



植物工場運営 超入門

Shohei Imamura

PFBoost

Running a Vertical Farm: A Beginner's Guide

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Introduction

Vertical farming is not a business you win just by buying the right equipment.

Since I entered this industry in 2011, I have spent more than ten years on the floor growing leafy greens in PFAL, and I have worked at more than ten of them, large and small.

Well-funded major players sometimes pull out within a few years, while other farms steady their profits by piling up one unglamorous improvement after another. Almost all of that difference comes down not to equipment or systems, but to how you run the floor. A staff member checking the leaves by hand, right beside the latest sensor—that is what a vertical farm is.

In the end, the floor is something you can only learn on the floor. Reading this book will not let you walk in and do the job tomorrow. But if you come in already carrying the knowledge that underpins the industry and the work, what you pick up on the floor speeds up noticeably. Why am I doing this task? What does this number mean? Between someone who knows the answers and someone who is merely moving their hands as told, the same day on the floor leaves each of them with something very different.

So I have rebuilt this book as **the one a boss or a senior colleague can hand to someone newly arrived on the floor and say, "Read this first."** It is a foundation book for getting a rough grasp of the whole picture of the industry and the work before you ever set foot on the floor.

How This Book Is Structured and How to Use It

The book is built in three parts.

- **Chapter 1** gives you the big picture of vertical farming as an industry. What kind of world it is, where it stands now, and where opinions differ.
- **Chapter 2** covers the basics of cultivation. Light, temperature, nutrient solution—the fundamentals of how vegetables grow.
- **Chapter 3** moves into the practical work on the floor. What there is to do day to day, and what a manager keeps an eye on.

Read it in this order, and when you step onto the floor you will be able to tell where you stand within the whole.

There is one thing I want to make clear. This book is devoted to handing over the foundations of the industry and the work, and it does not go deep into **the more advanced judgments that bear directly on profitability**—how to pin down optimal values, where to cut when reducing costs, designing sales channels, sizing up an investment, and so on. That is the territory of practical know-how distilled from experience on the floor, and the sister volume, *172 Hints to Improve the Profitability of Vertical Farms*, takes them up one by one. Once you have the whole picture from this book, reach for that one whenever the need arises.

What would mean the most to me is for this to serve as training material you hand to newcomers. Feel free to copy or share it. That said, I have not waived copyright, so please don't alter the contents.

About the Author



Shohei Imamura

Entered the vertical farming industry in 2011. As a floor worker and support-team manager, he has helped launch and run more than ten vertical farms, large and small. He has trained a cumulative total of more than 600 staff.

That experience convinced him that what determines a vertical farm's profitability is not the equipment or the systems but the skills and knowledge of the people who handle them. He now works independently, providing profitability-improvement consulting, support, and content for vertical farms.

Chapter 1: The Future and Prospects of the vertical farm

Welcome. What you are about to step into is the world of the "vertical farm" — a world that is hard to read from the outside. I have been in this industry since 2011, and for more than ten years, across more than ten facilities, I have watched PFAL sites grow leafy greens. The chaos of startups, the sites that pulled out, the vertical farms that quietly kept turning a modest profit. In this chapter, for you who have only just arrived on the floor, I want to hand you the whole picture of the industry, once, from end to end. The finer talk of how to actually make money I will leave to later chapters and to "172 Hints"; here I will first run straight through "what a vertical farm is, what state it is in now, and where the scenery splits" — the way a senior on the floor would tell it. Don't overthink it. Read it just to get the outline of the whole thing.

What a vertical farm is — separating the two types



When people hear the words "vertical farm," most of them picture a factory line. Press a button and standardized goods keep rolling out; install the equipment and you can mass-produce anything cheaply — that is the intuition a machine factory has trained into us. But if you walk inside still carrying that intuition, you will usually misread what you see. Even when two things are both called "vertical farms," what is inside can be as different as two separate living creatures. So first, let us just keep that distinction within reach.

Do you use the sun, or build everything with electricity?

There is one dividing line that matters most. Do you use the light of the sun, or do you make even the light yourself with electricity?

The type that uses sunlight — what is called the **greenhouse** type — you should think of as an extension of the plastic-film greenhouse. Light comes in through the roof for free. The factory-like part is everything other than light — temperature, humidity, CO₂, watering — the measuring and controlling of it. It is a facility that engineers not the light, but everything other than the light.

The other type, the **full PFAL**, shuts out the sun entirely in a windowless room. On top of that, it buys back the light that was originally free, with electricity, and rebuilds it itself. Not the light alone, but the HVAC and the humidity too — all of it is covered by electricity, in order to reproduce the outside weather inside the room. That is the price of cutting yourself off from the outside air. What I spent more than ten years inside was this one: a site growing leafy greens with PFAL. When I write "what I have seen" in this book, take it, basically, as a story within this range. The greenhouse type, and fruiting-vegetable or large-scale overseas cases, I touch on here only as estimates drawn from papers and from first principles.

In this book, unless I say otherwise, when I say "vertical farm" I mean the full PFAL. It is also, usually, where a newcomer is first assigned.

Why the crops you can grow lean toward leafy greens

Lettuce, spinach, baby leaf. What you hear about in talk of vertical farms is, most of the time, leafy greens. The reason follows plainly from the constraint of buying light back with electricity. Leafy greens do not demand much light, they are short, and you can stack many tiers of them on shelves. Their growing period is short too. So they just barely justify the cost of making light with electricity.

With crops that bear fruit, by contrast, the order of magnitude changes. Fruit-bearing crops like tomatoes need a large amount of light, and the taller they grow, the harder it is for light to reach the lower leaves, so efficiency drops as well. With staples like rice or wheat it is more extreme still. So what can be grown commercially under fully artificial light is, for now, mainly limited to short leafy greens.

This is where the word "factory" betrays you. An ordinary factory lets you make a wider range of things the more equipment you put in, but the full artificial light of a vertical farm works the other way — if anything, the range of what you can make is squeezed down tighter. And what is growing inside is alive, so you cannot, just because demand has dropped, pause the line and then restart it from the same place. Once the seed is sown, whether it sells or not, it grows at the speed of its own growth. It is not a device for mass-producing anything cheaply, but a device for putting out a limited set of crops steadily, cut off from the weather — not a factory that ramps up volume, but a factory that erases the swings.

Don't apply the industry's numbers to yourself as they are

Once you start looking into "how the vertical farm is really doing," the first thing left in your hands is, usually, numbers. "The loss-making rate is this many percent." "The initial investment is this many billion." This book, too, will look at such industry numbers later on. But let me say one thing first: a single number like that cannot serve as the yardstick for your own project as it stands. It is an average that lines up, in a single row, things that differ in type, in crop, and in scale. There is no guarantee anywhere that your combination fits a loss-making rate that counted full-artificial-light lettuce, greenhouse tomatoes, and a small half-hobby facility all together as "vertical farms." How to read the numbers themselves, I will take up again in a later section.

The order in which to check

Last, one thing as a foundation. When you look into vertical farms, if you try to decide from the type first, you will usually get lost. My recommendation is the reverse: start from the **exit**. Who will buy what, why, and at what price. Once that is settled, the **crop** you want is settled; once the crop is settled, the **type** is all but narrowed down by the required light intensity and plant height; and only then can you read other people's **numbers**, choosing only the cases whose conditions match yours. Exit, crop, type, numbers. As long as you don't break this order, you won't go far wrong.

Which sales channel a given crop pays off in — that judgment is revenue design itself, so in this book I stop at the entrance and leave the deeper judgment to "172 Hints." For now: that there are two types, the reason it leans toward leafy greens, and that you should divide the numbers before reading them. Carry these three, and let us go and look at the "now" next.

Knowing the "now" of the vertical farm

I entered the vertical farm industry in 2011, in the period of what was called the "vertical farm boom." Large companies were entering one after another, new vertical farms were going up across the country, and the media were covering it as "the agriculture of the future."

But what followed did not go as hoped. Even large companies with capital and brand strength pulled out within a few years, one after another. Installing the most advanced equipment did not, it turned out, mean success. The construction rush of that moment died down, and the way it now surfaces in conversation has changed too.

Why is it drawing attention again now?

Even as the talk of pullouts continued, interest in vertical farms has, if anything, grown stronger again over these past few years. The reason is clear: whether food can be secured stably — what is called food security — is a worry rising across the whole world.

The trigger is, usually, a moment when "food might stop arriving from outside." When an infectious disease halts logistics, when conflict makes transport routes unstable — each time, inquiries about vertical farms rise. That pattern keeps repeating. A vertical farm is not so much a technology for lowering the cost of transport as a technology that lets you keep producing without relying on transport at all. Even if logistics stop, you can keep producing inside the facility. So it is being re-evaluated, freshly, as "a means to produce food within your own country, swayed by neither the weather nor international affairs."

This shows up more strongly the more a region is saddled with an environment unsuited to agriculture. Where the climate and soil are wrong for farming, water is scarce, and most food is leaned on from imports — in such regions, the vertical farm is less a managerial option than something tied directly to a nation-level question of how to secure food. The yardstick for whether it pays off is, from the start, different from a country like Japan, where it tends to be discussed as "electricity is expensive, so it doesn't add up." In regions where growing in open fields is itself difficult, the drawback of "the vertical farm is high-cost" grows relatively smaller, and it becomes easier for it to hold up as a business. The gains and losses of a vertical farm change their scenery depending on where, and by whom, they are seen.

That said, it is not all good news. The vertical farm relies on imports for much of its equipment and materials — LEDs, control systems, growing media, piping. You want to build the facility

precisely because food stops arriving when transport halts, yet the very parts to build that facility are themselves at the mercy of transport — this contradiction is something you should hold onto honestly. The matter is not so tidy that you can simply declare "and that is exactly why it's the vertical farm."

Read entrant companies not by "number" but by "where they make money"

When attention gathers, you also get more chances to survey the lineup of entrant companies. Headlines like "another major player enters" and "that company pulled out too" drift past regularly.

At such times, you tend to judge by the number — "if this many are gathering, it must be promising." But look closely at the lineup, and you notice the makeup is all over the place. There are manufacturing-sector companies that originally did semiconductors or electronics; there are ones that came from food service or distribution; and there are newcomers like agricultural ventures. Even if you count these together as "X companies entered," it is, more often than not, just a mix of people who are actually doing separate things.

The view I have settled on is to divide them into three layers by where they stand up their revenue — that is, by "where they make money."

The first is the **layer that makes money selling equipment and plants**. Many are manufacturing-sector, and for them the vegetables are close to a demonstration meant to show off the strength of their own equipment. What they want to sell is the device, not the vegetables themselves — companies like that stand out. The second is the **layer that sells the vegetables it grew, to the outside**. Agricultural ventures and specialist players are here, genuinely competing on "the price of vegetables." The third is the layer, like food service and distribution, that **grows for its own use**. This one is not competing to sell vegetables on the market at all.

These three, even under the same banner of "running a vertical farm," differ completely in whom they fight and in the conditions under which profit comes out. So just because there are many companies, it does not follow that competition is fierce. What matters is how much of which layer is clustered around the sales channel you are aiming at. If layers that sell vegetables are fighting over the same supermarket shelf, then that shelf really is crowded. But the manufacturing-sector players who want to sell equipment do not compete much on that

shelf. The number "X companies entered" tells you almost nothing about how crowded the sales channel you are trying to enter actually is.

While you are a newcomer, reading this far is enough. When you see figures for entries and pullouts in the news, build the habit of pausing one beat to sort them: "is this a story of selling equipment, of selling vegetables, or of using them in-house?" That alone makes the scenery of the industry look considerably more three-dimensional. Which band your own company aims at, and where the openings are — to actually discern that and make your move is, from there on, a managerial judgment, so in this book I stop at the entrance and leave the deeper reading to "172 Hints."

What has changed, and what has not

Over these ten-plus years, some things have certainly changed. The performance of LED lighting has improved enormously. When I first came onto the floor, there were still vertical farms using fluorescent lamps. The management of cultivation data and the streamlining of systems have advanced too. On the technical side, there has been steady progress.

Some things have not changed. What I feel strongly after more than ten years in this industry is that **what governs the profitability of a vertical farm is not the equipment or the system, but the "people" who run it.** Beside the latest IoT sensor, a staff member checks the state of the leaves by hand. Beside the AI's environmental control, a veteran's "feel" is at work. The vertical farm is that kind of place.

Even so, the vertical farm holds possibility

I honestly think this is not a situation you can be optimistic about. Still, there are certainly vertical farms turning a profit even in harsh conditions. What they share is knowing "how to run the floor."

Not the quality of the equipment, but how deeply the floor staff understand cultivation and how steadily they pile up day-to-day judgment. I have seen, again and again, vertical farms that changed enormously off the back of the smallest improvement.

Stable production unswayed by the weather, high productivity on limited land, a large reduction in pesticide use. These strengths hold value in many regions. And so long as the demand to secure food on one's own keeps rising in the world, the situations where this

technology is needed will, if anything, multiply. In this book, I will convey the basic knowledge that forms its foundation, as a whole picture.

But for all the talk of possibility, the reality is not so sweet. Next, we will look at the other side — the "harsh reality" — head-on: why so many vertical farms suffer in the red.

Why does the vertical farm end up in the red?

Possibility or not, the reality is that many vertical farms are forced into harsh management.

- "The capital investment cost too much."
- "The vegetables don't grow the way I expected."
- "I made them, but they don't sell."

These are voices you often hear on the floor. Why do so many vertical farms suffer in the red?

The first thing to hold onto is that the single all-encompassing label "the vertical farm is a loss-making industry" is what dulls judgment the most. Seeing headlines like "60% are in the red" over and over, you somehow come to take it as "that's just how this industry is." But when you actually look at vertical farms one by one, there are profits and there are losses, and you start to see where that difference comes from. What I feel, having worked with PFAL sites for more than ten years and at more than ten places, is that the real dividing line is not whether it is an industry, but "how it is built."

"Startup-phase losses" and "structural losses" are different things

"Losses" said in one breath, yet things of different natures are mixed in. Lumping them together as "in the red, so it's no good," without separating them, is the most dangerous thing of all.

One is the startup-phase loss. A vertical farm's equipment depreciates even when it is not operating. In the startup phase, shelves sit empty for some months, and the yield, too, normally falls short of the planned figure at first. So the first few years tend to fall into the red. But this is a loss that shrinks every month as the operating rate rises and the yield stabilizes. You could say it is partway through the normal process of an investment heading toward recovery.

The other is the structural loss. Operation and yield have both risen as far as they will, yet the size of the loss does not move. This is no longer a startup problem; it is a loss decided at the design stage, one you cannot escape as long as you make that crop with that equipment.

What to look at is not the sign of whether it is in the red, but which way that loss is moving over time. If the loss shrinks the more time passes, it is a startup-phase loss. If it does not budge as time passes, it is a structural loss. What the former needs is cash flow and patience; what the latter needs is a rethink of the crop, or a pullout — the moves to play are completely different.

The three levers that move profitability

So, within that "how it is built," what is it that decides profitability? The lists of merits and demerits run to many items, but the levers that truly move profitability come down, in the end, to three. **Electricity, sales channels, and frontline capability.** The bulk of the money going out is electricity; what caps the money coming in is the sales channel; and what finally sways both is the frontline capability — how much you can actually harvest on the floor.

