots can constantly absorb water and nutrients, growth is fast and this leads to higher harvest volume
- Reduced pest and disease risk: the risk of pests and diseases transmitted through soil can be greatly reduced
- Easier watering: there is no need to water every day. If the concentration and volume are managed, the nutrient solution can be supplied automatically
- Lower root rot risk: if dissolved oxygen (DO) in the nutrient solution is kept sufficient, roots can always take in fresh oxygen. However, if DO is insufficient, that is a different story, and root rot can occur even in hydroponics (especially when water temperature is high and DO easily drops)

Main Types of Hydroponics Systems

The following two are often used in vertical farms.

1. NFT (Nutrient Film Technique)

A method in which plants are fixed in a sloped grow bed and nutrient solution is circulated with a pump.

- Advantage: only a small amount of nutrient solution is needed, which leads to cost reduction
- Disadvantage: easily affected by changes in nutrient solution temperature

2. DFT (Deep Flow Technique)

A method in which a deep cultivation tank is filled with nutrient solution, and plants are floated in it and grown.

- Advantage: because the amount of nutrient solution is large, it is resistant to temperature changes and stable cultivation is possible
- Disadvantage: compared with NFT, the amount of nutrient solution is larger and the equipment becomes larger

NFT and DFT are systems called "recirculating hydroponics," which are often used in vertical farms.

Hydroponics and Other Environmental Control

Hydroponics is one feature of a vertical farm, but it is not enough on its own. Environmental factors such as temperature, humidity, light, and CO₂ concentration are also artificially controlled together.

- Temperature control: the optimal temperature differs depending on the plant species
- Humidity control: humidity also greatly affects growth and is related to disease occurrence
- CO₂ supplementation: plants absorb CO₂ through photosynthesis. If the concentration is raised, photosynthesis is promoted and growth accelerates

In a vertical farm, multiple environmental factors are managed in combination. We will look at each factor in more detail from the next sections onward.

Temperature Control

Temperature control is one of the most important items that greatly determines the success of a vertical farm.

Why Temperature Control Is Important

Plants have a temperature range suited to their growth. If they fall outside that range, growth is affected.

- Poor growth: growth slows, leaf color worsens, and in severe cases the plant dies
- Occurrence of malformed fruit: in fruiting vegetables such as tomatoes and strawberries, poorly shaped fruit develops
- Increased pest and disease risk: when plant strength declines, resistance to disease and pests weakens

Suitable Temperatures by Crop

A vertical farm is less affected by outside air and can keep temperature and humidity constant. The rough guidelines by crop are as follows.

- Leafy greens such as lettuce: prefer a relatively cool environment, with around 15-25°C being optimal
- Fruiting vegetables such as tomatoes: prefer a warm environment, with around 20-30°C being optimal
- Herbs such as basil: around 20-25°C is optimal. However, some prefer high temperatures, and some tolerate low temperatures well

Temperature control matched to the type of vegetable being grown and its growth stage is the foundation of stable production.

Using the Day-Night Temperature Difference (DIF)

In a vertical farm, day and night time periods can be created artificially with LED lighting, so there is a method of controlling growth by adjusting the temperature difference. Here, "daytime" means while the lights are on (light period), and "nighttime" means while the lights are off (dark period). The temperature difference between the light period and dark period is called "DIF."

- Light period temperature > dark period temperature (positive DIF): stems elongate
- Light period temperature < dark period temperature (negative DIF): stem elongation is suppressed

In leafy greens such as lettuce, if stems elongate too much, leaves become smaller or quality declines. If negative DIF is used well, seedling legginess can be prevented and production

efficiency can be raised. However, producing results with DIF requires familiarity and experience, and what can be done also changes depending on the equipment.

Examples of Temperature Control Failures

Summer Temperature Control

In midsummer, temperatures tend to rise.

- Set the air-conditioning temperature appropriately. Depending on the equipment, even with the same set temperature, measured values may change by season
- Use shade curtains and insulation materials to reduce the effect of outside temperature

Temperature Unevenness

It is common to see lettuce sown on the same day become large on one side and small on the other.

- Use circulation fans to circulate air inside the farm
- Install multiple temperature sensors and grasp the temperature distribution
- Adjust the placement of supplies and racks so that air flows smoothly

The Basis for Temperature Settings Is the Condition of the Crop

When thinking about the temperature inside the cultivation room, the final basis for deciding the setting value is "the condition of the crop." Those of us who set the temperature are required to have the observational ability to correctly grasp the condition of the plants.

Humidity Control

Alongside temperature, humidity is something that must be managed. Plants release water from their leaves through "transpiration" and regulate their own temperature. Humidity directly affects this transpiration.

Why Humidity Control Is Important

A vertical farm is less affected by the outside environment, but because it is an enclosed space, it has the characteristic that humidity rises easily.

Risk of Condensation

In a closed plant factory, particular attention is needed for condensation.

- Breeding ground for mold: mold prefers places with high humidity, and places where condensation occurs become an ideal home for it
- Spread of disease: when condensed water droplets attach to leaves, pathogens multiply easily and disease risk rises
- Equipment failure: condensation causes short circuits in electrical systems and corrosion of metal parts

Humidity Control in a Closed Plant Factory

In a closed plant factory, adjusting humidity through ventilation is difficult, so keep the following points in mind.

1. Use Dehumidifiers Effectively

- Choosing a dehumidifier: choose one with capacity suited to the size of the farm and the types of plants being grown
- Installation location: it is effective to install it in places where condensation is likely to occur

2. Reconsider the Cultivation Environment

Do not rely only on dehumidifiers. Reviewing the cultivation environment itself is also important.

- Planting density: if planting is too dense, airflow worsens and humidity around the plants rises easily. Adjust to an appropriate density while watching growth conditions
- Temperature control: temperature and humidity are closely related. Because condensation occurs easily when room temperature changes suddenly, carry out temperature control carefully

3. Observe the Condition of the Plants

Do not look only at the numbers on the hygrometer. Look at the condition of the plants as well. If you see symptoms such as wilted leaves, spots on leaves, or slow growth, humidity may be the cause.

Humidity Is Deeply Related to Tipburn

Humidity is closely related to tipburn. This is because in a high-humidity environment, leaf transpiration is suppressed and root activity also declines (tipburn is covered later in this chapter). Humidity control is not easy in an enclosed space, but if you take it lightly, it directly affects growth.

Using CO2



Why Plants Become More Vigorous When CO2 Concentration Is Raised

Plants absorb CO2 from the air through photosynthesis and grow by producing nutrients such as sugars. The CO2 concentration in normal air is about 400 ppm, but in a vertical farm, by raising the final indoor concentration to about 1,000 ppm, photosynthesis is promoted and growth accelerates ("up to 1,000 ppm" means the target final concentration, not the amount of increase).

Benefits of Raising CO2 Concentration

- Growth speed increases, and the period until harvest can be shortened
- More vegetables can be harvested from the same area
- Vegetables with better taste, aroma, and nutritional value can be grown

Methods of CO2 Supplementation

To raise CO2 concentration in a vertical farm, "CO2 supplementation" is generally carried out. There are mainly three methods.

1. Carbon dioxide gas cylinders: suitable for relatively small vertical farms

- Advantage: can be introduced relatively cheaply
- Disadvantage: cylinder replacement work occurs, and storage space is also needed

2. Liquid carbon dioxide: for medium to large facilities

- Advantage: can supply a large amount of CO₂
- Disadvantage: introduction cost is required

3. Combustion-type CO₂ generators: generate CO₂ by burning kerosene or natural gas

- Advantage: running costs are relatively low
- Disadvantage: because heat, water vapor, and combustion by-products are also generated at the same time as CO₂, closed artificial-light facilities must manage exhaust heat, added humidity, and combustion gases (the application conditions differ from greenhouses)

Which method is optimal differs depending on scale, budget, cultivated crop, and other factors.

Managing CO₂ Concentration

In CO₂ supplementation, concentration management is important. A system that combines CO₂ sensors and a control device is common.

- CO₂ sensor: measures the CO₂ concentration inside the cultivation room in real time
- Control device: automatically adjusts the amount of CO₂ supplied based on the measured value

The Cost and Effect of CO₂ Supplementation

CO₂ supplementation requires initial investment and running costs. Even so, no matter how well you arrange light and temperature, plants do not grow without CO₂. CO₂ is one of the basic elements of a vertical farm, alongside light, water, and temperature.

Managing Air Conditioning and Airflow

Alongside temperature, humidity, and CO₂, the flow of air is something you should understand.

Air Tends to Stagnate in an Enclosed Space

A vertical farm is less affected by the outside environment, but air circulation tends to stagnate, and various problems occur if it is not managed properly.

The Role of Airflow in a Closed Plant Factory

Airflow has the following roles. 1. **Improving CO2 supply efficiency:** even if CO2 concentration is raised, without airflow it will not spread evenly, and photosynthesis efficiency will fall 2. **Eliminating temperature and humidity unevenness:** due to the effects of lighting and air conditioning, temperature and humidity become uneven depending on location. In particular, temperature differences easily occur between the upper and lower levels of cultivation racks 3. **Breaking the leaf boundary layer:** on the leaf surface, there is a thin layer of air called the "leaf boundary layer," and when this layer is thick, the movement of CO2 and water is obstructed 4. **Suppressing disease risk:** in an enclosed space where humidity tends to become high, airflow is also important for suppressing the growth of mold and bacteria

Methods for Creating Airflow

In a closed plant factory, the main methods for creating airflow are to use "fans" and "air-conditioning equipment."

1. **Fans: Deliver Airflow to Specific Points.** Fans are effective when you want to send airflow to a specific spot.

- Circulate CO2 that tends to accumulate in the lower parts of cultivation racks
- Send airflow to places where temperature unevenness easily occurs and make it more uniform
- Lower humidity in specific areas

2. **Airflow Function of Air-Conditioning Equipment: Circulate Air Throughout the Farm.**

Air conditioning has not only temperature and humidity adjustment functions, but also a function for sending air.

By combining fans with the airflow function of air-conditioning equipment, the air environment can be controlled effectively. Be conscious of creating airflow in the same direction across the entire facility so that airflows do not cancel each other out.

Air Speed and Air Direction

When creating airflow, pay attention to air speed and air direction as well. 1. **Air speed**: if it is too strong, it stresses plants and inhibits growth 2. **Air direction**: changing it can increase the efficiency of air circulation

- Aim it along walls to make air easier to circulate
- Send it along cultivation racks to distribute CO2 efficiently

Grasp Airflow Through Temperature and Humidity

Air-conditioning and airflow management is simple if you understand the basics. Areas where air tends to stagnate can be identified by measuring temperature and humidity. Once you find places where unevenness appears, adjust the airflow to improve those areas.

Handling Fertilizers

In hydroponics, fertilizer is important alongside nutrient solution.



Conditions Required of Fertilizers in a Vertical Farm

When choosing fertilizers for a vertical farm, consider the following points.

- Water solubility: in hydroponics, fertilizer is supplied to plants in a state dissolved in water. It must dissolve easily in water and be easy to absorb
- Purity: when high-purity fertilizer with few impurities is used, the component balance of the nutrient solution becomes stable and the risk of growth inhibition decreases
- Fast-acting: because the aim is to harvest in a short period, fast-acting fertilizers that plants can absorb immediately are suitable

Straight Fertilizer and Pre-mixed Fertilizer

There are two types of fertilizers used in vertical farms: "straight fertilizer" and "pre-mixed fertilizer." "Straight fertilizer" is fertilizer that contains only specific nutrients such as nitrogen, phosphate, and potassium. "Pre-mixed fertilizer" is fertilizer in which the necessary nutrients have been mixed in advance. Which one to use changes depending on the situation and cultivation policy.

Advantages of Using Straight Fertilizer

- Pinpoint nutrient supplementation: based on nutrient solution analysis results, lacking nutrients can be supplemented with straight fertilizer
- Cost reduction: straight fertilizer is generally cheaper than pre-mixed fertilizer
- Original formulation: multiple straight fertilizers can be combined to create your own formulation

Advantages of Using Pre-mixed Fertilizer

- Easy: the necessary nutrients are blended in advance, which saves preparation and management work
- Products matched to the purpose: there are products matched to crops and growth stages, such as those for leafy greens and those for fruiting vegetables

Rough Guide for Choosing Between Them

When you have just started cultivation and do not know which fertilizer to use, I recommend using pre-mixed fertilizer first.

Fertilizer Formulation

Fertilizer formulation is one of the important jobs in a vertical farm. Both experience and data are needed, and eventually you will need to acquire formulation skills. As a reference, I will introduce "SimpleFert," a free nutrient program spreadsheet I created based on my on-site experience. By simply entering the required information, you can calculate the fertilizer amounts. <https://pfboost.com/en/how-to-simplefert/>

Nutrient Solution Management



Nutrient solution is made by dissolving fertilizer in water. In a vertical farm, the nutrient solution is the lifeline that determines plant growth.

Nutrients Contained in Nutrient Solution

In hydroponics, nutrient solution made by mixing water and fertilizer is used instead of soil.

The main nutrients contained in nutrient solution are as follows.

- Nitrogen (N): promotes growth of leaves and stems, and is essential for synthesizing proteins and chlorophyll. When deficient, leaves turn yellow
- Phosphorus (P): promotes development of roots and formation of flowers and fruit, and is involved in energy metabolism. When deficient, root development worsens
- Potassium (K): promotes photosynthesis and increases resistance to disease. It is also involved in water regulation inside cells. When deficient, leaf edges die
- Calcium (Ca): strengthens cell walls and stabilizes growth. When deficient, new leaves deform or fruit develops blossom-end rot
- Magnesium (Mg): a component of chlorophyll and essential for photosynthesis. When deficient, the areas between leaf veins turn yellow
- Sulfur (S): a component of proteins and also involved in enzyme activation. When deficient, leaves turn yellow overall

These are called macronutrients, and plants cannot grow if any of them are missing. Other nutrients called micronutrients are also important.

Basics of Nutrient Solution Management: EC and pH

The two especially important indicators in nutrient solution management are "EC" and "pH."

EC (Electrical Conductivity)

EC is an abbreviation for "Electrical Conductivity," and it indicates how easily electricity flows. When fertilizer dissolves in water, electricity flows more easily, so by looking at EC, you can indirectly understand the concentration of fertilizer dissolved in the nutrient solution.

- High EC: the nutrient solution is concentrated
- Low EC: the nutrient solution is dilute

If EC is too high, plants become unable to absorb water, and there is a risk that they will die. Adjusting to an appropriate EC concentration according to plant species and growth stage is the most important point in nutrient solution management.

pH (Hydrogen Ion Concentration)

pH is an abbreviation for "power of Hydrogen," and it indicates the degree of acidity or alkalinity of the nutrient solution. Plants basically grow best around weakly acidic pH (pH 5.5-6.5). When pH falls outside the appropriate range, the following problems occur.

- Inhibited nutrient absorption: nutrients in the nutrient solution become difficult to absorb
- Growth disorders: root development worsens, and leaf color becomes poor
- Root damage: roots are damaged, and absorption of water and nutrients is obstructed
- Insufficient absorption of trace elements: iron, manganese, and other elements become difficult to absorb, leading to poor growth

Because pH also affects the solubility of nutrients in the nutrient solution, keeping it within the appropriate range is important.