These three differ in nature. Electricity and sales channels can be pinned down on paper before ground is broken. At what price you draw electricity, what you make and to whom you sell. These can be decided in advance, at the stage of blueprints and contracts. Frontline capability, on the other hand, is a multiplier that only comes into play once you have started running. With the same equipment, the same electricity unit price, the same sales channel, both how much you harvest and the quality change completely depending on how the floor is managed. So frontline capability is the variable that comes to bite into profitability last, and you need to grasp it separately.

The order matters. Above all, the one to look at first is the sales channel. Of the three, the sales channel is the one most easily put off, and the one most impossible to take back. The distinction comes through fairly well with one question: "Before you make it, has it been decided who buys how much, at what price, every week?" A project that cannot answer this with numbers is dangerous, however splendid its equipment. Conversely, if this is filled in, you can work backward from there to the scale you need and to the ceiling on fixed costs you can allow. If the order is reversed — the equipment is there first and you are out looking for a buyer — that itself is a symptom on the loss-making side.

Here, let me raise one reversal you often see on the floor. Among vertical farms in the red, somehow a "splendid facility" turns up mixed in. The places that put in the latest equipment and run at a larger scale can be the very ones that look the deepest in the red. By ordinary thinking, the better the equipment, the more advantageous it should be — and yet. The trick is simple: if you put in the equipment first without working backward from the sales channel, that investment bears down as a fixed cost before any sales stand up. The LEDs, the HVAC, the automation line — the monthly depreciation runs even at a zero operating rate. It is not that splendor itself brings on the red; it is the equipment running ahead while the sales channel was left behind, surfacing in a conspicuous form.

A challenge has a "ceiling layer" and a "reach-rate layer"

To put this another way, the challenges of a vertical farm split into two layers.

One is the layer that decides the very ceiling of profit the vertical farm can reach in a year.

"What to make, and where to sell it" — the combination of crop and sales channel quietly decides, at the moment ground is broken, the upper limit of cost the vertical farm can carry. Once it is built, no amount of effort on the floor can claw it back.

The other is the layer that decides how close to that fixed ceiling you can bring the actual results. How electricity is used, how people are deployed, the yield. The day-to-day running belongs here. The troubles that surface as problems belong to this layer, and its role is to raise the reach rate toward the ceiling set above.

So, as an order: before you build, you raise the ceiling itself in the upper layer; after you build, you harvest it through running. A common failure is to try to recover through running alone while the ceiling stays low. The whack-a-mole feeling — that holding down electricity drops the yield, and cutting people leaves other things unattended — usually sets in when you try to win it back through running alone, without accounting for the constraints upstream. Before you start whacking, go once and look at "which upstream choice brought on this symptom." Then, on top of that, tighten the running. It is a matter of order.

Electricity is both the largest cost and the largest environmental impact

Of the three levers, electricity has something special about it. It is, at once, one of the very largest line items of money going out and the largest factor in a vertical farm's environmental

impact. On the cost side and on the environmental side alike, where it all comes home to is electricity.

This comes from the fate of the PFAL method. The light the open field received from the sun for free, the PFAL buys back with electricity. So in a PFAL, electricity accounts for roughly 20 to 40 percent of production cost, and most of that electricity is eaten by lighting. Compared with the open field, the energy per harvested item becomes vastly larger. What is heavy as a cost is, by that very fact, heavy as an environmental footprint. The reason that measures to cut electricity reduce the electricity bill and the environmental footprint at the same time lies in this structure.

That said, here is one thing to keep in mind: the line items move in tandem. If, trying to cut electricity, you squeeze the lighting or the HVAC too far, the denser planting may make things steam up and damage the lower leaves, or sorting losses may rise — and you can lose more in yield than the electricity bill you cut. Cost is not something you can shave in any single place in isolation; the order in which you cut, and the discernment of how far to cut, come into play. The specific way to make those judgments lies beyond the range of this book. The discernment of optimal values and the judgment of cost reduction, the design of sales channels, the judgment of investment — those deeper examinations tied directly to profitability are dealt with in detail in the companion volume, "172 Hints to Improve the Profitability of the vertical farm." Here, it is enough to grasp the entrance to the way of thinking — to see the red not by sign but by slope, that profitability is decided by the three of electricity, sales channels, and frontline capability, and that a challenge has a ceiling layer and a reach-rate layer.

How to read industry numbers and news

Once the structure of the red comes into view, it is, this time, the industry numbers and news circulating in the world that start to bother you. Out on the floor, they catch your eye whether you like it or not. "The market is on the order of X billion." "Half are in the red." "A major player pulled out again." A senior may hand you a report and say, "read this." What troubles you is that, the moment you try to apply any of the numbers to your own vertical farm, something does not quite sit right. The bigger the number you look at, the more, if anything, it feels useless for the judgment in front of you on the floor. That mismatch has a proper reason. Here, I will hand you a yardstick for not being knocked about by numbers. The deep reading I leave

to "172 Hints"; just the entrance here.

"Half are in the red" points to an average that does not exist

The first thing that catches the eye is the one line, "half of vertical farms are in the red." I often hear of cases where this number stayed someone's hand from entering or expanding. But this is an average that lumps PFAL and Greenhouse, leafy greens and fruiting vegetables, all together in one. The structure of profitability is a wholly separate thing for each, so the average points to some "somewhere" that does not exist, and tells you nothing about which side you are on.

In fact, even in recent surveys of the actual situation, when you re-divide by type, the scenery faces the other way. PFAL is still about half on the loss-making side, and its mainstay is leafy greens of the lettuce kind. Yet in the same survey, when you turn your eyes to the Greenhouse, more than 70 percent are in the black or at break-even, and here the mainstay is fruiting vegetables like the tomato. Count it centered on lettuce and it is "half in the red"; on the tomato side, the profits are many. The same "vertical farm," yet simply by re-dividing the population by type and crop, the headline and the scenery swap places.

So when you see a loss-making rate in an industry report, first check "which type and which crop is this number a tally of." This is the first yardstick.

A pullout news item is not measuring that vertical farm's future prospects

When I first came into the industry, the floor stirred every time a major player's pullout news came in. "So it really is no good after all." But when you examine the substance of a pullout from the outside, the technical story of "the vegetables wouldn't grow" hardly ever comes to the front. What comes out is the electricity bill that grew heavier little by little, the buyers who did not spread as far as expected, the people who did not last. What stops is not the technology of making, but whether the operation keeps turning, year after year.

If that is so, then to measure "the industry is over" by the mood of the day a pullout makes the news is off the mark. Whether the industry as a whole grows or ends, and whether the single vertical farm in front of you lasts, are separate questions. When you look at one case from the outside, your footing is how that vertical farm holds up the four things of electricity, capital, sales channels, and people. Where, at what price, and on a contract of how many years does

it source its electricity? Is the capital stretched out to a picture beyond the point where the subsidy runs out? Are the buyers not skewed toward a single company? Are the people not turning over and over? Even if you cannot peer inside, this much of an outline you can count from the outside.

That said, to go on from there and bet "and therefore it will pull out" is impossible. The same skews are normally present even in vertical farms quietly continuing in the black. What the outer form tells you is, at most, candidates for weak points. Think of it as counting not to predict, but to see the fragility in advance.

A listed company's profit is a profit earned by its core business

You may also take a listed company's name as a handle, thinking, "for vertical farms, it's this company." If the earnings are in the black, you can rest easy for now and move on — but where did that profit come from? When you line up the segment data of listed companies doing vertical farms, a certain shape emerges, common across many of them. The vertical farm part is in the red, yet the company as a whole is in the black. The core business is an electronics maker or steel or logistics, earning solidly over there, and it holds the vertical farm like a new venture. In other words, what you are seeing is not the business viability of the vertical farm, but the depth of the core business's pockets. When I myself was on the operating side of a PFAL vertical farm, I sometimes felt in my bones the air of "this business is protected by the parent." So long as the core business is earning, there are indeed vertical farms that have no reason to stop even in the red.

The stock price is the same. Seeing the headline "vertical farm stock rises," you want to read it as the industry's momentum, but what is being bought is, in the end, the core business. It cannot be separated out from any evaluation of the vertical farm. Before resting easy on the company-wide numbers or the stock price, the yardstick is whether you can look at this on its own: by whose expectation, and what kind, is the vertical farm itself being held up?

Overseas success is made by location, not by the facility

Reading a tour report from Singapore or the Netherlands, have you never half-thought, "if we did this in Japan..."? High yield, fast investment recovery. But as you go to copy the numbers into your plan, your hand suddenly stops. The premise on the electricity bill is, from the start, different.

The reason the leading hubs grew seems to lie not so much inside the facility as on the side of the country itself. Singapore places food self-sufficiency at the heart of its security and pays subsidies, creating demand by national policy. The Netherlands has, underlying it, a greenhouse culture from the era when natural gas was cheap, and on top of that the vast European market is right next door, connected by land. Cheap electricity, thick subsidies, a fat sales channel close by — what has grown are the places where several such locational conditions overlapped at once; it is not that the facility was outstandingly superior. Japan's electricity unit price is structurally high, its subsidies are one-off and hard to read, and there is no fat shelf a vertical farm's lettuce slides easily onto. Build only the same facility, and you will not get the same result.

So overseas cases are not to be read as a ranking of "which country to imitate," but to line up the overseas premises and the Japanese premises one by one and see the difference between them. To see the border between the conditions you can transfer and the conditions you cannot. This is the fourth yardstick.

Use numbers in two stages

By the time you get this far, you start to feel that the "market size of X billion" total you were looking at first need not be looked at any more. But there is no need to throw it away. Just change its role.

The total is not a number that answers "can I win," but a number for reading "will the players in this market increase from here on." Where you sell and the price of equipment are not decided by you alone; they shift as entry increases. And whether that growth is happening in the Greenhouse's fruiting vegetables or in the PFAL's leafy greens lands on your own floor in completely different ways. If makers aiming at the same sales channel as you have increased, supply rises and pushes the selling price down. So keep the total around as the entrance for reading the sense of scale and the direction of entry — the wind direction, that is.

As an order: grasp the large flow with the total, and decide the matters of your own vertical farm with the numbers of your own block — this two-stage stance. The industry's numbers and news are not your answer itself; use them to read which way the premises on which you rest your answer will swing from here on. Stand that way, and you can keep from being knocked about, one item at a time, by pullout news and by market size. How to actually lay out the

numbers of your block, and how to discern selling price and scale — the actual motions of the hands are dealt with in detail over in "172 Hints."

The reality of the profitable vertical farm

In the reading of numbers, I said "decide it in your own block." So, the vertical farms that are actually turning a profit in that block — what is different about them? We have looked only at stories of the red, but in that same industry there are certainly vertical farms that make money. If you turn this into a hunt for a winning pattern — "do it like that company and you'll win" — you will usually get your legs swept out from under you. The reality of vertical farms that make money lies somewhere a little plainer, and a little more honest.

A success case is not a "winning pattern" but a "bundle of conditions"

When you hear from a fellow operator, "we got into the black with lettuce," you tend to want to know how — "how did you do it?" The person speaks concretely about yield and sales channels. But the more you listen, the less it feels you could copy it as it stands at your own place. The location is different, the conditions on the electricity bill are different. This sense of "the more I listen, the less it feels reproducible" is the most honest reaction.

A vertical farm's success case is not a copyable winning pattern, but a **"bundle of conditions" that only works when location, power source, sales channel, and crop happen to mesh**. So if even one condition differs, the same way of doing it gives a different result. There is no ill will in the one who speaks. The location was blessed with climate and land, there was a sales channel nearby that took the product steadily — such "premises that were already in place" are, for that person, too obvious to mention, and so they fall cleanly out of the success story.

These four are not an exhaustive frame claiming to cover all of the conditions for success. They are the first yardstick for breaking a case apart by "can it be copied, or not." Location and power source are conditions decided first and immovable; sales channel and crop are conditions you can recombine afterward. First, unbundle the bundle along this line. And what you must not forget is that there is one more layer. Even if all four conditions are in place, if the people who run it drop out, the quality collapses. **Both success and failure are the same bundle of conditions, plus the frontline capability that runs it, seen from a different side.**

Failure cases are exactly what teach you the missing condition

Vertical farms that pulled out do not accumulate as cases. What surfaces is only the stories that got into the black, and the vertical farms that vanished tend to be cleared away with the single phrase "it was a mistake in management judgment." But this way of clearing them away is, at root, the same as copying a success case whole. In the success story, the "premises that were in place" fall out. In the failure story, the "condition that was missing" gets swapped out for, and hidden behind, the single phrase "a mistake in management judgment." Only the direction is reversed; it is the same pitfall.

The land's power cost ran higher than assumed, there was only one buyer and they pushed the price down, the crop chosen could not be produced stably at the quality that sales channel demanded — when, really, one of location, power source, sales channel, or crop was simply missing from the start, you turn it into a story about a person's ability: "the president's decision was soft." Do that, and the worst lesson of all is what remains — "I'm excellent, so I'll be fine."

That said, you must not swing too far the other way either. There are also collapses where all four conditions were in place, but the person who carried the startup dropped out and the yield fell, or disease got in once and the cycling of the shelves stopped. This is not "a condition was missing" but a failure where "the side running the bundle collapsed." So a failure case, too, is read in exactly the same way as a success case. Which of the four was missing, and toppled it? Or were the four in place, yet the running side collapsed? Hard to come by though they are, failure cases are really the richest teaching material of all.

Behind the black, there are premises that go unspoken

One more troublesome thing is that behind the figures for profit and yield spoken of in success cases, premises that never surface lie hidden. Let me raise just three representative ones. The first is the makeup of subsidies. Is it a black achieved on sales, or a black achieved on top of a subsidy covering some percentage of the initial investment? The second is staffing density. If that black rides on labor close to unpaid work by the president or family, never booked as personnel cost, it collapses the moment a single person drops out. The third is the contract terms of the sales channel. If "they take it for us" is little more than a verbal promise renewed yearly, then the condition called sales channel is far more fragile than it looks.

These are the parts that cannot be filled in without asking the parties directly. What the reader can do is to read the outer form (location, scale, crop, whether subsidies were used) as fact, and to leave the substance in the form of questions, with the label "this is an estimate" attached. The moment you think you can declare the cause of victory or defeat from public information alone, you have already misread the case. And the same four columns can be drawn up for your own company too. Line up the case's premises against your own company's location, power source, sales channel, and crop, one step at a time. The question shifts from "can I copy it?" to a judgment of applicability: "can I reproduce this premise at my own company?"

The substance of "making money" is dug into from here on

This much is the stance for reading vertical farms that make money. So, to actually make money at your own vertical farm, where do you move? Each of those steps goes beyond the range of this book's introduction. Here I will line up only the entrance to the way of thinking — and every one of these is a theme this book does not delve into, and that the companion volume "172 Hints" handles one by one.

- **Profitability is decided more upstream than downstream.** A vertical farm's profit tends to flow to the upstream layer that sells equipment and know-how, more than to the cultivation itself.
- **Profitability changes with where you place it.** Equipment that changes the very premises of location and scale, like the container type, has things it suits and things it does not.
- **A single-year black and cumulative recovery are different things.** Even if a given year is in the black, when you finish recovering the initial investment is an entirely separate story.
- **Among costs, there are those you can shave and those you cannot.** Where in the initial investment you may cut, and where, if you cut, it bites you later.
- **Lock down the sales channel first.** Rather than entering from the crop, decide first on the sales channel that takes the product steadily, and work backward to the crop.
- **The strength of the urban type is not nearness but holding the unit price.** The value of growing near a city lies not in the shortness of the transport distance, but in the price at

which you can keep selling.