Making Nutrient Solution

To make nutrient solution, mix water and fertilizer in the appropriate ratio. 1. **Preparing the water:** tap water, well water, filtered water, and other sources are used, but tap water is common. When using fertilizer that contains ammonium nitrogen, remove residual chlorine by letting the water stand or by using sodium thiosulfate or similar methods 2. **Preparing the fertilizer:** when using pre-mixed fertilizer, dissolve the appropriate amount in water according to the product instructions. If using a recirculating system, it is efficient to prepare a stock solution at about 100 times the concentration of the final nutrient solution, then dilute it into the

final nutrient solution using an injector or automatic supply device (this is not a "100-fold diluted solution," but a 100-fold concentrate before dilution) 3. **Mixing:** dissolve the fertilizer little by little in the water while stirring well. Calcium forms precipitates with phosphate and sulfate in high-concentration undiluted solution, so some types are made by dividing the stock solution tanks into A and B (in the diluted final nutrient solution, calcium and phosphate/sulfate coexist) 4. **Adjusting EC and pH:** measure with an EC meter and pH meter, and adjust if necessary

- EC value: if it is lower than the target value, add fertilizer; if it is higher, add water to dilute it
- pH value: if it is lower than the target value (leaning acidic), add a pH up agent to raise pH; if it is higher than the target value (leaning alkaline), add a pH down agent to lower pH

Managing Nutrient Solution

During cultivation, the nutrient solution is not always in a constant state. 1. **Measurement:** measure EC and pH values at least once a day (if the frequency is reduced, grasping changes is delayed). If the timing of measurement is kept to the same time every day, daily changes become easier to compare. In large-scale environments, there is a limit to manual measurement 2. **Recording:** always record measured values. This lets you grasp changes and is also useful for investigating causes when problems occur. A notebook or spreadsheet software is fine 3. **Adjustment:** if values are outside the targets, adjust them

- EC value: if it is low, add fertilizer; if it is high, add water to dilute it. In large-scale farms, an automatic supply system is essential, and when the value falls below the setting, automatic nutrient replenishment is carried out
- pH value: add pH adjuster little by little, and bring it closer to the target value while stirring well. Be careful, because if you add a large amount at once, fertilizer components may precipitate

4. **Nutrient solution renewal:** when cultivation continues for a while, the balance of fertilizer components breaks down, or unnecessary components accumulate. Carry out "nutrient solution renewal," replacing the nutrient solution regularly. The frequency depends on the crop and season, but in general, once every two to three months is a rough guide.

Situations like "I do not know the cause, but growth somehow does not look good" happen often. With experience, you can make a guess at the cause, but beginners cannot always do that. At such times, trying nutrient solution renewal as a gamble is also one option. Being able to choose this when you are in trouble is one of the strengths of hydroponics 5. **Observation:** observe not only EC and pH values, but also the condition of the plants. If there are changes in leaf color or shape, or in growth conditions, there may be a problem with the nutrient solution

Points to Note in Nutrient Solution Management

1. **Excess or deficiency of fertilizer:** if EC is made too high, excess fertilizer inhibits growth. In particular, excess nitrogen makes leaves prone to legginess. Conversely, if EC is too low, fertilizer deficiency causes poor growth 2. **Sudden changes in pH:** adding a large amount of pH adjuster at once causes pH to change suddenly and stresses the plants. Adjust slowly, little by little 3. **Water temperature (nutrient solution temperature):** the temperature of the nutrient solution affects fertilizer solubility, root activity, and growth. In general, around 20°C is the suitable water temperature. If water temperature is too low, nutrient absorption worsens and growth slows. If it is too high, dissolved oxygen (DO) drops, roots are damaged, and disease occurs more easily. Basically, there is no problem if it is about the same as the air temperature inside the cultivation room (this is about room temperature, not outside temperature) 4. **Hygiene management:** nutrient reservoirs and piping should be cleaned regularly. If algae and debris accumulate excessively, pathogens multiply easily.

Many people worry about algae that appears in nutrient solution. It certainly looks bad and dirty, but it is something that inevitably appears. Taking the approach of managing it so that it does not increase too much is fine

Improving Precision with Data

If you use data, the precision of nutrient solution management rises further.

- Cultivation records: record EC value, pH value, water temperature, fertilizer type and amount, and growth conditions, and grasp the relationship between nutrient solution condition and growth
- nutrient solution analysis: if you request it from a specialized organization, you can accurately grasp the concentration of each component in the nutrient solution. If you adjust

the formulation based on the analysis results, more appropriate management becomes possible

- Use of environmental data: if environmental data such as temperature, humidity, and CO₂ concentration are analyzed in relation to EC value, pH value, and growth conditions, the precision of environmental control and nutrient solution management rises

Tipburn



"The lettuce was growing so well, but just before harvest, the tips of the leaves started turning brown and dying." When working in a vertical farm, tipburn is a growth disorder you cannot avoid.

What Is Tipburn?

Tipburn is a physiological disorder in which the tips and edges of leaves turn brown and die. In the early stage, only the leaf tips discolor slightly, but as it progresses, the dead area expands, and the whole leaf may die. If you feel that "the tips of the leaves are a little black," that may be a sign that tipburn is occurring.

Causes of Tipburn

Tipburn is not a simple problem that can be settled with a single solution. The main factors are as follows.

Point 1. Calcium Deficiency

One of the biggest causes is calcium deficiency inside the plant body.

- The calcium concentration in the nutrient solution is low
- Calcium absorption is inhibited because root function has declined
- Inside the plant body, calcium is not being transported to the leaf tips

In my experience, cases where the calcium concentration in the nutrient solution itself is insufficient are rare. In many cases, there is enough Ca in the nutrient solution, and the real cause is that for some reason Ca inside the plant body is not moving to the leaf tips (insufficient Ca translocation). Some people sometimes think too simply, "If calcium is lacking, let us increase Ca fertilizer," but unless the Ca concentration in the nutrient solution is the cause, increasing Ca fertilizer is likely to have the opposite effect (higher EC, precipitation, antagonism with other ions).

Point 2. Humidity Is High

When humidity is high, it may seem that plants will grow vigorously, but that is not always true.

- Decline in root activity: when humidity is high, plants no longer need to force themselves to absorb water, and root activity drops
- Suppression of transpiration: when transpiration is suppressed, the movement of calcium to the leaves is obstructed

Point 3. Rapid Growth

Fast growth is a good thing, but rapid growth requires many nutrients. If nutrient absorption cannot keep up with the growth speed, calcium in particular becomes insufficient easily, and tipburn becomes more likely to occur.

Point 4. Other Factors

In addition to the above, the following factors are also involved.

- Variety: some varieties are prone to tipburn
- Temperature: temperature stress such as high or low temperature
- Light: light that is too strong, or a light environment with poor photosynthetic efficiency
- Airflow: if air circulation is poor, humidity rises easily

Because the factors are intricately intertwined, identifying the cause can be difficult.

Countermeasures for Tipburn

The keywords when thinking about countermeasures are "transpiration" and "growth speed." Maintain transpiration properly through humidity control, and if growth is too fast, review environmental conditions such as light intensity, temperature, and CO2 in the direction of lowering them (the direction of suppressing growth). (If growth is accelerated further, the symptoms worsen, so here the direction is to reduce, not increase.) However, fast crop growth itself is something producers generally welcome. If that causes excessive tipburn, measures to suppress growth also become necessary. This balance is also the difficulty of tipburn countermeasures.

I Also Struggled with Tipburn

I have written about the mechanism and countermeasures, but tipburn is not easy to solve. I struggled with it a great deal myself. To raise the profitability of a vertical farm, it is necessary to understand tipburn and learn how to deal with it well. I have written in detail about the knack of delicate environmental adjustment in the following content.

172 Tips for Increasing the Profitability of Vertical Farms: Know-How Refined On-Site for More Than 10 Years

Legginess

Alongside tipburn, another representative growth disorder is "legginess." Legginess is the phenomenon in which plants stretch their stems more than necessary in search of light. Think of a houseplant by a window stretching thinly toward the light — it is a similar image.



When legginess occurs in a vertical farm, it has the following effects.

- Lower yield: stems elongate, and the important leaves become small.
- Lower quality: tissue becomes weak, and shelf life and eating quality decline.
- Lower work efficiency: plants fall over easily, and harvest and management work take more effort.

The troublesome point is that leaves that have become leggy in the early growth stage do not recover completely even if the environment is adjusted afterward.

Causes of Legginess

There are three main causes of legginess.

- Insufficient light intensity: when LED lighting intensity is insufficient, plants stretch their stems in search of light.
- Unbalanced light quality: when the wavelength balance is disrupted, including not only red and blue but also green, far-red light, and other wavelengths, legginess is more likely.
- Dense planting: if density is too high, plants compete with one another for light. I understand the desire to make use of limited space, but packing in too much has the opposite effect.

Countermeasures for Legginess

Reviewing the light environment

- Increasing light intensity: secure the appropriate light intensity according to the crop being grown and its growth stage. If possible, consider adding lighting.
- Adjusting light quality: choose LED lighting with a balanced wavelength mix.
- Lighting placement: if light is applied not only from above but also from the sides, uneven light is reduced.
- Use of reflective material: because light can be used efficiently, it helps compensate for insufficient light intensity.

Adjusting planting density

- Maintain density matched to the crop and growth stage. In particular, judge the timing of transplanting accurately.

Other environmental factors

- If temperature is too high, legginess is more likely. Carry out appropriate temperature control.
- Excessively high humidity also encourages legginess. Adjust it through ventilation and dehumidification.

Because legginess cannot be reversed once it occurs, early detection and response are more important than anything else.

To Further Level Up Crop Management

So far, I have explained the basic knowledge of crop management. This knowledge is important, but once you go on-site, situations will arise where you wonder, "Even if I have the knowledge, what exactly should I start with?"

As support for that, I will introduce the "farm operations management templates" I have prepared.

- **Template for designing the cultivation process:** a tool that calculates the required number of beds, panel types, days to harvest, and other items by working backward from the target harvest volume. You can also simulate changes in the number of transplantings and operating days.
- **Nutrient program tool:** fertilizer design combining pre-mixed fertilizer and straight fertilizer can be calculated simply by entering the required information. It turns areas that easily become dependent on individual veterans at experienced sites into a reproducible form.
- **Work schedule template:** based on the cultivation process, it calculates daily work content and required staffing. It helps prevent excess or shortage of personnel and organize assignments.

These tools are not all-purpose. Customization is also needed to use them on-site. However, as a first step toward "turning knowledge into actual procedures," they are useful. There should also be parts where you can read which points of farm operations management to keep in mind from the structure of the templates themselves.

<https://pfboost.com/en/templateform/>

Chapter 2 Summary

- Crop selection is judged by the three points of "market needs," "ease of cultivation," and "compatibility with the equipment"
- LED lighting has three advantages: energy saving, long life, and wavelength selection
- In hydroponics, NFT (Nutrient Film Technique) and DFT (Deep Flow Technique) are mainstream
- Temperature, humidity, CO₂, and airflow management affect one another, so they must be considered comprehensively
- In nutrient solution management, the two indicators EC and pH are the most important
- Tipburn and legginess are the growth disorders that occur most frequently in vertical farms

More specific improvement methods and numerical standards for each theme are explained in detail in "172 Tips for Increasing the Profitability of Vertical Farms."

Chapter 3: Practicing Farm Operations Management

Creating a Production Plan

From here, we will look at what farm operations management in a vertical farm involves. The first theme is the production plan.

1.施設設備仕様														
エリア	ベッド数	1ベッド面積	使用ベッド数	稼働率										
育苗	20ベッド	7.6㎡	10ベッド	50.00%										
生育	160ベッド	27.0㎡	131ベッド	81.56%										
2.原価計算														
	育苗(30日)	1日あたり	フリール	ロメイン	サンチュ	グリーン								
使用ベッド	育苗	30.00	4.00	0.67	0.67	3.14								
	生育	130.50	62.00	11.00	11.00	44.00								
	育苗面積	3520㎡	1704㎡	302㎡	302㎡	1212㎡	0㎡	0㎡	0㎡					
	生育面積比率	100.00%	48.41%	8.58%	8.58%	34.42%	0.00%	0.00%	0.00%					
	人件費	¥6,900,000	¥230,000	¥111,353	¥19,737	¥19,737	¥79,174	¥0	¥0					
	原材料費(選種)	¥2,375,400	¥79,180	¥12,500	¥20,440	¥20,440	¥16,800	¥0	¥0					
	原材料費(栽培)	¥3,519,158	¥117,305	¥56,793	¥10,066	¥10,066	¥40,380	¥0	¥0					
	水道光熱費	¥6,245,104	¥208,170	¥100,784	¥17,863	¥17,863	¥71,659	¥0	¥0					
	その他	¥7,199,660	¥239,989	¥116,189	¥20,594	¥20,594	¥82,612	¥0	¥0					
	製造原価	¥26,239,322	¥874,844	¥406,620	¥88,700	¥88,700	¥290,628	¥0	¥0					
	製造原価/面積	¥242	¥25	¥29	¥24	¥24	¥240	¥0	¥0					
3.栽培工程設計														
※種・フィルム代など、品目固有のもの														
品目名	栽培工程	使用資材	ベッド原価	ベッド数	作業枚数/日	稼働日数/種	日数	株数	苗の準備率	原材料費(選種) (円)	原材料費(栽培) (円)	計画の日数	ベッド数の差算	作業枚数の差算
フリール	種所発芽	300株	16枚	1.9ベッド	15枚	7.0日	2.0日	4500株	0.00%	¥3,000	¥13,500	2日	1.88ベッド	15枚
	育苗	300株	42枚	4.0ベッド	15枚	7.0日	11.2日	4500株	100.00%	¥0	¥0	11日	3.93ベッド	15枚
	生育	50株	50枚	18.0ベッド	82枚	7.0日	11.0日	4100株	91.20%	¥0	¥0	11日	18.04ベッド	82枚
	生育	20株	50枚	44.0ベッド	200枚	7.0日	11.0日	4000株	97.60%	¥2,000	¥8,000	11日	44.00ベッド	200枚
								0株	0.00%	¥0	¥0			
ロメイン	種所発芽	300株	16枚	0.3ベッド	6枚	3.0日	2.0日	1800株	0.00%	¥3,000	¥12,600	2日	0.32ベッド	6枚
	育苗	300株	42枚	0.7ベッド	6枚	3.0日	10.9日	1800株	100.00%	¥0	¥0	11日	0.67ベッド	6枚
	生育	50株	50枚	3.0ベッド	34枚	3.0日	10.3日	1700株	94.50%	¥0	¥0	10日	2.91ベッド	35枚
	生育	20株	50枚	8.0ベッド	84枚	3.0日	11.1日	1680株	98.90%	¥2,000	¥7,840	11日	7.92ベッド	85枚
								0株	0.00%	¥0	¥0			
サンチュ	種所発芽	300株	16枚	0.3ベッド	6枚	3.0日	2.0日	1800株	0.00%	¥3,000	¥12,600	2日	0.32ベッド	6枚
	育苗	300株	42枚	0.7ベッド	6枚	3.0日	10.9日	1800株	100.00%	¥0	¥0	11日	0.67ベッド	6枚
	生育	50株	50枚	3.0ベッド	34枚	3.0日	10.3日	1700株	94.50%	¥0	¥0	10日	2.91ベッド	35枚
	生育	20株	50枚	8.0ベッド	84枚	3.0日	11.1日	1680株	98.90%	¥2,000	¥7,840	11日	7.92ベッド	85枚
								0株	0.00%	¥0	¥0			

Why a Production Plan Is Necessary

A way of working that follows the seasons and weather, as in conventional agriculture, does not work in a vertical farm. Because we can create the environment ourselves, we need to decide in advance what to produce, when, and how much.