If I fold the reality of vertical farms that make money into a single line, it is **not the newness of the equipment nor the scale, but whether you read the bundle of conditions all the way through, and whether there is a floor that runs it**. And which of those to move — grasp the whole picture in this introduction, and then check them one by one in the hint collection.

What is the decisive difference from open-field farming and protected cultivation?

I have carried the talk of profitability this far, but why profitability takes such a structure becomes clear when you look at what sets a vertical farm apart from other agriculture. While you are a newcomer, you tend to think, "it's the same vegetables we make, so what we do must be similar too." But in reality it differs from the very root. The difference is easy to organize if you look at it along two broad axes — **how far you take the environment into your own hands**, and **what you rely on to judge**.

Environmental control: from leaving it to nature, to full control

The first axis is who decides the environment in which the crop is grown.

- **open-field farming**: relies on the forces of nature — rain, wind, sunlight. It needs wide land, and there is the heavy labor of soil-making and watering too. It is easily swayed by the weather, never far from the risks of typhoons and drought.
- **protected cultivation**: in a plastic-film or glass greenhouse, it shields the crop from the weather to some degree. Since temperature and humidity can be adjusted to a degree, production is more stable than in the open field. In exchange, there are the construction and maintenance of the facility, and fuel costs.
- **vertical farm**: grown in an enclosed indoor space. Temperature, humidity, light, CO2 concentration and the rest are controlled artificially, building up an environment optimal for growth. Unswayed by the weather, it can produce stably throughout the year. In exchange, capital investment and the electricity bill mount up, and the knowledge to handle it is required.

As you move from the open field to protected cultivation to the vertical farm, the parts that were left to nature pass, little by little, into human hands. The vertical farm, at the far end of

that line, does not borrow from nature but has people make the environment itself. What I have done for more than ten years is this very end of it — the world where temperature, light, and humidity are all decided by us. Survey the open field and protected cultivation from the outside, and you see clearly that even the same "engineering the environment" is dealing with something entirely different.

The nature of the work: from feel and experience, to data-based judgment

The second axis is what you advance the day-to-day work by. When the way you grasp the environment changes, the capability demanded on the floor changes too.

- **open-field farming**: from soil-making to harvest, long years of experience and feel do the talking. There is much heavy labor, and the swing of seasonal busy periods is wide.
- **protected cultivation**: on top of open-field experience, the technology of environmental control inside the facility is required. Temperature management, ventilation, and irrigation become a steady piling-up of frequent observation and adjustment.
- **vertical farm**: automation by computer control has advanced, so there is less of the civil-engineering-style heavy labor of the open field. But much manual work remains — harvest, packing, final planting and so on. What moves to the center is reading the state of growth from data, catching odd signs early, and putting a move in. For that, analytical ability and IT skills are required, and a viewpoint that runs from production plan to shipment becomes necessary too.

What I don't want you to misunderstand here is that this is not a story of feel being unnecessary in a vertical farm. What data tells you is "what happened"; "why it became so" and "how to move next" are, in the end, the judgment of a human who has watched the vegetables on the floor. Only when there is someone who can re-read the latest sensor's numbers with the eyes of the floor does it become stable production. The biggest difference from the open field and protected cultivation is, I think, not the presence or absence of equipment itself, but that **this "ability to move back and forth between data and observation" becomes the center of the day-to-day.**

Understanding the distance between research and the floor

When I say "the ability to move back and forth between data and observation," you may think: then can I acquire it by studying with books and papers? Here a little care is needed. The vertical farm is work close to science. Light, HVAC, nutrient solution, environmental control. Take any of them, and none holds up without the accumulation of research. So while you are a newcomer, you get the urge to study by reading specialist books and papers. That itself is a good thing. When I was on the floor, too, I read quite a few books and papers on cultivation technology, hunting for any hint that might make the floor even a little better.

But there is one thing I want you to know here. **The "optimal" written in a paper is not the same as the "optimal" of a floor that ships thousands of plants every day.**

When you try to actually apply a cultivation method as written, it often does not fit well. The reasons are, broadly, three.

The first is that the cost viewpoint is missing. Even if it says "yield rose 20% under this condition," how much it costs to reproduce that condition in a commercial facility usually goes unwritten.

The second is the difference in scale. An experiment that handled a few to a few dozen plants in a lab, and a floor managing thousands of plants, differ completely in their premises. It is not rare for a method that worked when tried small to stop working the moment you scale it up.

The third is the difference in environment. A lab can align temperature, humidity, and light precisely, but on the floor the HVAC's capacity has limits, the environment goes uneven depending on the shelf position, and it takes on the influence of the outside air season by season. The "optimal conditions" on paper are hard to reproduce in a real vertical farm.

This is not a story of the researchers being at fault. A paper lives in a world judged by "is it academically new," and "is it usable on the floor" is, in most cases, not even within the scope of evaluation. So research that is scientifically valuable yet hard to use on the floor inevitably arises. It is a problem of structure.

So is studying a waste, then? It is not. Just read it knowing there is a distance. **Research fails if you bring it in as it is, and leaves you behind if you ignore it.** The right way to get along with it is in between. Read it, try it small on your own floor, and keep at hand only what reliably works. A single book changing the floor overnight almost never happens. You trial-and-error over years, and at last what you can call "this works" is what remains. Almost everything I can

speak of even now is what I forged that way, on the floor.

While you are a newcomer, it is enough just to know that "what you read is not necessarily usable on the floor as it stands." Read and decode it, try it, make it your own. This capability becomes, in the long run, the difference on the floor.

The three roles of a vertical farm manager

The profitability we have seen this far, and the distance from research too, take form only when, in the end, there is a person who bundles it all together and runs the floor. Let me lay out that role last. The roles demanded of a vertical farm manager split broadly into three. "Protecting stable quality," "bringing the team together," and "securing revenue." First, on the foundation of these three, grasp what kind of work you will shoulder from here on.

1. Protect stable production and quality

In a vertical farm, every environmental element — temperature, humidity, light, CO₂ concentration and the rest — is managed by human hands. Because these influence one another, change one and it ripples to the others. To keep shipping vegetables of stable quality every day within that complex environment — this is the manager's most basic role.

In a vertical farm just started up, this was, above all, the work that earned respect. The person who could "just grow them without letting them die" was the one relied upon. But on the PFAL leafy-green floors I have seen, the technology to grow them without letting them die has gathered quite a set of tools, and you can now harvest without leaning on personal artistry as much as before. So this role keeps running, always, as a foundation, but once the vertical farm starts turning, the manager's center of gravity shifts, little by little, to the next role.

2. Bring the team together

A vertical farm does not turn on one person. Most of the day-to-day work moves through the hands of the floor staff. Drawing out the ability of each staff member and keeping the day-to-day work turning is the manager's job. It includes passing knowledge of environmental control and cultivation on to the staff, and increasing the number of people who can judge on their own.

As people increase, this role suddenly grows heavy. Rather than growing them yourself, you have no choice but to move to the side that arranges "how people grow." At the large vertical farm whose startup I was part of, the floor staff reached a scale of 100 people, and getting it so that good quality and bad could be judged by everyone in alignment became, in itself, a major challenge. Not one person's feel, but bundling the knacks scattered across the floor into a form that stays even after someone quits. The more a person holds experience as raw feel, the more they get stuck on whether they can put it into words and hand it over.

3. Secure revenue

Draw up the production plan, manage costs, work out the sales strategy. Read the market's needs, keep taking on new challenges. A vertical farm does not last on dreams and ideals alone. If you cannot secure revenue, the floor does not last either.

Here is something I want to say honestly. What decides the size of the profit and loss itself is, usually, outside the manager's hands. At what scale you can make, how much you can harvest, at what price it sells, where it sells — these four already fix the rough shape of profitability. Unit prices like the electricity bill, and the swapping out of equipment, are not at the manager's sole discretion either. So is the manager powerless? Not quite — within the frame fixed from outside, there are parts you can move through how you arrange the day-to-day running. Reduce the amount you throw away, raise the proportion that meets the standard and sells at the proper price, raise the skill of the workers. Without touching the equipment, how the profit and loss looks changes right there. The step-deeper judgments — how far to tighten which value, where to sell, when to invest — I leave to later chapters and to "172 Hints," but as an entrance, hold here at least the eye to look separately at "the part fixed from outside" and "the part you can move through running."

The center of gravity of the roles moves with the vertical farm's stage

These three are less a parallel list than something where, depending on the vertical farm's stage, which one weighs heaviest swaps around. In the startup phase, "growing them to completion stably" earns the respect; once on track, the center of gravity shifts to "how to tighten profitability"; and as people increase, it leans toward "how to hand down the floor's knowledge." Though the title is the same, the substance you shoulder gradually changes over. This is less the person's own growth than something closer to an order: the vertical farm side

puts out the next problem, and the substance that responds to it changes.

That said, what moves is the "emphasis"; it is not that any role ever appears that you may leave alone. Stable production, team-building, and revenue all keep running at every stage without stopping. With hygiene in particular, once pests or disease appear they can spread across the whole vertical farm, so prevention — keeping them from multiplying and from spreading — is always required.

What I want you, the newcomer, to grasp is this time axis. The skill demanded at this very moment is no more than a snapshot of the stage the vertical farm is now in. Don't measure your own experience and strengths by the "current role" alone; read them by "which role grows heavy a few years from now." See it that way, and whatever role you come to bear from here on, you should be able to take it on without being thrown.

Chapter 1 summary

- A vertical farm is a different thing depending on whether it is the "greenhouse type" or the "full PFAL." What this book deals with is the world of the full PFAL, of leafy greens.
- Against the backdrop of worry over food security, it is drawing fresh attention right now. But the scenery of profitability changes depending on where, and by whom, it is seen.
- See the red not by sign but by slope. What moves profitability is the three of electricity, sales channels, and frontline capability, and a challenge has a "ceiling layer" and a "reach-rate layer."
- Industry numbers and news, even while they speak of "the industry," do not speak of "your own block." Re-divide by type and crop, and use them to read the direction of the premises.
- Vertical farms that make money are not a winning pattern but a "bundle of conditions." More than the newness of the equipment or the scale, what counts is whether you read the bundle all the way through and there is a floor that runs it.
- A vertical farm differs at the root from conventional agriculture, and "the ability to move back and forth between data and observation" becomes the center of the day-to-day.
- The manager's roles are the three of "stable production," "team-building," and "securing revenue," and their center of gravity moves with the vertical farm's stage.

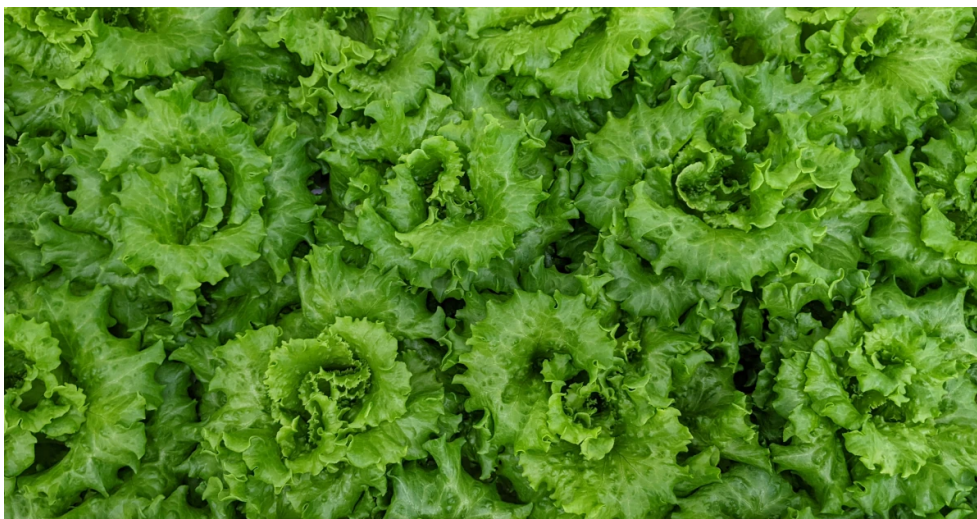
- The step-deeper judgments tied directly to revenue go to later chapters and to "172 Hints."

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

Chapter 2: The Fundamentals of Crop Management

In the previous chapter, we looked at the big picture of the vertical farm—how it works, what it can do, and what makes it hard. Now we take a step further into the knowledge you actually need to grow vegetables. Choosing the crop, giving it light, balancing water, air, and nutrients, spotting trouble and acting on it—we will walk through, in order, the things we do on the floor every day. Each of these may look like a separate topic, but on the floor they are all connected. Keep that in the back of your mind as we start with the very first question: what to grow.

What are the keys to choosing the right crop for a vertical farm?



Because a vertical farm controls its environment artificially, in theory you can grow almost anything. But once you try to actually turn a profit on the floor, the crops you can realistically choose narrow sharply. Of all the things I found strange while visiting one farm after another, the strangest was this: even when two farms grow the same lettuce, it is not unusual for one to be in the black and the other in the red. What ultimately decides whether profit remains is not the name of the vegetable.

The "profitable vegetable" is not decided by the crop

Search "vertical farm profitable vegetables" and you will find endless rankings: lettuce is best, no, strawberries, no, melons. The more you read, the more you start to feel the right answer is lying around out there somewhere. But there is no guarantee that answer holds at your own

site. Even with the same lettuce, profit appears or vanishes depending on where you sell and how you run it.

I have seen this happen with lettuce many times. Sold through a farmers' market, it turned over reliably; the moment I tried to wholesale the same thing for foodservice, the unit price collapsed, and I was busy but had nothing left in hand. The reverse happened too: an herb I could only produce in small quantities, carried directly to a restaurant, turned out surprisingly profitable. Line these up, and what is profitable is not the crop itself but the crop paired with where you sell it.

A profitable vegetable, then, is less a fixed list than something you read off **the product of three things: the sales channel's unit price, the cycle time, and the difficulty of growing it**. Lettuce was exactly this. Through a farmers' market you can command a high unit price, so fast turnover translates straight into profit. Pushed into foodservice, the unit price drops, only the turnover remains, and no profit stays in hand. With the same equipment, the sales channel decides unit price and turnover, and on top of that lands the labor of cultivation. So the question is not "which vegetable" but "given my sales channels, for which crop does unit price × turnover justify the cultivation labor."

In fact, the crops on which a vertical farm can pencil out are confined to a narrow range: leafy greens and herbs at the center, with fruiting vegetables only under the right conditions. Staples like rice, wheat, and corn—despite being core crops that account for roughly 60% of the world's food energy—are reported to have no prospect of clearing the break-even line at all under current costs and technology. What is profitable is not a property fixed to the crop; it is dragged along by whether that crop can secure a sales outlet that delivers unit price and turnover.

Lettuce is common because it "fails less catastrophically"

Look around real vertical farms and most of them are lettuce-centered. Even among leafy greens it is lettuce, lettuce, lettuce, with barely a hand laid on fruiting vegetables. This is not because lettuce is the most profitable—it is because lettuce fits the factory format best. What matters here is the "difficulty of growing it" term from the earlier formula.