If you grow crops without creating a production plan, the following problems occur.

1. Mismatch between demand and supply: producing crops or quantities that do not match market demand, leaving products unsold.
2. Failure in cost management: costs such as electricity, water, labor, and fertilizer come first, leaving little or no profit. In particular, material and labor costs must be planned before planting. Without a prior outlook, unplanned expenses swell.
3. Uneven quality: management of environmental conditions and work becomes ad hoc, and the harvested vegetables will not be uniform.

The Three Steps of a Production Plan

What vegetables to produce, when, and how much. Organize this in three steps.

Step 1. Demand Forecasting

First is market research. Identify what kinds of vegetables are needed, when, and how much.

- Target market: supermarkets, restaurants, individual consumers, and where you will sell
- Sales price: how much it can be sold for in each market
- Seasonal fluctuation in demand: changes in demand by season
- Competitors: the situation of other companies producing the same crops

You forecast by referring to past sales data and market trends, but no one knows the answer to "if we make this, it will definitely sell." This is only the work of forming a hypothesis.

Step 2. Formulating the Production Plan

Based on the demand forecast, turn it into a concrete plan.

Crops to cultivate: evaluate by three factors: market needs, cultivation period, and profitability.

Target production volume: decide a realistic volume from facility size, equipment capacity, labor, and sales channels. Cultivation schedule: align harvest timing with market demand and calculate backward from the cultivation period. Required resources: estimate seeds and seedlings, fertilizer, materials, personnel, electricity, and water.

It is important to look at these comprehensively and build a realistic plan.

年月	作物	生種1				生種2				生種3				生種4			
		播種	育苗	定植	収穫	播種	育苗	定植	収穫	播種	育苗	定植	収穫	播種	育苗	定植	収穫
2024/05/01	水	4500				1800											
2024/05/02	木	4500								1800							
2024/05/03	金	4500	4500	4500		1800	1800	1800					1800				
2024/05/04	土	4500	4500	4500						1800	1800						
2024/05/05	日	4500	4500	4500													
2024/05/06	月	4500	4500	4500		1800											
2024/05/07	火	4500	4500	4500						1800							
2024/05/08	水	4500	4500	4500		1800	1800	1800									
2024/05/09	木	4500	4500	4500						1800	1800	1800					
2024/05/10	金	4500	4500	4500		1800	1800	1800									
2024/05/11	土	4500	4500	4500						1800	1800	1800					
2024/05/12	日	4500	4500	4500													
2024/05/13	月	4500	4500	4500		1800											
2024/05/14	火	4500	4500	4500	4500	4100				1800		1800	1700				
2024/05/15	水	4500	4500	4500	4500	4100				1800	1800	1800					
2024/05/16	木	4500	4500	4500	4500	4100							1800	1700			
2024/05/17	金	4500	4500	4500	4500	4100				1800	1800	1800					
2024/05/18	土	4500	4500	4500	4500	4100							1800	1800	1800		
2024/05/19	日	4500	4500	4500	4500	4100				1800	1800	1800					
2024/05/20	月	4500	4500	4500	4500	4100							1800	1700			
2024/05/21	火	4500	4500	4500	4500	4100				1800			1800				
2024/05/22	水	4500	4500	4500	4500	4100							1800	1700			
2024/05/23	木	4500	4500	4500	4500	4100				1800	1800	1800					
2024/05/24	金	4500	4500	4500	4500	4100							1800	1800	1700		
2024/05/25	土	4500	4500	4500	4500	4100	4100	4000		1800	1800	1800			1700	1680	
2024/05/26	日	4500	4500	4500	4500	4100	4100	4000					1800	1800	1800	1700	1680
2024/05/27	月	4500	4500	4500	4500	4100	4100	4000		1800			1700				
2024/05/28	火	4500	4500	4500	4500	4100	4100	4000					1800				
2024/05/29	水	4500	4500	4500	4500	4100	4100	4000		1800	1800	1800					
2024/05/30	木	4500	4500	4500	4500	4100	4100	4000					1800	1700			
2024/05/31	金	4500	4500	4500	4500	4100	4100	4000		1800	1800	1800			1700	1680	
2024/06/01	土	4500	4500	4500	4500	4100	4100	4000					1800	1700	1680		
2024/06/02	日	4500	4500	4500	4500	4100	4100	4000		1800	1800	1800					

Step 3. Progress Management and Review

A plan is not finished once it has been created. It is something you correct while running it.

- Monitoring growth conditions: observe and record regularly.
- Checking sales conditions: whether sales are proceeding according to plan, and whether inventory is appropriate.
- Grasping problems: when a gap appears, analyze the cause.
- Reviewing the plan: revise the schedule and production volume as needed.

The production plan is the axis of vertical farm operation.

Seeding



From here, we will look at on-site work know-how for actually growing vegetables.

What Is Seeding?

"Seeding" means sowing seeds. Because vertical farms do not use soil, the method differs from conventional agriculture.

Methods of Seeding in a Vertical Farm

Seeding in hydroponics is based on different premises from soil cultivation.

- Soil cultivation: sow seeds directly in soil
- Hydroponics: sow seeds in a growing medium

A growing medium is a material that supports plant roots in place of soil and supplies water and nutrients.

Seeding Procedure

The basic hydroponic seeding process is as follows.

1. Preparing the growing medium: set the growing medium in a dedicated tray, soak it in water, and moisten it sufficiently. 2. Seeding: sow seeds in the growing medium with tweezers or a dedicated seeding machine.

- Seeding density differs by crop.

- After seeding, keep humidity by covering the container or taking similar measures to prevent drying and runoff.

3. Watering: gently apply water with a spray bottle or similar tool. 4. Leaving it in place: manage temperature, humidity, and light appropriately, and wait for germination.

How to Improve the Germination Rate

When germination does not go well, check the following five points.

- Seed quality: choose fresh seeds with a high germination rate. Temperature and humidity during storage also have an effect.
- Choice of growing medium: germination rate and growth change depending on the type.
- Water content: make sure it holds enough water. In particular, insufficient water content in urethane media is often a major cause of poor germination.
- Temperature management: the temperature suited to germination differs by crop.
- Uniform watering: if water pressure is too strong or uneven, seeds are washed away or germination becomes uneven. Water gently and uniformly.

Seeding is the first step in crop management. A gap here affects every later process.

Propagation



The next process after seeding is "propagation." This refers to the period in which germinated seedlings are grown to a condition where they can withstand transplanting.

Why Propagation Is Important

The period after seeding, when seedlings grow to a certain size, is called the "propagation period." In vertical farms, a dedicated propagation room or propagation racks may be provided.

The quality of the propagation stage is directly connected to later cultivation results.

- Higher establishment rate: roots spread more easily during transplanting and final planting, and seedlings adapt more easily to the new environment.
- Faster growth speed: strong seedlings continue growing smoothly afterward, shortening the period until harvest.
- Higher quality: seedlings with good nutritional condition are resistant to disease.
- Higher yield: growing healthy seedlings pushes up the final yield.

Propagation Procedure

Preparation of the propagation environment in hydroponics is as follows.

- **Temperature:** set according to the crop and growth stage. For lettuce, it is common to manage the air temperature in the propagation room, not the water temperature, at around 25°C. Small seedlings are vulnerable to low temperatures, so be careful not to lower it too much.
- **Humidity:** if it is too high, disease occurs easily. Relative humidity (RH) of about 60-70% is a rough guide.
- **Light:** many varieties do not need light for seed germination itself, but when cotyledons unfold after germination and photosynthesis begins, appropriate light intensity must be secured. If lighting is not used during the germination period, be careful not to delay starting lighting after cotyledon expansion (a delay in starting lighting causes legginess and weak seedlings).
- **Nutrient solution:** while seedlings are small, it is common to set EC (nutrient solution concentration) low and raise it according to growth. However, based on my experience, if management is difficult, keeping EC at a consistently low level does not cause practical problems (this does not mean keeping it constant at the same high EC as the main cultivation area. It means operation kept constant at a low to medium value).

What is important in management after germination is the timing of transplanting. When seedlings become larger and their leaves begin to overlap neighboring leaves, that is a sign

that they are ready for transplanting. If they are left as they are, light does not reach them sufficiently and normal growth is obstructed.

1	A	B	C	D	E	F	G
2	播種日	播種数	5日目発芽率	発芽苗	移植数	過不足	備考 ※異常時の対応等
3	2024/05/01	4500	95%	4275	4100	175	
4	2024/05/02	4500	95%	4275	4100	175	
5	2024/05/03	4500	95%	4275	4100	175	翌日の不足分に充当
6	2024/05/04	4500	85%	3825	4100	-275	前日分から充当、不足は翌日分を使用
7	2024/05/05	4500	95%	4275	4100	175	
8	2024/05/06	4500	95%	4275	4100	175	
9	2024/05/07	4500	95%	4275	4100	175	移植時、葉の黄変確認
10	2024/05/08	4500	95%	4275	4100	175	移植時、葉の黄変確認
11	2024/05/09	4500	95%	4275	4100	175	移植時、葉の黄変確認

Keeping Propagation Records

Propagation becomes the starting point for the later cultivation period. If mistakes or trouble occur here, negative effects remain for a long time.

By recording environmental data and seedling growth conditions during the propagation period, you gain the following benefits.

- Early discovery of problems: signs of poor growth or disease can be caught early.
- Cause investigation: when trouble occurs, records make it easier to look back and identify the cause.
- Accumulation of know-how: propagation methods can be improved by referring to past records.
- Data-based management: management becomes possible through numbers, not only experience and instinct.

Records may feel troublesome at first. However, accumulated records can greatly improve cultivation accuracy. It is enough to start with what you can do.

Transplanting & Final Planting



Seedlings that have completed the propagation stage are moved to a wider space.

Transplanting

Transplanting is the work of moving seedlings to a wider space. If roots and leaves remain cramped, the following problems appear.

- Nutrient deficiency: roots cannot absorb enough nutrients, leading to poor growth.
- Light shortage: neighboring leaves get in the way, reducing the amount of light per plant.
- Increased disease risk: resistance drops, and plants become more susceptible to disease.

When seedlings become larger, moving them to a wider space lets them absorb enough nutrients and accelerates growth.

Final Planting

Final planting is the last transplanting performed before harvest. By repeating transplanting in stages, both harvest volume and quality are raised.

As mentioned earlier, plant spacing that is too narrow causes problems, but if it is too wide, the following happens.

- Wasted space: limited cultivation space cannot be used effectively.
- Decreased harvest volume: harvest volume per unit area decreases.

A vertical farm is a system that raises production efficiency by stacking grow beds vertically. You want to use space fully, but if you pack too much in, growth is affected. Balancing both is important.

The key point in final planting is finding the "optimal plant spacing" that lets crops grow without stress while maximizing the number of plants cultivated. This is something to refine on-site for each combination of crop and equipment.

Harvest & Trimming



The final cultivation processes are harvest and trimming. This is the moment when the seeds you sowed yourself become finished vegetables ready for sale, but at the same time, it is also the starting point of a new process toward sales.

How Harvest Proceeds in a Vertical Farm

Harvest work in a vertical farm is quite different from open-field farming. The basic approach is to divide the work like a production line.

- Harvest: harvest vegetables from grow beds.
- Transport: carry harvested vegetables to the trimming area.
- Trimming: remove leaves that will not be sold as part of the product.

The process is similar to an industrial production line, and division of work greatly affects efficiency.

What Is Trimming?

Trimming is the work of preparing harvested vegetables. It is not simply about appearance; it is related to product value itself.

Vegetables that are neatly shaped and trimmed offer the following benefits.

- They look fresh and appetizing
- They create a sense of reassurance
- They give an impression of high quality



Basics of Trimming

The following three points are what you should be conscious of in trimming.

- Remove damaged leaves and discolored leaves
- Shape the product
- Meet product standards

For leafy greens, remove several damaged outer leaves and leave the clean leaves in the center. Standards such as the number of leaves, length, weight, and shape may be decided in detail depending on the farm and buyer.

Rough Trimming Cuts into Profit

If trimming is done roughly, it directly affects profit in the following ways.

- Lower yield: too many leaves are removed, reducing the quantity that can be sold.
- Lower quality: if leaves are scratched or torn, product value drops.
- Lower work efficiency: rough work causes rework and ultimately takes time.

Trimming is a process directly connected to yield, quality, and work efficiency.

Harvest and Trimming Are the Culmination of Cultivation

Harvest and trimming are the final on-site step. Both speed and accuracy are needed. No matter how carefully crop management has been done up to this point, if the final finishing is rough, everything is ruined.

Work After Harvest

Harvested vegetables cannot simply be left as they are. The steps between harvest and shipment determine quality.



A Race Against Time for Freshness

Vegetables begin to lose freshness from the moment they are harvested. When freshness drops, the following changes occur.

- Appearance: freshness and juiciness are lost, and vegetables wilt.
- Taste: flavor declines, and bitterness and harshness increase.
- Nutritional value: vitamins and minerals decrease.
- Safety: bacteria multiply more easily, increasing the risk of food poisoning.

To protect freshness, it is necessary to carry out post-harvest handling appropriately.

Four Processes After Harvest

Work after harvest is broadly divided into four processes.

1. **Transport:** carry vegetables from the cultivation area to the work area.

- Temperature management: maintain an appropriate temperature even while moving them out of the cultivation area.
- Damage prevention: use containers and carts to absorb shocks.



2. Weighing and sorting: helps ensure consistent quality. Standards for size, shape, weight, and other items differ depending on the farm and buyer. Remove vegetables outside the standard. It can be done manually, but introducing an automatic sorting machine raises efficiency.

3. Packaging and packing: put vegetables into bags or packs.

- Freshness retention: packaging gently suppresses respiration and water evaporation.
- Protection: protect against shocks and scratches during transport.
- Improvement of product value: improve appearance and also communicate information with packaging materials.
- Packaging materials: choose films, trays, nets, and other materials according to the crop and sales method.

4. Storage: store at appropriate temperature and humidity.

- Maintaining freshness: suppress respiration at low temperature.
- Preventing quality deterioration: prevent drying and rot through humidity management.
- Storage location: use refrigerators or cold storage rooms with temperature and humidity matched to the crop and storage period.

Points in Quality Control

There are four points for connecting post-harvest work to quality.

- **Temperature management:** maintain temperature from harvest to shipment. In particular, if products are repeatedly taken in and out of the refrigerator, condensation occurs inside and outside the packaging and on the vegetable surface, and the speed of deterioration increases sharply. This is a point easily overlooked on-site.
- **Hygiene management:** thoroughly maintain hygiene in the work area and on tools.
- **Records:** by recording inventory count and harvest date and time, you can trace the cause when a problem occurs.
- **Inspection system:** check conditions before shipment and see whether quality standards are met.