Lettuce has a short growth period and fast turnover, is short enough to stack in tiers, and its light and nutrient solution management are well established. In other words, in a closed

environment you can run it with high reproducibility, on schedule. Fruiting vegetables are not like that. Tomatoes and strawberries require control of pollination and fruit set, take a long growing period, and grow tall. For the same floor area and energy bill, the cultivation labor is far heavier.

There is one more side to "difficulty" that I have felt strongly on the floor. Lettuce does not easily collapse into catastrophic crop failure even when your temperature or nutrient solution concentration is somewhat off. Growth unevenness is also relatively small, and the learning cost to get it up to shippable quality is lower than for other crops. This matters when you picture the kind of people who come into vertical farming. At the sites I have helped launch, newcomers from other industries were very common—people who do not know plant physiology in their bones, coming in carrying a large capital investment. From that position, "we cannot afford to fail" comes first. Choosing lettuce first—which does not collapse even when your hands slip a little, and has a low learning cost—was a perfectly natural judgment, aimed less at maximizing profit than at avoiding ruin.

So the lettuce-centered scene is not the profitable answer; it is the result of choosing the solution least likely to collapse in the factory format. Put the other way around, for a grower who can manage the difficulty of fruiting vegetables, or for someone who holds a sales channel that stands precisely because it is fruiting vegetables, there is room left outside that uniform row. Keep in mind that there is a reason a newcomer starts with lettuce.

Why rice, wheat, and root vegetables are not on the shelves— $\text{area} \times \text{days} \div \text{unit price}$
Conversely, why don't you see rice, wheat, daikon, or carrots in a vertical farm? Not because you can't grow them. Technically, root vegetables and grains will grow in a factory. And yet they almost never reach the market. The reason lies somewhere other than whether you can grow them.

A vertical farm's costs mostly come down to **area and time**. Lighting and HVAC are like rent that charges you for as long as you occupy a given shelf area, and what matters is how many days that area stays occupied and how much harvest comes out of it. Lettuce is short, light, and turns over in about 30–40 days. Root vegetables take many months to bulk up and have a low unit price relative to their weight and volume. Carrots need roughly 70–120 days from sowing to harvest. The same area is occupied for one month in the one case, three to four

months in the other. From that alone you can imagine how far apart "how much you earn per area per day" pulls. So root vegetables are not held back because the technology hasn't caught up; they are quietly dropped at the spreadsheet stage.

With grains this comes out most starkly. Rice, wheat, and corn have low unit prices, long growing periods, and are tall and hard to stack in tiers. They go against the factory-friendly conditions on all three counts. There is a telling estimate: even in a best-case scenario of growing wheat in a vertical farm in Sweden, the electricity cost alone was put at the equivalent of \$40,000 per ton—roughly 100 times the world wheat price at the time. This is not a problem of cultivation technology; the contest is over at the division stage. You may want to wait for technology to make it cheaper eventually, but in the data, an industry-wide trend toward getting cheaper the more you produce is almost nowhere to be seen.

Root vegetables hit one more wall before profitability even comes up. Carrots and daikon send a thick, straight root deep into the ground, yet today's mainstream vertical-farm equipment is built for leafy greens—a thin floating raft and recirculating nutrient solution. The medium lacks the depth and the support, and once the root zone fills with solution, oxygen tends to run short too. For someone designing a new line, root vegetables drop out at the profitability division first, so the discussion never reaches the equipment; for someone who already has leafy-greens equipment and thinks "let's grow root vegetables on the empty shelves too," the root won't fit the equipment even before profitability comes up. Which wall comes first depends on where you are standing. To state my conclusion from the floor honestly, it settles on the obvious: root vegetables are best grown in soil.

There are exceptions, but only when the conditions are met

Even the crops I've called "ill-suited" so far have exceptions. But an exception passes only because some condition was met, and you cannot necessarily carry that whole condition over to your own crop.

One direction is the exception that **earns through turnover**. Microgreens (the seedling leaves of vegetables) are extremely fast, just 7–14 days from sowing to harvest. Compared with lettuce's 30–40 days, you can turn the same area over many times a year. The per-gram unit price is also easy to set high, and there is a growing move to differentiate them as functional foods enriched with nutrients. If you are building new, they are well worth considering. But

dropping them straight onto an existing lettuce factory is not easy. The harvest workflow on shelves stacked as high as ten tiers—whether you pull out the medium and all, or have workers cut on the upper tiers—is something entirely different from lettuce. If you are going to do it seriously, the realistic approach is to plan dedicated transport and harvest equipment from the construction stage.

The other is the exception that **earns through unit price**. As long as the unit price per area per day is high enough, even a slow-turnover crop can make it onto the shelf. Extremely high-value root vegetables like medicinal ginseng, and wasabi, are examples. Wasabi has a high unit price, is scarce, and is popular overseas too—putting the name on the list is correct as far as it goes. But here you have to be careful. My read is that wasabi's high unit price is not attached to the crop wasabi itself, but to a relationship with a buyer: this producer, from this region, delivers this quality reliably. The very buyers who pay well—high-end restaurants, sushi shops—already have established suppliers and won't easily switch to some new grower they've never heard of. So the moment a newcomer manages to grow wasabi, all they hold is the crop portion of the reason for the high price; the crucial relationship has to be built from zero. And because the high-paying outlets don't absorb volume, the calculation that figures annual revenue from "unit price × expected shipment volume" usually misses. Being able to grow it and the business actually turning over are two different stories.

Rice is the same: "impossible" is not uniformly impossible everywhere. Land where electricity is absurdly cheap, a buyer nearby who pays well, an outlet like pharmaceutical raw material that sells for several times the normal price—how far these three line up changes how it looks. Cases where factory rice cultivation succeeded overseas usually presuppose a location that is water-scarce and cheap on power—the opposite, if anything, of Japan. What looks like a story about technology is often really a story about location.

First, lay out your own sales channels

Where to start, then? Not from the crop. Rankings and success stories are useful for reference, but you can't turn them straight into a blueprint. Information out in the world is biased toward stories that went well, and data on farms that pulled out hardly survives at all. In fact, a considerable share of Japan's PFALs are said to have folded within about a decade. Behind the successes that surface lies a fair amount of unspoken withdrawal.

So the first thing you put on paper is not a crop schedule but a single line of arithmetic—and that's fine. Take the same shelf area as your basis, work out "assumed selling price ÷ days occupied," set lettuce as the benchmark, and line up the candidates in the same table under the same conditions. Write in the cycle time, the difficulty of growing, the yield, and even the labor of maintaining the sales channel, then compare them by annual profit per area. That is your first move. The way to arrange it is to set fast-turning, easy-to-read leafy greens at the center, and consider fruiting vegetables and high-unit-price niches second. Fruiting vegetables and wasabi do have room on unit price, but they only stand once the conditions line up, so the realistic order is to firm up the base numbers with leafy greens first, then layer the rest on.

Talk of new crops is fun, and what's possible grows year by year. But it comes alive only among crops that have passed through the gate of profitability; place it before the gate and it becomes a detour. What suits and what doesn't is read not from a crop ranking but from this sales channel's unit price × turnover × difficulty, and how much you earn per area per day. Keep just that eye, and the next time a new crop appears, you can start from the first sheet of paper without panic.

That said, from here on—which crop pencils out for which sales outlet, how to go after high-unit-price outlets, whether a switch to fruiting vegetables justifies the investment—is a discussion that steps into profitability design itself. In this book I stay at the entrance to the way of thinking, and leave the deeper judgments to *172 Hints to Improve the Profitability of Vertical Farms*.

Once the vegetable is decided, next comes how to grow it. The three pillars of growing vegetables in a vertical farm are light, water, and air—and we start with light, the most emblematic equipment of a vertical farm.

Making the most of LED lighting



The most emblematic equipment in a vertical farm is the LED lighting lined up row upon row. Conventional agriculture had no choice but to rely on sunlight, but in a vertical farm you can create an optimal light environment for growth artificially with LEDs.

Three benefits LED lighting brings to a vertical farm

1. Energy savings cut costs

Electricity is a cost a vertical farm can't ignore. Because LED lighting has excellent energy efficiency, you can expect a meaningful reduction in the electricity bill.

2. Long life eases maintenance, too

Fluorescent lamps need periodic replacement, each time costing money and effort. LEDs last far longer and reduce how often you replace them. In a vertical farm that uses a large amount of lighting, this cost difference is significant.

3. You can choose the color of light to match the plant

Plants need different light wavelengths (colors) depending on species and growth stage. LEDs come in many wavelengths—red, blue, white, and so on—so you can choose to match the crop you're growing. Conventional vertical farms mainly used LED lighting that combined red and blue light, but in recent years white LEDs closer to sunlight have spread as well.

Knacks of installation and operation

To draw out an LED's effect, fine touches like the installation method and the lighting duration matter too.

- Multi-tier cultivation: to make effective use of limited space, it's standard to stack cultivation racks in many tiers—"multi-tier cultivation."
- Angle and distance of illumination: by adjusting the LED's angle and the distance to the plant, you can raise photosynthetic efficiency.
- Lighting duration: plants grow by repeating a "light period," when they photosynthesize, and a "dark period," when they respire and translocate nutrients.

"Brighter isn't always better"

Talk about LEDs and you naturally start to think the stronger the light, the better it grows. I thought so too when I was new. Make one tier of a rack boldly bright and, sure enough, the harvest goes up. Weight and appearance improve. Brighter really was the right call, you get to think—until you see the electricity invoice at month's end. You raised the light 1.5×, but the yield didn't go to 1.5×. Subtract the added electricity cost from the added sales, and what's left in hand is actually thinner than before. Months like that start to show up. Running PFAL lettuce hydroponics myself, I've seen plenty of cases where pushing the light harder left the take-home thinner.

What you want to know here is the term PPFD, which expresses the quantity of light. Think of it as the amount of light particles reaching the leaf, and that's enough. The crucial point is that the PPFD–yield relationship is not proportional. From a weak starting level it climbs sharply at first, but the more you raise it, the smaller the gain from making it still brighter. The electricity cost, meanwhile, rises in almost a straight line with the light. So the added sales dull off gradually, while the added electricity cost rises straight. Somewhere a point arrives where the electricity cost outweighs the return on the added light. That is the place to stop strengthening the light.

The tricky part is that this stopping point doesn't settle on a single number. When electricity is cheap, a strong setting looks plenty positive; as the unit price rises, the same setting suddenly turns heavy. Same shelf, same variety, same light, and yet from month to month "this is right" and "this is overdoing it" swap places. So memorizing one optimal PPFD figure and pinning it to the wall is no way to get along with it. Light is something whose stopping point moves with the electricity cost—holding that view is a sense worth acquiring while you are still new.

Stepping into dynamic management that re-derives the optimal PPFD from the power unit price, and the judgment of selecting fixtures by luminous efficiency, takes you into a deep topic tied directly to profit. How to make that call is covered in detail in *172 Hints to Improve the Profitability of Vertical Farms*.

Light

The LED is merely a tool for making light. What truly matters to the plant is what kind of light that tool delivers, at what strength, and for how long—that is, the content of the light itself. Since the previous section was about machinery, here we step back a little and pin down the basics of how a plant receives light. It's not a difficult story. Light has three dials—strength, color, and time—and the product of those three decides the day's quantity of light. Hold that, and it's enough.

Strength—stronger isn't necessarily better

First, strength. Light is essential to a plant's growth, but it isn't the simple case that the stronger it is the more it grows. Past a certain point the gain in photosynthesis plateaus, and strengthen it further and the leaf gets damaged, swinging into the negative. In a PFAL, where you are buying light back with electricity, there's also the problem that the electricity for any light beyond what's needed is simply wasted.

So the basic rule is to choose LEDs to match the strength the crop wants. Fruiting vegetables that set fruit want strong light, but leafy greens like lettuce don't need light that strong. They are short and grow even under weaker light. This is one more reason leafy greens are favored in a vertical farm.

Color—plants have wavelengths they can put to use

Next, color. Light changes color with wavelength, and plants put each color to a different use. Roughly speaking, red light (about 600–700 nm) is the most effective for photosynthesis and drives growth. Blue light (400–500 nm) is also used in photosynthesis and works to thicken the leaves and firm up the stems. Green light (500–600 nm) is said to be less effective for photosynthesis, but it reaches deep into the leaf and is thought to be involved in shaping the plant as well. So the older vertical farms mainly ran the very "vertical-farm-looking" purple light

of red and blue alone, but in recent years ones that include green, and white LEDs closer to sunlight, have increased.

I, too, have used many kinds of LED, and growth looks better to me under types with green added, or close to white, than under the red-and-blue-only type. The hands-on impression is that leaf color, gloss, and form come out more honestly. Discerning which colors to blend, and how, to benefit a given crop is a deep topic tied directly to cost, so here I'll just leave the entrance: color has differences in use.

Time—the time you make it bright, and the time you make it dark

The third is time. It isn't the case that you should just keep the light on all day. Plants grow by repeating a "light period," when the light is on, and a "dark period," when the light is off. In the light period they make nutrients by photosynthesis, and in the dark period they send those nutrients throughout the body for growth—a respiratory rhythm of earning by day and settling up by night. How many hours a day you illuminate—this design—is called the photoperiod.

In a PFAL, unlike under the sun, you get to decide the bright hours yourself. This is a powerful advantage, but it also means you have to decide. Illuminate longer and you bank more photosynthesis time, but the electricity bill mounts, and if the dark period is too short it can throw the plant off. So a judgment arises about where the setting benefits both the crop and the bottom line. Stepping into discerning that optimal point takes you into profitability design, so in this book I keep to the basic: you need both the time you make it bright and the time you make it dark.

The day's quantity of light—DLI, the three multiplied together

Finally, just one idea that ties the three together. Multiply strength and time and you get the total quantity of light the crop received in a day. This is called DLI (daily light integral).

There's no need to overthink it. Weak light, given for a long time, still raises the total; strong light, if only briefly, won't push the total up. How much light a plant received in a day is decided neither by the instantaneous brightness alone nor by the on-time alone, but by their product—a perfectly obvious point. The reason "I strengthened the light but it didn't grow as much as I expected," or "I trimmed the lighting time but it didn't drop that much," happens on the floor is often that we reflexively look at strength alone, not at the day's total. Hold strength,

color, and time as three separate dials, and at the end read it off the day's total. As the basics of light, keeping this view at hand is enough to start.

If light is a story that completes itself above the plant, then next is a story at the plant's feet—the water its roots are soaking in. In a vertical farm, that water becomes the very foundation of cultivation.

The hydroponics system



Alongside lighting, the defining feature of a vertical farm is hydroponics. Instead of soil, you grow by placing the roots directly in water and nutrients. This is why you can grow fast and uniformly, and also the part that takes the most daily care on the floor.

Why hydroponics in a vertical farm

Doing without soil pays off in several ways. With no soil needed, you aren't tied to location—you can grow even in cities or on land with harsh conditions. Because the roots are always in contact with water and nutrients, growth is fast and turnover rises. You also lower the risk of pests and disease carried through soil, and you aren't chased by daily watering—manage the nutrient solution's concentration and volume and it can be supplied automatically.

One commonly misunderstood point, up front. People often say hydroponics doesn't get root rot easily, but this is conditional. As long as the dissolved oxygen (DO) in the water is kept sufficient, the roots take in fresh oxygen and stay healthy. But if oxygen runs short, root rot happens even in hydroponics. In particular, as the water temperature rises, the oxygen that

can stay dissolved in that water decreases. So keep in the back of your mind that it's not safe because it's in water, but safe because oxygen is sufficient.

NFT and DFT—flow it thin, or pool it deep

The two commonly used in vertical farms are NFT and DFT.

NFT (nutrient film technique) fixes plants in a sloped grow bed and keeps a thin flow of nutrient solution running over them with a pump. Because it's flowing, oxygen reaches it easily, and the volume of nutrient solution used is small. The flip side is that, with so little water, it's easily affected by outside conditions and the water temperature changes readily.

DFT (deep flow technique) pools plenty of nutrient solution in a tank-like cultivation channel and floats the plants on it. With a large volume of water, it's strong against temperature swings and easy to grow stably. The flip side is that the equipment gets large, and oxygen tends to escape near the bottom.

Both belong to the recirculating family that runs the nutrient solution around with a pump. Besides these, DWC (deep water culture), which steeps the roots deep in water, can be treated as essentially in the DFT family in that it pools water. Aeroponics, which mists the roots, has the most abundant oxygen because the roots are exposed to air, but since it pools no water it dries out fastest of all when it stops. It suits a limited set of sites that can build in fairly thorough provisions for noticing the moment it stops.

It's not "which one is superior"

When building anew, or reconfiguring, the first thing you usually run into is "NFT, or DFT?" Look up a comparison table and each item has a circle by one or the other, and the totals come out roughly a draw. I've seen many people stall on this for days. Let me say it plainly: there's no absolute superiority to the method itself. Watching lettuce for years, when I traced the cause of wobbling yield or quality, nearly every time it was not the method but the state of the water that day. Root rot in NFT isn't the method's fault—it's that the flow dropped and the root tips dried out. Weakening in DFT isn't the method's fault either—it's that the water temperature rose and oxygen escaped. Whichever you choose, in the end it comes down to the water management that follows.

So how do you decide the method? You can be straightforward about it: it's decided by the constraints at hand. If you want to ride out a few minutes through a power cut or a failure, and you want the water volume as that insurance, lean DFT. If you want to add shelf tiers and keep them light, and keep the plumbing simple, lean NFT. It's a range decided almost automatically by scale and the width of risk you can tolerate. It's not a fork worth agonizing over for days. The time you'd spend agonizing is better spent on the water management after you've chosen—it pays off far more in yield.

Reversible or irreversible—the line that really matters in hydroponics

Grasp the difference between NFT and DFT along one axis and the management that follows gets much easier. That axis is "reversible or irreversible."

Something that drifts but, once you notice and step in, returns to the band so the roots recover—this kind of **reversible** thing is one you catch on the operations side. DFT's bottom oxygen thinning, the water temperature rising—these you look at daily and pull back when they stray. It's a job of people and records.

On the other hand, when an NFT flow stops and the root tips dry out, that drying doesn't come back. A tip once hit doesn't return even if you restore the water. This is **irreversible**. Daily visual checks alone can't block it, so you have a machine detect the stop and fire an alert, and with emergency power or a backup pump, you crush the stoppage itself in advance. It's a domain you erase on the equipment-and-provision side.

The line is drawn like this: **catch reversible things on operations; don't load irreversible things onto operations—erase them in advance with equipment and provisions**. The reversible drift that creeps in, a person watches; the irreversible failure that strikes suddenly, machines and provisions stop.

One thing to add: reversible-or-irreversible is not a label stuck to the method. Even with NFT, if you have a setup that tells you instantly when it stops, that speed takes the fear out of it. And even with DFT, if you leave summer's high water temperature or stagnation unattended, the plentiful water now turns into warm water that won't cool, and the roots rot—the strength of having water volume flips on you if you don't watch. So you can't flatly say DFT is safe because it has water volume. What moves the boundary is not the attribute of the method but the width of the drift, and how long you left it.

This "after you've chosen, what do you look at daily, and how"—in what order you look at flow rate, water temperature, and dissolved oxygen, and where you draw the line between fine and bad—is what truly separates yield. That is worked out concretely in *172 Hints to Improve the Profitability of Vertical Farms*.

Once the water comes into view, what is inseparable from it is the air filling the space around the roots and the leaves. Temperature, humidity, CO₂, and the wind that carries them—from here we move on to the air surrounding the plant.

Temperature management

Temperature management is one of the most critical items, and it largely determines a vertical farm's success.

Plants have a temperature band suited to their growth. Stray from it and it shows—slower growth, poorer leaf color, and in bad cases, death. In fruiting vegetables it can produce misshapen fruit, and as vigor declines, resistance to pests and disease weakens too.

Optimal temperatures by crop

A vertical farm is less affected by outside air and can hold a steady temperature. Rough targets by crop are roughly as follows.

- Leafy greens such as lettuce: prefer a relatively cool environment, around 15–25°C
- Fruiting vegetables such as tomatoes: prefer a warm environment, around 20–30°C
- Herbs such as basil: around 20–25°C, though some prefer heat and some stand up well to cold

Temperature management matched to the type of vegetable and its growth stage is the basis of stable production.

What you manage is the air; what the plant responds to is the leaf

Here, let me slip in a distinction that pays off when you're stuck on the floor. What we set and manage is the cultivation room's "air temperature." But what the plant actually responds to is the "leaf temperature."

Normally these two roughly agree, so it runs without distinguishing them. The distinction surfaces when growth won't even out across shelves even though you're holding the setting

properly—when, for example, growth differs between the top and bottom tiers of the same rack. At first you'll suspect how the air hits, or the distance to the LED, but there's one more factor: the upper tier tends to trap heat from the lighting. LEDs are called energy-saving, yet a considerable share of the power consumed leaves as heat. So even at a 25°C setting, the leaves themselves on the upper tier, close to the lighting, can run hotter than the air.

Why does leaf temperature matter more? Because both photosynthesis and respiration are enzyme reactions, and what sets their speed is not the air but the temperature of the leaf itself. Even at the same 25°C setting, if the upper-tier leaf is actually 27°C, then for that leaf the temperature is no longer 25°C. The setting is uniform yet growth is uneven—that often takes this form: you've made the air uniform but not the leaves.

What HVAC can directly move is the air, so it becomes a two-stage setup: you watch both, with air as the input and the leaf as the result. Point a radiation thermometer at the upper- and lower-tier leaves and actually measure how many degrees they differ from the air setpoint, and the quirks of your own shelves start to show up in numbers. Incidentally, this gap is large by day when the light is strong, and small at night when the lighting is off.

Lowering the night temperature is for "tightening"

In a vertical farm you can create day and night artificially with LED lighting, so you can steer growth using the temperature difference. Here "day" means the light period (lighting on) and "night" the dark period (lighting off), and the temperature difference between the light period and dark period is called "DIF."

At night the lighting is off, so leaf temperature and air temperature roughly agree. There's nothing like the daytime case where the heat from the light source lifts only the leaves. The trouble is that you end up lowering that night temperature on a vague sense that "night is for cooling down," while the reason for lowering it doesn't quite sit right.

It clicks once you think it through from "what is night the time for?" By day the plant takes in light and makes sugar by photosynthesis; at night, with no light, it can't make new sugar and respire on the sugar it banked by day. This respiration runs faster the higher the temperature, so cooling the night curbs that consumption of sugar overnight.

One thing to watch here: don't naively equate "curb consumption" with "that much more remains and grows." In reality, the colder you make it isn't the more it grows. In leafy greens it

tends to come out the other way: warmer (up to a certain range) actually grows better. So what is the point of lowering the night temperature? Less to boost yield than as a quality-side adjustment: curbing leggy growth and tightening the plant. If you don't lower the night temperature enough, the stems tend to stretch and the form falls apart. So it fits the on-floor feel better to treat the night temperature as a lever that tunes the tightness of growth rather than one that earns the amount of growth.

And it isn't the case that the more you lower it the better, either. Lower it too far and leggy growth stops, but the pace of growth also slides onto the dulling side. The night temperature is settled by the balance between tightening and growing properly. For lettuce, around 18°C at night is one example of that compromise.

The criterion for the setting is, in the end, the state of the crop

Midsummer tends to run hot, and HVAC power weighs heavily too. You want to raise the setting even 1°C to ease the burden, but you can't say for sure what it will do to growth, so you can't touch it—this is a common summer-floor stall. In fact, that 1°C works in completely different directions depending on whether you raise it by day or by night, and breaking up temperature unevenness ends up being the wind's job after all. The judgment behind such active operation is a theme in itself, so here I keep to the entrance of the way of thinking: air and leaf are different; the night temperature is for tightening.

When you weigh the cultivation-room temperature, the criterion for the setpoint is, in the end, the state of the crop. Rather than tracing a table of correct setpoints, you read—at your own site—the gap between leaf and air temperature, the day–night difference, and the look of the leaves and roots, and judge whether it fits. We who set the temperature are asked for the observational skill to read the plant's state correctly. The deeper operational talk—how to move that day–night 1°C, how to judge the gap and the day–night difference—is covered in *172 Hints to Improve the Profitability of Vertical Farms*.

Inseparable from temperature is how much water the air holds—humidity. At the same temperature, the leaves' condition changes completely with humidity.

Humidity management

Alongside temperature, humidity is indispensable to manage. Plants release water from their leaves through what's called transpiration, and that flow carries the water and nutrients drawn up by the roots throughout the body. Humidity bears directly on this transpiration.

The 60% on the hygrometer changes its meaning with temperature

At a PFAL factory, the common operation, I imagine, is to hold the room temperature roughly constant and keep using dehumidification to suppress the moisture rising up from the hydroponics. You watch humidity as a range, aiming for 60%, and as long as the hygrometer settles around there, well, it's probably fine.

But haven't you had this experience? At the same 60%, the look of the plants is somehow different from day to day. The leaves have crispness on some days, less on others. And yet the hygrometer number hasn't changed.

This is probably not your imagination. The 60% on the hygrometer is a percentage: of how much water the air can hold at that temperature, what fraction is filled right now. Because it's a percentage, when the temperature moves, the remaining capacity the air can still take changes even at the same 60%. Warm air can hold a lot, so even at 60% there's a large remaining capacity to absorb. When the room temperature drops, the full-tank amount itself shrinks, so even at the same 60% there's little capacity left to absorb.

From the leaf's view, this capacity the air can still absorb is exactly the pull strength with which water can be released as transpiration. This is what's called **VPD (vapor pressure deficit)**.

On a day with a higher room temperature, the plants looked in good shape because the air's pull was working, transpiration was turning over, and nutrients rode that flow to the leaf tips. The day when "it's 60% but it feels sluggish today" is the day the room temperature dropped, the pull weakened, and even though the leaf wanted to release water it couldn't release fully, so things were a bit congested inside—seen that way, it roughly adds up.

In other words, while you thought you were watching the hygrometer, what was really at work was the pull strength that, behind it, was set in tandem with temperature. The relative-humidity percentage is one cross-section of the result, a different thing from the continuous axis the plant is feeling.

Dehumidification and room temperature move one pull from different sides

Once you get this far, one view changes. You've managed "room temperature constant, humidity 60%" as two separate knobs, but from the plant's view, dehumidification and room temperature aren't two separate things—they move the same single axis (that pull strength) from different sides. Lower the humidity or raise the temperature, and the air's remaining capacity to absorb widens. From the leaf's view, either operation moves in the direction of strengthening the pull.

They aren't interchangeable, though. Temperature moves not just the pull but the plant's metabolism itself—the speed of growth, respiration—along with it. Dehumidification touches the pull alone while leaving that relatively untouched. They act on the same axis, but the range they drag along is different. So if your aim is the single point of pull strength, you ordinarily match it with dehumidification, which doesn't bring extras along, and leave temperature as the final margin—that's the order.

Let me draw one honest line: what I've confirmed in my own body is only the range of leafy greens in a PFAL. The broad framework that dehumidification and temperature act on this single axis has settled in for me there, but exactly which VPD it's best to run at must change with crop and growth stage, and that's not something I can assert.

VPD can be read with the two instruments you already have

Once the pull-strength axis comes into view, you might think, "so do I need a new instrument?" The answer: no. Since VPD is a quantity determined by temperature and humidity, the two on the wall—a thermometer and a hygrometer—already put it within reach. Whether you look it up on a chart or compute it with a conversion formula, the value that comes out is the same. Less a new machine than a matter of rereading the two numbers you already have as "pull" rather than "percentage."

If anything is lacking, it's not the instrument but where the pull is. The wall thermometer and hygrometer usually measure the air in the middle of the room. But the pull was about what the plant—the leaf—is feeling. When the plants stand packed and the leaves grow dense, the air inside that thicket feels different from outside. Put your hand in and it's a bit stuffy. Within the same room, spots of strong pull and weak pull coexist. The single point in the room only shows their average.

Why humidity management matters—the pitfall unique to a closed space

A PFAL factory is less affected by outside air, but being a closed space, moisture tends to build up. On the pull-weakening side—that is, the side where humidity is too high—there are several things you want to stop.

First, **condensation**. Water the air can no longer hold comes out as droplets on cooled walls, equipment, or leaves. A spot where condensation forms easily becomes a home for mold, and droplets on leaves let pathogens multiply too. It can also lead to electrical shorts and metal corrosion. The microbes themselves are everywhere and can't be reduced to zero. So the aim is not to keep them out but to **not increase them, not spread them**—through condensation or stuffiness. It comes down to not creating poorly ventilated dense planting, or conditions prone to condensation from sudden room-temperature swings.

The too-high-humidity side is also the entrance to **leggy growth**, where the plant stretches up thin and lanky (leggy growth is dealt with in the latter half of this chapter). Conversely, the too-strong-pull side has its own pitfall, and that is the tipburn story next.

Distinguishing it from tipburn—the same "tip dieback," but the cause is opposite

The first trouble the floor runs into around humidity is usually **tipburn**, where the leaf tip withers and crisps. And it's not the old leaves but the tip of the newest, most vigorously growing leaf that gets hit.

Given the pull discussion, a distinction becomes necessary here, because tipburn appears whether the pull is **weak or strong**. From the look of the symptom alone, you can't tell which side it was hit from.

The true nature is, in short, calcium not reaching the leaf tip. Calcium is carried on the transpiration flow and, once delivered, doesn't move from where it arrived—a settled-in nutrient. So the deficiency shows up first at the newest leaf tip, which is the farthest away and wants it the most. The mystery of the most vigorous leaves being the ones hit is simply that their demand is the greatest.

On top of that, the two sides split into opposite causes.

- **The weak-pull side** (a stuffy spot deep in the thicket)—the flow itself doesn't arise, so calcium can't be carried. It's a jam with the exit closed.
- **The too-strong-pull side** (a period when the wind hits, things tend to dry out, and growth is shooting up)—the leaf as a whole is releasing water, but growth is faster still, and the

calcium is used up on the body side before the flow reaches the tip. The flow exists, but the extremity is left behind—a kind of distribution shortfall.