2024/5/11		2024/5/11																																											
品目		フリル					フリル					フリル					フリル					フリル																							
製品規格		L	M	M	S	PB	5kg	1kg	500g	500g	L	M	M	S	PB	1kg	L	M	M	S	PB	1kg	L	M	M	S	PB	1kg	L	M	M	S	PB	1kg	L	M	M	S	PB	1kg	L	M	M	S	PB
ケース入数		10	1	12	12	12	1	1	1	10	1	12	12	12	12	1	10	1	12	12	12	1	10	1	12	12	12	1	10	1	12	12	12	1	10	1	12	12	12	1	10	1	12	12	12
総重量(kg)		110	90	75	80	80	6500	1300	600	110	90	90	75	80	1300	110	90	90	75	80	1300	110	90	90	75	80	1300	110	90	90	75	80	1300	110	90	90	75	80	1300	110	90	90	75	80	1300
1.製造数					8	92	2		8					8						8	92					8	92					8	92					8	92						
2.出荷数							2																																						
3.在庫数			6	12	92				8	66	29	8	58	37	3	4					8	100	58	29	3	11					16	92	5												
4.廃棄数														2																															
5月11日																																													
5月10日				1					42	5		42	5	3	4					42	5	2	2														42								
5月9日			6	3					8	16	12	8	16	12					8	16	12			4						8						8	16								
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合計		0	0	6	4	0	0	0	8	58	29	8	58	29	3	4	0	0	8	58	29	3	11	0	0	8	0	0	8	0	0														
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Post-harvest work is the final process for delivering cultivation quality as product quality.

Employee Management and Education

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収穫・トリミング	9	8	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7				
収穫補助	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2	2				
計量	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
包装	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	3	3															
検品	2	2	2	2	2	2	2	2	2	2	1	1	1	1	1	2	2															
梱包	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1				
ピッキング・在庫管理	1	1	1	1	1	1	1	1	1																							
清掃・洗浄	1	2	3	3	3	3	3	3	3	1	1	1	1	2	2	2	3	3	3	3	3	3	3	3	3	3	4	4	12	12		
定植														3	3	3	3	4	4	4	4	4	4	4	4	4	4	4	4	4		
移植1																																
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午前シフト人数	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	7	
全日シフト人数	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	13	
合計	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	20	

We have looked at crop management knowledge and techniques up to this point, but a vertical farm does not run with technology and equipment alone. Developing the people who operate it is essential.

Required Knowledge and Skills

In vertical farm job listings, you often see "no experience required," but the knowledge needed on-site is wide-ranging.

It spans many areas: knowledge of plant growth, cultivation technology, equipment operation and management, hygiene management, quality control, data analysis, and problem-solving ability.

The Two Pillars of Employee Education

Think of education in two stages: basic and specialized.

Basic education: for all employees

This is for new employees and people with no experience. It covers basic knowledge of vertical farms and basic work procedures.

- Overview of vertical farms: differences from other agriculture
- Basics of crop management: temperature, humidity, light, CO₂, nutrient solution, and other factors
- Hydroponics systems: mechanisms, types, advantages and disadvantages
- Work procedures: each process of seeding, propagation, transplanting, final planting, and harvest
- Hygiene management: methods for preventing the occurrence of disease and pests
- Quality control: methods for stably supplying high-quality vegetables
- Safety management: precautions related to work safety

In particular, have new employees study hygiene management and quality control intensively. As long as they participate in the work, a minimum level of knowledge is essential.

Specialized education: mainly for managers

Employees who have completed the basics should acquire specialized knowledge and skills.

- Cultivation technology: cultivation methods and environmental control for specific crops

- Equipment management: management and maintenance of hydroponics systems, lighting, and air-conditioning equipment
- Data analysis: analyze cultivation data and use it for problem discovery and improvement
- Quality control: more advanced quality control methods and inspection techniques

Employee management and education are factors that greatly affect the results of a vertical farm. Compared with equipment investment, they look plain, but in reality they have the greatest impact.

Thorough Hygiene Management

A vertical farm must constantly manage the risk of pathogens and pests.



Why Hygiene Management Is Important

Because a vertical farm is an enclosed space, once disease appears, it can spread rapidly. For mold and bacteria that like high temperature and high humidity, a poorly managed vertical farm is an ideal breeding ground.

The Three Pillars of Hygiene Management

1. Hygienic zoning (setting clean zones)

This is a method of dividing the inside of the farm into areas by cleanliness level, and it is the foundation of hygiene management.

- Contaminated zone: areas with much contact with the outside, such as outside the farm, material receiving entrances, and changing rooms

- Transition zone: the area where preparation for entering the cultivation area is carried out. Changing into work clothes, handwashing, and sanitizing are carried out here.
- Clean zone: areas where the highest level of cleanliness must be maintained, such as cultivation areas

Establish a one-way flow of movement from contaminated zone to transition zone to clean zone. Before entering the clean zone, always pass through the transition zone, remove contamination sources there through changing clothes, handwashing, and sanitizing, and then enter the clean zone (do not pass straight through the transition zone into the clean zone). If hygiene depends only on employees being careful, the hygienic environment quickly becomes disordered. It is important to arrange it through rules and systems.

2. Cleaning and sanitizing

Regularly clean and sanitize every place and piece of equipment inside the farm. The basic order is to carry out cleaning (physical washing) first, then disinfecting (sterilization) afterward. If disinfectant is sprayed while organic matter or plant residue remains, the effect drops greatly, so do not switch the order of the processes.

- Cleaning (washing): physically wash away dirt and plant residue. The targets are broad, including cultivation areas, work areas, hydroponics equipment, floors, walls, lighting fixtures, and air-conditioning equipment.
- Disinfecting (sterilization): after cleaning, use disinfectant to kill pathogens that washing cannot remove.
- How to think about frequency: thoroughly cleaning every place every day is not realistic. Prioritize places with high humidity, places that get dirty easily, and places people touch frequently.
- Records: leaving records of the places cleaned and the date and time helps prevent omissions and investigate causes.

名前ボックス (Ctrl + J)		B	C	D	E	F	G	H	I
1			【日次・週次】栽培室						
2	清掃実施期間:	から	まで						
3	清掃箇所	詳細	清掃方法	月	火	水	木	金	土
4	栽培ラック	プラスチック部	ゴミ取り→ワイパー						
5	栽培ラック	金属部	アルコール拭き						
6	高所作業車	全般	ゴミ取り						
7	コンベア	全般	アルコール拭き						
8	計量器	全般	アルコール拭き						
9	計量台	全般	アルコール拭き						
10	脚立	全般	アルコール拭き						
11	床	全般	ほうきがけ→水洗い→ワイパー						
12	排水溝	全般	ゴミ取り→水洗い						
13	ゴミ箱	本体	ゴミ取り→水洗い						
14	除湿機	フィルター	水洗い						
15	除湿機	内部	アルコール拭き						
16	除湿機	外表	アルコール拭き						
17	高所作業車	全般	アルコール拭き						
18	スイッチ	全般	アルコール拭き						
19	清掃用具	全般	アルコール拭き						
20	清掃用具ラック	全般	アルコール拭き						
21									
22			清掃担当者						

Because leafy greens are often not washed after harvest, the hygiene environment during cultivation directly becomes the hygiene condition of the product.

3. Employee hygiene management

The behavior of each person working on-site determines the entry and spread of pathogens and pests.

- Handwashing: do it thoroughly and frequently before entering the farm, before and after work, after using the toilet, and at other times.
- Wearing dedicated clothing: wear dedicated work clothes, hats, masks, and gloves.
- Health management: when you have a cold or feel unwell, do not push yourself and take a break.



However, having everyone maintain a high level of hygiene awareness requires time and education. In the short term, the realistic approach is to maintain it through systems and

procedures.

Key Points in Hygiene Management

The places that require particular attention inside the farm are as follows.

- **Entrances and exits:** entry routes where people and objects frequently come and go. Prevent entry with air curtains and sticky traps.
- **Floors:** dirt and water droplets accumulate easily and become breeding grounds. Regular cleaning and sanitizing, and securing drainage, are important.
- **Walls:** mold easily occurs due to condensation. Be conscious of preventing condensation and keeping them dry.
- **Hydroponics equipment:** pathogens easily multiply in nutrient reservoirs and piping. Leaves and root debris accumulate easily, and these places are hard to clean. Clean and sanitize them consciously.
- **Air-conditioning equipment:** clogged filters and internal dirt cause lower air-conditioning efficiency and failure. Clean and replace filters, and clean the inside regularly.
- **Work tables and cultivation materials:** attached dirt and residue become sources of pathogen growth and pest occurrence. Always clean and sanitize them after use.