The end result, calcium not reaching, is the same, but whether it's clogged or out-distributed, the cause is opposite. So when you make a first guess, rather than read the symptom itself, you look together at where it appeared and which way the pull was running at the time. If it appears on a day when the inner row, where air gets stuffy, is generally sluggish, suspect the weak side; if it appears during a burst of growth where the wind hits, suspect the strong side—that sort of thing.

Note that, since it's a problem of how calcium is distributed, simply making the nutrient solution's calcium more concentrated still won't get it to the young inner leaves—keep that in mind. The delivering flow matters more than the total amount. The intricate countermeasures against tipburn itself are dealt with again in the latter half of this chapter.

A first move you can make tomorrow without adding a machine

If, having read this far, you want a first move you can make tomorrow without bringing in a new machine, I'd start by putting a hand into the place where the pull seems weakest.

No tools needed. Put your hand into the most overgrown, stuffiest-looking inner row. Is it sluggish and stuffy compared with outside, or is the air actually moving? That alone lets you feel, on your skin, where the weak spots in your room are. The wall numbers only tell you the room average, so go find by hand the places left behind by that average. And once you compute the VPD from the current temperature and humidity, roughly where you're running right now comes into view as a number too.

Once you've found one, next is wind. Without bringing in a new machine, try slightly changing the direction or arrangement of the fans already running, to see if you can push air into that depth. If the stuffiness clears, the pull at the weakest spot moves closer to the room average, and the unevenness shrinks.

Incidentally, when summer comes, the question "can't we lower the dehumidification bill?" will always arise. Loosening dehumidification swings toward the pull-weakening side. Loosen the whole room uniformly and the first to cry out isn't the average but the weakest inner row. So before "what fraction to cut," first shave the unevenness and raise the floor of the weak spot—the call to loosen isn't too late after that. Discerning this area—the optimal width of pull

and the trade-off with cost—becomes a book's worth of talk if you step in. The rest of the thinking is left to *172 Hints to Improve the Profitability of Vertical Farms*.

One last thing. What I've confirmed in my body is only the range of leafy greens in a PFAL, and today's story too is a read within that hands-on feel. Change the crop or the equipment and how weak spots emerge, and how wind works, should change too. So take this move, as well, less as the answer than as a first foothold for questioning your own site.

After temperature and humidity, we turn to the content of the air itself—the CO₂ the plant uses as raw material for photosynthesis. Here too, what matters is not just how much there is but whether it reaches the leaf.

Using CO₂



Plants absorb CO₂ from the air in photosynthesis and make nutrients such as sugars to grow. The CO₂ concentration in ordinary air is about 400 ppm, but in a vertical farm, raising it promotes photosynthesis and quickens growth. As a rough target for indoor concentration, it's common to bring it up to around 1,000 ppm in the end (this 1,000 ppm is the target final concentration, not the amount to add).

Raising the concentration can generally be expected to bring effects like the following.

- If light and temperature are sufficient, growth speed rises and the period to harvest can be shortened
- If those conditions line up, the harvest per same area can also be increased
- Photosynthesis becomes active and the plant grows sturdily

Methods of raising the concentration

The work of raising the CO₂ concentration is called "CO₂ enrichment." There are mainly three ways of supplying it.

1. CO₂ gas cylinders: suited to relatively small facilities. Cheap to introduce, but cylinder replacement and storage space are needed 2. Liquid CO₂: for medium-to-large facilities. Can supply large amounts, but introduction costs are high 3. Combustion-type CO₂ generators: burn kerosene or city gas to make CO₂. Running cost is relatively cheap, but since heat, water vapor, and combustion gas come out along with the CO₂, a closed-type PFAL has to handle the exhaust heat, humidity rise, and combustion gas (the conditions of use differ from a greenhouse)

Which method you choose changes with scale, budget, and crop. But choosing the device is a discussion premised on whether it reaches, covered later; whichever method you choose, if the CO₂ can't be carried to the area around the leaf, the effect is impaired all the same. For the cost comparison and selection judgment between methods, it's enough to hold the framework of the thinking and work it out in *172 Hints to Improve the Profitability of Vertical Farms*.

For managing the concentration itself, it's common to combine a CO₂ sensor and a control device. The sensor measures the indoor concentration in real time, and the control device adjusts the supply automatically based on that value.

The meter reads 1,000, yet only the inner row won't grow

Here's where the floor catches most often.

At many sites CO₂ is run as "hold at 1,000 ppm" and HVAC as "keep the setpoint"—different people, different meters. And yet it happens that the meter points to 1,000 while, within the same room, only the inner row's growth dulls. At first you think photosynthesis has plateaued, but look closely and the row near the outlet is fine; only the inner row, where the air doesn't move, is dulling. Once this happens, it's less a problem of the amount of CO₂ than of whether the air is moving.

Why does this happen? A leaf doing photosynthesis absorbs the CO₂ right near its surface and leaves a thin film-like layer there. This is called the "leaf boundary layer." If the air here doesn't move, what's absorbed isn't replenished, and the concentration around that leaf alone

stays thin. The concentration around the leaf ends up as a subtraction: how much the air re-delivers against what the leaf absorbed. So even if the room meter points to 1,000 ppm, at the leaf surface in the windless inner zone, only a lower amount may actually be available.

Does that ring a bell?

In a full PFAL with leafy greens, where light is constant from LEDs, you can't explain a difference in growth row by row with "not enough light." The meter number is a value at some single point in the room, and the air around the inner-row leaves isn't necessarily the same. The problem is how much is actually reaching the area around the leaf, yet as long as you watch the single-point meter, the CO2 enrichment unit, and the HVAC each separately, that difference won't come into view.

Concentration and airflow are separate problems

What you want to hold here is that **CO2 concentration and airflow are separate problems.**

No matter how many enrichment units you add to push the whole room to 1,200 or 1,300 ppm, if there's no movement around the leaf the boundary layer stays thin, and the inner row stays dull. Conversely, the row near the outlet exchanges air even with weak airflow, so it's reaching properly even at the same 1,000 ppm. In other words, how much reaches is decided not by the amount you pump in but by the enrichment method and how you make the airflow. Before adding amount, first doubt whether it's being carried.

What's more, CO2 doesn't keep working endlessly the more you add. There's an upper limit to the CO2 photosynthesis can use, and in a PFAL with constant light and temperature, above a certain concentration the gain in yield gets smaller even as you add. What's easy to mistake here is the difference between a "saturated and plateaued" state and a "can't be carried to the back, so it looks plateaued" state. When transport is actually just clogged, if you assume it's saturated and add enrichment units or raise the cylinder concentration, all that's left at month's end is the line "the CO2 bill went up but yield didn't change." This is the pattern that throws away the most money.

The handle for telling them apart isn't hard. Cut a light strip of paper or tissue, attach it to the tip of a stick, and hold it up at leaf height. Just from "it flutters near the front, droops motionless in the back," you can see with your eyes that this place isn't being carried to. On top of that, at a site where you've found the back is windless, redirecting the wind into the stagnant back, or

adding a small circulation fan, can work better than adding more CO₂. How to generate the wind itself is dealt with later in "HVAC and wind management."

CO₂ is one of a vertical farm's basic elements alongside light, water, and temperature. However well you arrange light and temperature, without CO₂ the plant won't grow. But remember that what matters in enrichment is not just what number you set the room concentration to, but whether that amount can be carried to the inner leaves. The deeper points—discerning the optimal concentration, and judging the cost and payback by method—are dealt with in detail in *172 Hints to Improve the Profitability of Vertical Farms*.

The "is it being carried to the leaf" that came up again and again with CO₂—that carrier is the wind. Temperature, humidity, and CO₂ all reach the leaf, in the end, by riding the flow of the air. Here, let's look at the wind itself that carries them all together.

HVAC and wind management

We've looked at temperature, humidity, and CO₂, and while they seem to be managed separately by separate equipment, they're actually connected by a single thread. That one thread is the flow of air—the wind. A vertical farm is less affected by outside air but, being a closed space, the air tends to stagnate, and left alone, dead zones form. However well you arrange temperature, humidity, and CO₂, it means nothing if that air isn't moving to where the leaf is. Wind is the carrier that delivers them all together to the leaf.

The roles wind plays

Wind plays roughly the following roles.

- **Deliver CO₂ to the leaf:** even if the indoor meter points to 1,000 ppm, that's a value at some single point in the room. Where the air doesn't move, what the leaf absorbed isn't replenished, and the area around the leaf alone thins out. There are situations where moving the air works better than increasing the enrichment amount.
- **Even out temperature and humidity unevenness:** under the influence of lighting and HVAC, temperature and humidity differ from place to place. The top and bottom tiers of a multi-tier rack especially tend to show a temperature difference, and wind evens this out.
- **Exchange the air at the leaf surface:** the leaf surface has a thin air layer called the "leaf boundary layer," and if this doesn't move, the inflow and outflow of CO₂ and moisture

stagnate. Wind moves this layer and aids the exchange.

- **Don't let moisture build up:** in a closed space where humidity rises easily, carrying out the water vapor pooled around the leaf is also wind's job. Since microbes are always present, not letting them build up or spread works better than blocking the entrance.

Wind is "how you distribute it" more than "total amount"

To generate wind you mainly use blowers and the HVAC's own blowing function. The division of roles is that blowers work spot by spot, while HVAC circulates wind through the whole factory.

What you want to remember here is that **stronger wind isn't better**. Raise the air volume to reach the back and now the front leaves dry out too much or take stress. Since it's all connected through the single knob of air volume, stand the back up and the front won't stand. What really works is how you distribute it, more than raising the total. For example, add a small circulation fan only to the back or the gaps between shelves where air tends to stagnate, and move only the one thinned-out point. This way you avoid raising the whole air volume.

The basics of distribution aren't difficult either.

- Don't place blowers facing each other; arrange them so the wind makes one circuit in the same direction across the whole facility (when flows cancel each other out, dead zones remain)
- Corners where wind has trouble curling around are regular dead zones, so hit them hard
- To even out the temperature difference between tiers of a rack, use the vertical direction; to make a wide grow bed uniform, the horizontal—use the direction to suit the job
- Don't keep wind blowing directly on the leaves; flow it over or beside the plant (a continuous direct blast damages the leaf)

Find dead zones by temperature and humidity

HVAC and wind management is simple once you hold the basics. Areas where air is stagnating come into view if you measure temperature or humidity. Within the same room, wherever the inner row alone is hotter or more humid is a dead zone. Stick a light piece of paper on the tip of a stick and hold it at leaf height, and you'll see the windlessness with your eyes—the front flutters while the back droops. Once you find unevenness, adjust how the wind

is applied to fix it. This is enough for most cases.

But once you reach the point where adding fans still won't circulate the wind, because of how the shelves are built or the shape of the room, you enter the domain of redesigning the airflow itself by calculation. That also becomes a large investment judgment, so hold just the entrance to the thinking, and the deeper design is dealt with in *172 Hints to Improve the Profitability of Vertical Farms*.

Once light, water, and air are arranged, the last element is nutrition. In hydroponics, all the nutrition the plant needs is dissolved into water and given by hand. First let's look at how to handle the fertilizer itself that becomes its source.

Handling fertilizer

In hydroponics, you dissolve fertilizer in water to make the nutrient solution. In this section we look at how to handle that fertilizer itself. How to measure and renew the nutrient solution is left to the next section; here we narrow to what to blend, and how.

The conditions a vertical farm asks of fertilizer

There are three premises for choosing fertilizer to use in a vertical farm.

- Water solubility: in hydroponics, fertilizer reaches the plant dissolved in water, so it must dissolve well and be easily absorbed
- Purity: using a high-purity fertilizer with few impurities keeps the nutrient solution's balance stable and reduces the risk of growth inhibition
- Fast action: since the aim is to harvest in a short period, a fast-acting form the plant can absorb immediately suits best

Single-nutrient fertilizer and compound fertilizer

There are two kinds of fertilizer: "single-nutrient fertilizer" and "compound fertilizer." A single-nutrient fertilizer contains only a specific nutrient such as nitrogen, phosphate, or potassium. A compound fertilizer is one in which the necessary nutrients are blended in advance.

Merits of using compound fertilizer

- Easy: with what's needed already blended, the labor of preparation and management is saved
- Products matched to purpose: there are products matched to crop and growth stage, such as for leafy greens or for fruiting vegetables

Merits of using single-nutrient fertilizer

- Pinpoint supplementation: based on the results of a nutrient solution analysis, you can supplement only the nutrient that's lacking
- Original blends: combine multiple single-nutrient fertilizers to make your own blend

Which you use depends on your cultivation policy. But at the stage where you've just started and don't yet know which to use, I recommend starting from compound fertilizer.

Single-nutrient fertilizer blending begins to make sense once you've got running.

"Cheap, so single-nutrient fertilizer" isn't necessarily so

The motive for reaching for single-nutrient fertilizer is usually to make it cheaper than commercial compound fertilizer. The raw-material unit price itself does tend to drop. But in exchange, the work of blending, the labor of measuring, the inventory of many kinds held at once, and the waste from not using it all up all ride along on top of the fertilizer cost. If you only make a small amount occasionally, the ease of compound fertilizer can win. Whether it's cheaper depends on scale and operation, and you can't settle it by looking at fertilizer cost alone.

The true value of single-nutrient fertilizer lies not in cheapness but in the freedom to move the contents to match crop and stage. What's fixed as one lump in compound fertilizer can be adjusted ion by ion. Whether you need this freedom is the dividing line for whether to advance to single-nutrient fertilizer.

EC matching doesn't mean the contents match

Here, let me set down one thing easily misunderstood on the floor.

You measure the nutrient solution's strength with EC (electrical conductivity), but EC only sees the total of all the dissolved ions. Even if the total is the same, the breakdown doesn't show on the EC meter. Whether nitrogen is high and potassium low, or the reverse, the meter shows the same number.

This bites in the recirculating method, where you reuse the nutrient solution. Since the crop doesn't absorb ions evenly, if you recirculate with a fixed blend, the EC can hold while specific ions alone quietly decrease. Trace elements especially—chloride, iron, manganese—tend to run dry first without showing up in the movement of EC. When "the EC matches, but somehow growth is poor," this bias in the breakdown can be behind it. So narrow it down to one or two ions that don't show on EC and decrease easily, and confirm them individually now and then—even that alone gets your hand on the shrinkage you can't catch with EC alone, sooner.

Splitting Tank A and Tank B is for calcium and phosphate/sulfate

Whether compound or single-nutrient, there's a type that splits the stock solution into two tanks (Tank A and Tank B). Don't mistake the reason it's needed.

The split is to keep calcium and "phosphate/sulfate" from meeting while concentrated.

Calcium, present at high concentration alongside phosphate or sulfate, forms a precipitate.

The white stuff that collects at the bottom is usually this calcium phosphate. So put calcium nitrate in one tank and the phosphate and sulfate types together in the other, and don't mix the stock solutions directly. Once diluted the concentration drops, so in the final nutrient solution calcium and phosphate/sulfate coexist without problem. The precipitate is frightening only within the concentrated stock solution.

Note that people often say to "split calcium and magnesium," but what should be split is calcium and phosphate/sulfate. And since precipitate forms more easily the higher the water temperature (calcium phosphate actually dissolves less readily when warmed), be especially careful making stock solution in summer.

Blending starts "from ions," not "from a target EC"

So how do you decide the crucial blend amounts?

Until you're used to it, you tend to put in the blend-table amount so the EC comes out about the same as last year, match it on the EC meter, and call it done. But as we saw earlier, EC doesn't see the breakdown. The proper line is the reverse: decide the target concentration of each ion first, and back-calculate the single-nutrient fertilizer amounts from there. EC is not a target you go to match at the start, but a tool to confirm at the end whether it has drifted—that's the order.

The knack here is to align by the ions' reactivity rather than by weight, and this is where the unit mEq/L (milliequivalents per liter) comes in. Monovalent potassium and divalent calcium differ in reactivity by about double even at the same weight. That said, hand-calculating this every time isn't realistic on the floor. In practice you compute it with a spreadsheet or a nutrient-program tool.

Fertilizer blending is one of a vertical farm's important jobs. It takes both experience and data, and in time it becomes your own blending skill. For reference, I've also prepared a free nutrient-program sheet, "SimpleFert," built from my field experience. Just enter the necessary information and it computes the blend amounts.

The concrete back-calculation procedure in mEq/L—which single-nutrient fertilizer to start from, how to subtract the ions that come along, how to shift it to match growth stage and water temperature—steps into the substance of blend design, so it's gathered in *172 Hints to Improve the Profitability of Vertical Farms*. Here, first hold just this stance: the blend table is not a fixed value to memorize but a blueprint to rebuild when the premises break down.

Dissolve fertilizer in water and you get the nutrient solution. How you measure and maintain that nutrient solution day to day is the central daily work of hydroponics.

Nutrient solution management



What you make by dissolving fertilizer in water is the nutrient solution. In a vertical farm, it becomes the lifeline that governs the plant's growth. The previous section looked at how to choose the fertilizer itself; here is the story of how you manage, day to day, the nutrient

solution you've dissolved it into.

Nutrients contained in the nutrient solution

In hydroponics, instead of soil you use a nutrient solution that mixes water and fertilizer. The main nutrients it contains are as follows.

- Nitrogen (N): promotes leaf and stem growth, and is essential to synthesizing protein and chlorophyll. Deficiency yellows the leaves
- Phosphate (P): promotes root development and the formation of flowers and fruit, and is involved in energy metabolism. Deficiency worsens root development
- Potassium (K): promotes photosynthesis and raises resistance to disease. Also involved in regulating water within cells. Deficiency withers the leaf margins
- Calcium (Ca): strengthens cell walls and stabilizes growth. Deficiency deforms new leaves or rots the tips of fruit
- Magnesium (Mg): a component nutrient of chlorophyll, essential to photosynthesis. Deficiency yellows the area between leaf veins
- Sulfur (S): a component nutrient of protein, also involved in activating enzymes. Deficiency yellows the leaves overall

These are called macronutrients, and the plant won't grow if any one of them is missing. Other nutrients called micronutrients are also important, though small in amount.

The basics of nutrient solution management: EC and pH

Two especially important indicators in nutrient solution management are "EC" and "pH." First, pin down these two.

EC (electrical conductivity)

EC stands for "Electrical Conductivity" and expresses how easily electricity flows. Because electricity flows more easily when fertilizer dissolves in water, looking at EC indirectly tells you the concentration of fertilizer dissolved in the nutrient solution.

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

If the EC is too high, the plant can no longer draw up water and risks withering. Too low, and growth stalls from fertilizer shortage. Adjusting to an appropriate EC matched to the plant type and growth stage is the starting point of nutrient solution management.

pH (hydrogen ion concentration)

pH indicates the degree of acidity or alkalinity of the nutrient solution. Most crops absorb nutrients most efficiently around the weakly acidic pH 5.5–6.5. Stray from this range and problems like the following arise.

- Impeded nutrient absorption: nutrients in the solution become harder to absorb
- Growth disorders: root development worsens, or leaf color worsens
- Insufficient absorption of trace elements: iron, manganese, and the like become harder to absorb, leading to poor growth

Since pH governs the very solubility of nutrients, the basic rule is to keep within this range first. But pH moves on its own as the roots absorb ions. It's not a value that's done once you've set it, and how far it moves varies with crop and medium, so think of it as something to watch daily.

Making the nutrient solution

To make the nutrient solution, you mix water and fertilizer in an appropriate ratio.

1. **Prepare the water:** tap water, well water, filtered water, and the like are used, but tap water is the common case. If using a fertilizer that contains ammonium nitrogen, remove residual chlorine by letting the water stand or with sodium thiosulfate 2. **Prepare the fertilizer:** if using compound fertilizer, dissolve the appropriate amount in water per the product's instructions.

For a recirculating system, an efficient method is to prepare a stock solution at about 100× the concentration of the final nutrient solution and dilute it down with an injector or automatic dosing device (a 100× concentrated stock before dilution, not a "100× diluted solution") 3.

Mixing: dissolve the fertilizer into the water little by little while stirring well. Because calcium forms a precipitate with phosphate and sulfate in a high-concentration stock, there's a type that splits the stock solution tank into two, 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 a pH meter and adjust if necessary. If the EC is below target, add a properly diluted nutrient concentrate; if high, add water to dilute. For pH, if low add a pH-up agent, if high a pH-down

agent, a little at a time

Managing the nutrient solution

During cultivation, the nutrient solution is never in a constant state. Daily management follows this flow.

1. **Measure:** measure the EC and pH at least once a day (drop the frequency and you'll be slow to catch changes). Measuring at the same time each day makes daily changes easier to compare. In large-scale environments, manual measurement has its limits 2. **Record:** always record the measured values. They let you track changes, and they help trace causes when a problem occurs. A notebook or spreadsheet is fine 3. **Adjust:** if it strays from target, adjust. Since adding pH agent in a large amount at once can precipitate fertilizer nutrients, add it a little at a time 4. **Nutrient solution renewal:** keep cultivating for a while and the nutrient balance breaks down or unneeded nutrients accumulate. Periodically perform a "nutrient solution renewal" to replace the solution. The frequency depends on crop and season, but generally once every 2–3 months is a guide. Fast-growing leafy vegetables consume quickly, so raise the frequency; in summer microbes become active and degradation quickens, so move it up

The situation "I don't know the cause, but somehow growth just isn't good" is common. With experience you can guess the cause, but as a beginner that's not so easy. At such times, doing a nutrient solution renewal on a gamble is one option. That you can make this choice when in trouble is one of hydroponics' strengths

5. **Observe:** observe not only the EC and pH but the state of the plant. If there's a change in leaf color, shape, or growth, there may be a problem with the nutrient solution

The way of thinking about hygiene management

Clean the nutrient reservoir and the piping periodically. When algae or debris build up, pathogens multiply more easily.

But hygiene tends to lean toward the entrance—how to keep microbes from getting in—while the floor's feel is a little different. Microbes can't be reduced to zero in the first place and are everywhere. So what matters is to not increase microbes and to not spread them. The same goes for algae: many people worry about it, but it occurs no matter what. It looks bad and is

dirty, but rather than aiming for zero, the stance of keeping it from increasing too much is fine. Rather than relying on sanitizing and beating it down endlessly, keeping the nutrient solution in a state where it doesn't stagnate and circulates normally is, in the end, more stable.

Just matching isn't enough—DO and the breakdown drift

That's the basics of nutrient solution management. Run the meter each morning, and both EC and pH are on target. The daily-report numbers line up neatly. And yet something's off. Does that ring a bell?

There are plenty of sites where just matching is nearly enough, but when an unexplained malaise appears despite matching, two points are easy to overlook. One is dissolved oxygen (DO); the other is the drift in the "breakdown" of nutrients.

Dissolved oxygen (DO) is a number to watch, not a number to match

Even when you manage EC and pH side by side, what you're watching is usually those two, and DO tends to get put off. The tricky part is that the trouble doesn't always come wearing the usual face. EC and pH are on target, yet something's off. Looking back later, that period was invariably one where the water temperature had risen, or the roots had increased and grown dense, and DO had probably dropped—it comes in that form.

EC and pH take on meaning only once the roots can actually take up the nutrients. That uptake runs on root respiration, and respiration needs oxygen. So once DO drops, no matter how on-target you match EC and pH, the root side can't use it all. It's a state where the board is set but the hands won't move.

What's more, DO isn't a value you push toward a target each day like EC or pH. It comes out as a result of conditions like water temperature, root mass, flow rate, and aeration. The means to move it—the aeration method, the water-temperature adjustment—are usually decided on the equipment side too, not knobs you can twist daily on the floor. So what you can do about DO is, rather than operate the value itself, confirm it isn't dropping and read early any slope heading toward deterioration. Think of it as something to watch for whether it falls below a certain level, not something to push toward one set target each day.

In the range I've run with leafy greens in a PFAL, my safe-side guide has been not to let dissolved oxygen fall below 5 mg/L, and if possible to hold around 8 mg/L. But this is not an absolute threshold that applies everywhere; it's a guide for the lower bound. Rather than

higher being better, think of it as a line set so as not to fall below here. When recording, rather than leaving DO's absolute value at a single point, it's better to log water temperature and DO as a set. Since the upper limit of oxygen that dissolves in water itself drops as water temperature rises, a drop to the same DO has no margin when the water temperature is high. One thing to keep in mind is that EC and pH looked on target during the trouble period. That is no grounds for "so the nutrient solution is fine." If anything it's the reverse: when DO escapes and uptake dulls, the unconsumed EC and pH appear stable. The numbers settling neatly may be the flip side of their not being used.

EC only tells the total

Alongside DO, what's easy to overlook is the very nature of EC. EC lumps the overall strength into one number. It adds up the concentrations of separate ions—nitrate, potassium, calcium, magnesium—into a single conductivity. So even if the total is on target, the ratios within aren't necessarily on target.

What's more, that breakdown drifts on its own even if left alone. The roots don't absorb ions evenly; depending on growth stage and crop, some are well absorbed and some are left behind. For example, in a period when potassium is well absorbed, even if you bring the EC back to target with replenishment solution, you add the depleted potassium to match the total while the other, unabsorbed ions gradually accumulate. The EC is the same, yet the contents drift into something other than the solution you first made. The more you reuse the solution in a recirculating system, the more this drift piles up.

In other words, "the EC matches but it's off" isn't just an impression. The moment you round it into the single number of EC, the breakdown information is dropped. That said, measuring each ion every day isn't realistic either. Rather, keep using EC, accepting it as total-amount management, and on top of that hold the premise that even when the total matches, the breakdown can drift. Then suppress the breakdown drift through operations—periodic nutrient solution renewal, and remaking it ahead of schedule when signs appear. That's enough. Let me list some signs that give you grounds to move it up.

| Sign | Detail | | --- | --- | | EC instability | Frequent adjustment becomes necessary, or there's unexpected fluctuation | | Sudden pH change | pH returns to an abnormal value soon after adjusting, or fluctuates greatly | | Color or smell of the nutrient solution | Cloudiness,

discoloration, or an unpleasant smell | | Stalled growth | New shoots grow slowly, leaves are small, stems are thin | | Worsening root condition | Browning, softening, or dieback of root tips is seen | | Onset of disease | Root rot or leaf disease increases |

The malaise appears not the same day but weeks later

Whether it's DO or the breakdown drift, they share one property: the breakdown shows up not the same day but with a delay. Even if today's numbers are within normal range, that breakdown comes back as yield or grade weeks later. So reread the nutrient solution log not only for "what was it today" but with an eye for "was there a week it broke down, and what was moving on the conditions side at that time"—only then does it connect to growth. One step further, designing records as KPIs and the deeper operational judgment of rebuilding the breakdown drift with single-nutrient fertilizer are dealt with in detail in *172 Hints to Improve the Profitability of Vertical Farms*.

Taste moves with operation, not method

The nutrient solution management story connects directly to the "taste" story. "Factory produce is watery," "no bite, kind of unsatisfying"—indoor-grown vegetables carry this reputation around. And it usually gets blamed on the facility type.

But the more someone actually grows and sells on the floor, the more they know it's not that simple. Taste changes considerably with the time since harvest. Even the same plant differs in sweetness between a morning cut and an evening one. How you manage it right before shipment also greatly changes how the bite comes out. The facility type itself does produce a taste difference, but the width that operation can move within the same method is large too.

Take the bite, for instance. With hydroponic lettuce, just stopping fertilizer 2–4 days before harvest considerably lowers the leaf nitrate that's the source of the bite. And if conditions are good, yield barely drops in that time. You tend to brace yourself with "tune the taste and you sacrifice the amount," but as for the bite, there's room to remove it while keeping the amount. For leafy greens and PFAL, what you do in the few days before harvest is an easy-to-read lever that moves the taste. But it's not all-purpose; squeeze the nitrogen too far and other costs appear, such as the leaf color thinning.

What matters here is that sweetness, bite, and aroma each peak under different conditions. The conditions where sugar accumulates and the conditions where nitrate is lowest are not the

same. "The setting that maximizes amount" and "the setting that maximizes sweetness" are also at different positions on the same dial. So unless you narrow your aim to one, every dial stops at a half-baked position. A vegetable grown without deciding the aim lands on a characterless, thin taste—not because you got greedy, but because, with no axis, every step ends up swinging halfway. The true nature of the watery factory produce is, rather than the method, the absence of that aim.

So the first thing to do is not to suddenly fiddle with light or fertilizer. It's to learn what your variety and your facility can produce and what they can't. Aroma especially tends to be capped by the upper limit the variety inherently has; however much you tighten operation, a variety that doesn't smell won't smell easily. For the first few crops, don't swing the aim—grow them plainly under the same conditions and eat them as they are, and the nature reveals itself: this variety doesn't smell to begin with; sweetness accumulates readily. Only once you know which axis can be moved can you choose which one to stand up.

Note that the profit-linked talk—which taste, if aimed at, turns into unit price, what kind of sales outlet to pair with, and the conditions under which a taste premium holds—is dealt with in depth in *172 Hints to Improve the Profitability of Vertical Farms*.

Improving precision with data

Use data and the precision of nutrient solution management rises further.

- Cultivation records: record EC, pH, water temperature, fertilizer type and amount, and growth state to grasp the relationship between the solution's state and growth
- Nutrient solution analysis: commission a specialist institution and you can accurately grasp the concentration of each nutrient in the solution. Adjust the blend based on the analysis results for more appropriate management
- Using environmental data: relate environmental data such as temperature, humidity, and CO₂ concentration to EC, pH, and growth state and analyze it, and the precision of environmental control and nutrient solution management rises

As long as you think of the nutrient solution as a number you match by meter each day, write in the daily report, and be done, it stays "matching work." But the moment you shift your view to "that way of matching shows up in the harvest weeks later," nutrient solution management turns into a clue for reading growth. Try rereading this week's log once with that eye.

By now the foundations of cultivation—light, water, air, and nutrition—are roughly in place. Even with the foundations in place, growth troubles appear on the floor. Last, let's look at the two a newcomer runs into earliest—tipburn and leggy growth.

Tipburn



"The lettuce was growing along nicely, then right before harvest the leaf tips started crisping brown." Growing leafy greens in a vertical farm, tipburn is a growth disorder you can't avoid. I, too, was tormented by it for a long time.

What tipburn is

It's a physiological disorder where the leaf tips or margins wither brown. At first the tip is only slightly discolored, but as it progresses the withered part spreads. In lettuce, it especially appears in the inner young leaves near the core of the head. The big outer leaves are crisp and healthy, yet only the margins of the small leaves in the center crisp and wither. If the leaf tip feels like it's "getting a bit black," it may be a sign.