Hygiene management is plain work, but it is work that supports the quality and safety of a vertical farm at the foundation.

Data Analysis

Another pillar of farm operations management is data analysis. When you hear "analysis," you may tense up, but the basic way of thinking is simple.

Why Data Analysis Is Important

In a vertical farm, various data can be collected, such as temperature, humidity, light, CO₂ concentration, and nutrient solution components.

In conventional agriculture, crop management relying on experience and instinct was mainstream. Experience and instinct are also important in a vertical farm, but they are not enough on their own. Using data makes the following possible.

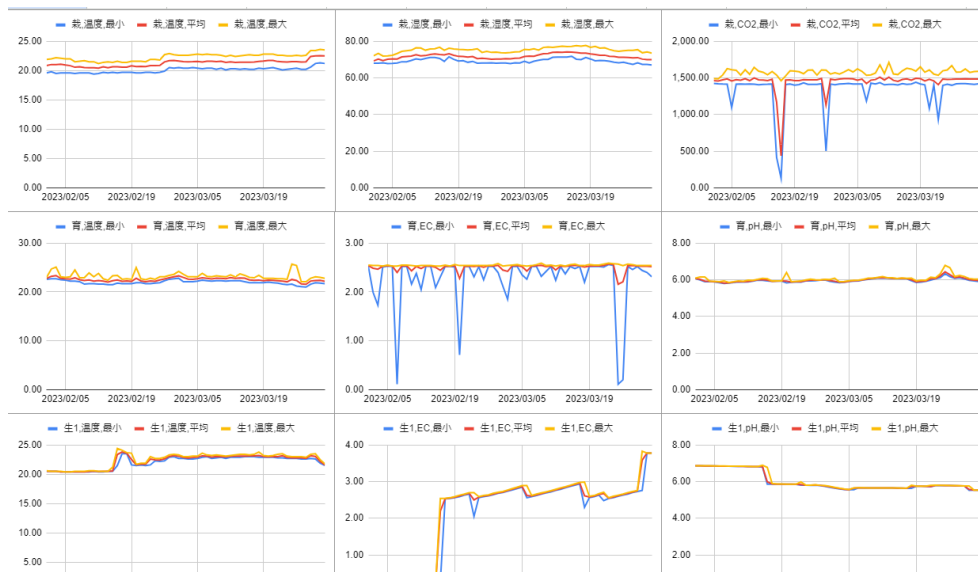
- Early discovery of problems: signs of poor growth or disease can be caught early.
- Identifying causes: when trouble occurs, data can narrow down the cause.
- Implementing improvement measures: improvements based on data are also easier to evaluate.
- Accumulating know-how: accumulated data becomes know-how unique to that farm.

Data That Should Be Collected in a Vertical Farm

There are mainly three types of data that should be collected.

1. Environmental data: numbers that quantify the environment inside the farm. 2. Growth data: numbers that quantify plant growth and condition. 3. Work data: records of work content related to crop management.

By managing these in a dedicated notebook or spreadsheet software such as Excel, the farm's "medical chart" is gradually created. (The above are representative examples, and there are many others.)



Basics of Data Analysis: First, "Visualization"

Data has no meaning if it is only collected. The first step is to visualize it with graphs.

- Line graph: suited to seeing changes over time
- Bar graph: suited to comparing the size of multiple data points
- Scatter plot: suited to examining the relationship between two types of data

Any tool is fine, but spreadsheet software such as Excel is low cost and can be used by anyone, so it is easy to start.

Practical Example of Data Analysis

How to Think When Tipburn Occurs Frequently

Suppose tipburn is occurring frequently in lettuce cultivation.

Collect environmental data from the occurrence area and nutrient solution analysis data, and compare them over time. Then you can see trends such as "the occurrence overlaps with periods of high humidity."

When you check the literature, it says that in a high-humidity environment, transpiration decreases and calcium supply to leaves is inhibited. If you understand that the cause is the combination of humidity and calcium, it leads to concrete countermeasures such as introducing dehumidifiers or reviewing humidity management.

This is the overall flow of data analysis. Proceed in the order of hypothesis, data, verification, and countermeasure.

Summary

Data analysis is a method for bringing reproducibility and verifiability into the world of agriculture, which has operated through experience and instinct. It is essential for making use of the strengths of vertical farms.

The "farm operations management templates" provided on my site are tools for data collection and analysis.

[Free] 13 Templates Used in Farm Operations Management for Vertical Farms

<https://pfboost.com/en/templateform/>

Chapter 3 Summary

- The production plan is created in three steps: "demand forecasting → plan formulation → progress management"
- Each process from seeding to propagation, transplanting, final planting, and harvest affects later quality

- Transport, sorting, packaging, and storage after harvest are the final line of defense for protecting "freshness"
- Employee education proceeds with the two pillars of "basic education" and "specialized education"
- Hygiene management has three pillars: "hygienic zoning," "cleaning and sanitizing," and "employee hygiene management"
- Data analysis makes early problem discovery and cause identification possible

Beyond Basic Knowledge: How to Build a Profitable Vertical Farm

Up to this point, I have explained the basic knowledge of farm operations management. All of it is important content for working, but what ultimately matters for an on-site manager is "profitability." This is the indicator of how much profit the business can generate.

The Gap Between Basic Knowledge and Profitability

When you learn the basic knowledge, questions like the following come next.

For example, in *Running a Vertical Farm: A Beginner's Guide*, I explained ways to address legginess, such as "increase light intensity," "adjust planting density," and "thoroughly manage temperature." However, at an actual site, questions arise such as:

- Specifically, what light intensity should be used?
- Is there a way to increase light intensity while keeping electricity costs down?
- How should planting density adjustment be decided in relation to harvest volume?
- How should temperature control be balanced against cost?

To raise profitability, you need to solve these questions according to the situation of your own farm.

The actual points of discussion are wide-ranging, including:

- Designing the cultivation process precisely and eliminating waste
- Adjusting nutrient solution components in detail and reducing fertilizer costs
- Introducing tools and systems that raise work efficiency
- Building unique sales channels and selling at high prices

To the Next Step

Running a Vertical Farm: A Beginner's Guide explains selected key points with the purpose of covering the basic knowledge for a vertical farm manager in a short time.

As the next step, there is another book that brings together know-how specialized in profitability.

172 Tips for Increasing the Profitability of Vertical Farms: Know-How Refined On-Site for More Than 10 Years <https://pfboost.com/en/profitability-of-plant-factories/>

Afterword

We have now covered the basics of vertical farms. If you have finished reading, you are no longer a beginner.

The "Practice" Beyond Basic Knowledge

However, the knowledge in this book is only the starting point. It is not enough by itself to make a vertical farm succeed.

- Use knowledge of temperature management to find the optimal temperature setting for each crop
- Use knowledge of nutrient solution management to improve fertilizer formulation and achieve both cost reduction and quality improvement
- Use knowledge of hygiene management to build a thorough hygiene management system

In this way, making knowledge your own through practice is the shortcut to growth.

Toward Further Growth

Even after finishing this book, many parts should remain unclear. Because this book is narrowed down to basic content, it does not go deeply into the practical details of running a farm.

What is directly connected to profit is the practical know-how beyond the basics.

If you want to learn more practical know-how, or if you want to know concretely how to raise profitability, please visit my website.

Some people say that vertical farms "cannot make money," but I think there is still room for improvement depending on the method. On-site, I have often seen small improvements lead to major results.

<https://pfboost.com/en/>