It's said to be "calcium deficiency," but

On the floor, the first thing said is "calcium deficiency." So you add Ca. But it appears again. If this matches your experience, the cause is elsewhere.

In my experience, cases where the calcium concentration in the solution itself is short are actually not that many. In most cases the Ca is sufficient. And yet the symptom appears. In other words, tipburn is not so much the **total amount** of Ca being short as Ca **not reaching**

the inner leaves—not a problem of the amount itself, but of how it's distributed within the plant. So piling on more and more Ca fertilizer with "if it's short, let's add more" is usually counterproductive. Even if you concentrate the solution, if the destination is biased it won't reach the core. On the contrary, the EC rises, or it competes with other ions, inviting fresh trouble.

Why "distribution" breaks down

Ca is carried with the water, flowing through the plant's xylem. And water is pulled to where transpiration is high.

What's at work here is the difference between shelves. The stronger the shelf, with light applied well, the more vigorously the big outer leaves transpire. Then Ca gets pulled more and more toward those outer leaves. Meanwhile, the young leaves at the core still transpire weakly, the humidity inside the plant is high, and the air doesn't move easily. The water flow itself is thin, so Ca doesn't reach. The center alone of the strongest shelf—the most vigorous, the one you most want to harvest—wither; the mechanism is right here.

That it appears more readily the harder you push growth is for the same reason. The faster it grows, the more the young inner leaves keep multiplying, and new leaves appear as fast as you distribute. Arrival at the core can't keep up with the speed of growth. "Fast and big" and "safe all the way to the core," pushed to the limit, don't face the same direction. This too is the difficulty of countering tipburn.

The keywords are "transpiration" and "growth speed"

The two entrances to countermeasures are these.

- **Transpiration:** too-high humidity suppresses transpiration and also lowers root activity. Too low, conversely, and water gets pulled only to the outer leaves, drying out the core instead. Humidity is deeply tied to tipburn, so handle it carefully here (see also the humidity management section).
- **Growth speed:** if too-fast growth is worsening the symptom, review it in the direction of **lowering** light, temperature, and CO₂—that is, slowing growth a little (accelerating worsens it, so here you decrease rather than increase).

How you apply wind is involved too. Flow a stable airflow horizontally along the shelf, evenly, and the distribution to the core changes. A wild, strong wind that just dries the margins of the outer leaves, by contrast, does harm instead. Even the same "wind"—think of a uniform, stable airflow and a turbulent strong wind as different things.

How to handle what has appeared

Prevent all you like, and still, what appears appears.

Even when tipburn appears, the effect on taste itself is limited. But the appearance is clearly inferior. Since vegetables are chosen by appearance, it affects shipment quality. So you're pressed to judge whether to remove the lightly affected plants, or to trim the damaged part before shipping.

Just one thing here. Don't desperately try to remove even the tiniest tipburn. Tear leaves off recklessly and rot can advance from the wound. Rather than going after everything that appeared, discern whether it's at a level that affects shipment quality and step in there. That comes out ahead on balance.

See it as one thread, distribution

There are tolerance differences by variety. Types with a roomier leaf form let water circulate to the inside more easily, and varieties whose growth doesn't run wild are slower to break down in distribution. But this is just one move that loosens the whole linked system a little; push too hard and even a strong variety breaks out as usual. The story doesn't close with variety.

Likewise, fiddle with one factor alone—"just lower humidity," "just strengthen the wind"—and the burden shifts to another factor. Lower humidity alone and the core dries out further; strengthen the wind alone and the outer-leaf margins get damaged. Tipburn is a symptom that arises with light, growth speed, airflow, transpiration, root zone, and nutrient solution all connected together. Not attacking any one alone, but seeing it as one thread, is least likely to get tangled.

Facing an affected plant, what to suspect and in what order. How to swing the finishing environment, narrowed to the few days before harvest. How to tell whether it's a flow problem or whether the solution's Ca is really hitting bottom. The specifics around here are profit-linked discerning points, so they're gathered in detail in the next hint collection.

172 Hints to Improve the Profitability of Vertical Farms

If tipburn was a story of "reaches or doesn't reach," the other representative trouble, leggy growth, is a story of "stretches or doesn't stretch." While you're new, remembering these two as a set is reassuring.

Leggy growth

Alongside tipburn, another representative growth disorder is "leggy growth." Leggy growth is the phenomenon where a seedling stretches up thin and lanky, extending its stem more than necessary. Picture a foliage plant by the window stretching thinly toward the light—it's close to that.

When leggy growth occurs in a vertical farm, effects like these appear.

- Yield down: only the stem stretches and the crucial leaves stay small.
- Quality down: the tissue grows weak, and shelf life and taste decline. The cell walls thin out, leaving it weak to disease too.
- Work-efficiency down: it falls over easily, increasing the labor of harvest and crop care.

And the troublesome part is that an internode once stretched doesn't return. A stretched hypocotyl tightening and shrinking once you fix the environment is not something I've seen in the range I've watched on the floor. So think of leggy growth as something to read in advance, before it appears, rather than fix after.

First suspect density, then read the environment

When leggy growth appears, you reflexively want to reach for an environmental knob—"right, how do I stop it?" But before that, there's an order to look in.

The first thing to suspect is not the environment. It's **variety, seeding density, and cell count**. Under the same environment, an easily stretching variety stretches. Pack the seed into a tray, and the very crowding with neighbors stretches the seedlings. The plug tray's cell count (72-cell, 128-cell, 200-cell, and so on) also governs not just how many you can make but what form of seedling results. The smaller the cell, the narrower the room for roots to spread, and the more it works against crops with a long propagation period.

In the range I've watched on the floor, leggy growth explained by "isn't that tray simply over-sown, aren't the cells too small?" before you agonize over the environment was not rare. So first, fix the variety, density, and cell count. This is the first stage.

On top of that, read whatever remains with the environmental knobs—the three factors of **light, night temperature, and humidity**. Put the other way around, when density or variety is the true cause, however much you turn the three environmental knobs it's a swing and a miss. Thinking only "leggy growth = the three of light, humidity, temperature" makes you skip the first stage that works most. The order is density first, environment after.

Reading the three environmental factors from the seedling's form

The stem stretching is a reaction the seedling triggers by sensing light. Crowded and shaded by neighboring leaves, or with the light itself weak, the seedling stretches its stem seeking light. This is the true nature of leggy growth. For the remaining three factors, make a first guess using the seedling's form as a clue. They can't be fully separated, but they do give a priority order for what to suspect next.

- **Weak light:** rather than the stem getting long, the leaves themselves tend to be thin and pale too. It's a posture of throwing the body out toward the light.
- **Night temperature doesn't fall enough:** when it stretches with warmth trapped after lights-off, the leaves keep their thickness and color while only the internodes stretch. It tends to appear when the place (lower tier) and the time (nighttime) line up.
- **Dampness builds up:** in time slots or on shelves where dehumidification works poorly, transpiration stalls, and the leaves grow somewhat large and soft while keeping their crispness, and beneath them the stem stretches loosely.

In other words, look not only at the stem length but at **when, where, and how the leaves are**, together. Thin and pale leaves lean toward light; ordinary leaves with only the internodes stretched lean toward night temperature; soft leaves on a shelf where dampness built up lean toward over-humidity—that's how you make the guess.

But this is a guide for a first guess, not a tool for confirming the main cause. The lower tier of a cultivation rack especially is a place where light, night temperature, and dehumidification all tend to go weak at once, and it breaks down at the very spot you most want to use. When it breaks down, don't lock onto a single cause.

The leggy growth that's appeared and not letting it appear next are separate stories. Here's one thing I want to separate. **What to do about the current crop that's stretching and not letting the same leggy growth appear in the next crop** are separate stories.

A seedling already starting to stretch is a race against time, and if you only move after narrowing the cause to one, the stretch advances meanwhile. So for the leggy growth appearing now, without waiting to identify the cause, lean everything to the conservative side: raise the light, lower the night temperature, strengthen dehumidification. But moving suddenly and largely is itself a stress, so do it in stages, and **don't raise it further on shelves where light is already sufficient**. Light isn't better the more there is; the boost is needed on weak shelves, not on sufficient ones.

The reading that narrows the cause to one, on the other hand, comes alive toward the next crop. In the morning, line up and compare the upper- and lower-tier seedlings, and from the stem length, the leaf color and thickness, and the softness of the leaves, guess which is answering in the loudest voice. Then, in the next lot, move only the single suspect and watch how the appearance changes, and you can confirm the main cause. Fiddle with three at once within the same crop and you won't know which one worked. Confirming one at a time takes on meaning precisely across separate lots.

How to handle a stretched seedling

A seedling that's already shot up changes the meaning of your move depending on the stage. If the stretch is still in the early hypocotyl stage and the true leaves are about to unfold, there's plenty of value in fixing the environment. You can stop the internode stretch from here, and there's room left to set the form right again on the true-leaf side that stacks above. If the internodes are already stretched and tilting over and the true leaves have begun unfolding, inheriting the stretch, then the judgment to write the plant off as off-grade comes up too. Place the core of the line at **whether the true leaves inherited the stretch**, while reading it together with the growing point, the life or death of the roots, and the stage of the crop cycle. At an early propagation stage, transplanting can be efficient; if harvest is near, not forcing a fix and harvesting it as a leggy plant can be the better deal.

Not letting it appear in the next crop—the pre-seeding check

If a stretched stem doesn't return, the value of your move is, after all, on the "don't let it appear in the next crop" side. The order of confirmation is the same: density first, then environment.

- **Seeding density and cell count:** against the seedling form you're aiming for and the propagation period, is it over-sown, are the cells too small? When the leaves of neighboring plants start to overlap or the lower leaves start to yellow, it's time to thin or transplant.
- **Light:** measure the light per shelf position in advance. Even the same LED can reach the lower tier less, and a weak shelf returns it as stretch.
- **Night temperature:** look at how the temperature falls after lights-off, per shelf. The lower tier tends to trap warmth at night.
- **Humidity:** pick up whether there are time slots or shelves where dehumidification works poorly.

Write these out per shelf before seeding, and rather than panicking after leggy growth appears, you can read the weak spots in advance and prepare. Rather than blaming the stretched stem, first suspect density, then read whatever remains as a signal of which setting the seedling is answering. Think of it that way, and the eye with which you look at the trays each morning should change a little.

Leggy growth ties directly to yield. How you combine and read density, light, night temperature, and humidity, and how far you push before you write it off—that judgment is, just as it is, the story of a vertical farm's profitability. For those who want to pick up usable perspectives more broadly on the floor, please look here too.

172 Hints to Improve the Profitability of Vertical Farms

To level up crop management further

So far—from crop selection through light, water, temperature, humidity, CO₂, and wind, to fertilizer and nutrient solution, and tipburn and leggy growth—we've worked through the basics of crop management. Each may look like an independent topic, but on the floor they all influence one another. Move humidity and it bears on tipburn; strengthen light and how temperature and water are used changes. Just keeping this connection in the back of your mind considerably changes how you size things up when trouble strikes.

But honestly, what I've written so far is, in the end, a foundation. Out on the floor, a moment always arises where "I have the knowledge, but what specifically do I tackle first, and where should I aim?" leaves you lost.

For example, even if this book can show the appropriate range for light and temperature, where the optimal value for your own factory and your own crop lies is something you can only discern while growing. Even to cut electricity and labor costs, which part to cut so that profit remains without dropping quality—that judgment only takes on meaning once you've held the basics. I myself took a long time to learn this area by trial and error.

This book has committed to assembling only up to the entrance to the way of thinking, before that. The profit-linked, one-step-deeper points—how to discern the optimal value, judging cost reduction, building up the numbers—are left to the companion volume, *172 Hints to Improve the Profitability of Vertical Farms*. First level the ground of the basics with this book, and when you feel ready to step one stage deeper, I hope you'll open that one.

Chapter 2 summary

- **Choose crops not by item but by "the sales channel's unit price × turnover × difficulty" and "how much per area per day."** Lettuce-centered isn't the profitable answer but the result of choosing the solution least likely to collapse in the factory format. New crops only after passing the gate of profitability.
- **Grasp light by the product of three—strength, color, and time (DLI).** Brighter isn't necessarily better, and the stopping point moves with the electricity cost.
- **There's no absolute superiority to the hydroponic method (NFT/DFT).** What works is the water management after you've chosen. Catch reversible drifts on operations; erase irreversible accidents in advance with equipment and provisions.
- **See air not as temperature, humidity, and CO2 separately but by whether it reaches the leaf.** What you manage is the air; what responds is the leaf. Humidity is not a percentage but a pull strength (VPD), and CO2 is not concentration but whether it's carried to the back. What carries them all together is wind, and what works is distribution more than total.
- **For nutrition, on the basis of EC and pH, watch the two points where matching alone isn't enough (dissolved oxygen and the breakdown drift).** EC only tells the total,

and the blend is back-calculated from ions. For hygiene, not zero microbes but "don't increase, don't spread"; not relying on sanitizing but on normal circulation.

- **Don't attack growth troubles alone.** Tipburn is not Ca's total but its distribution; leggy growth is density first, then environment. Both arise with multiple factors connected into one thread.

Each may look like a separate topic, but on the floor they all influence one another. Once you've firmed up the foundation in this chapter, next comes the stage of building up the numbers to match your own factory and your own crop. That one-step-deeper practice is handed on to the sister volume, *172 Hints to Improve the Profitability of Vertical Farms*.

Chapter 3: Farm Operations Management in Practice

In the previous chapters, we looked at how a vertical farm works as a system. From here, the focus shifts to what happens day to day inside that box, and to what the person standing on the floor actually does. There is still a gap between knowing the equipment and the theory, and being able to actually run the floor. This chapter sets out to close that gap.

Where do you start learning farm operations management? The three layers: seedlings, numbers, and people

"In the end, you just have to learn it by experience." This is the conclusion people who have just joined tend to reach about farm operations management. And it is half right. But this phrase usually comes bundled with the assumption that what you have to learn is a single, undivided lump.

In reality, farm operations management breaks down into three layers of a different nature: reading how the seedlings are growing, keeping watch over the numbers, and organizing people and the flow of work. These three are acquired separately, and only when they mesh together does the floor run. What to learn first also comes into view once you think in terms of these three layers.

The layer that reads seedlings, the layer that watches the numbers, and the layer that organizes people

Having watched a lot of people on the floor, I noticed something. Among new hires, there are people who look at a seedling and immediately sense, "this one looks a little weak." But that same person shows no reaction at all to changes in the EC (a measure of how concentrated the nutrient solution is) or the nutrient solution numbers. Conversely, there are people who can track the numbers meticulously but feel nothing when they look at the actual plants. At first I thought it was a matter of experience, but it does not seem to be a single line.

The way you see seedlings and the way you see numbers are separate abilities. Looking at a seedling and noticing "this looks weak" belongs to the layer that reads plant growth. It is a world you learn with your body—the firmness and color of the leaves, how the growing point extends. Tracking EC and the nutrient solution numbers, on the other hand, belongs to the

layer that watches the numbers. It is a way of using your head that reads not the physical plant but the trend over time. It is not that a shallow level of experience prevents you from doing both; because the layers are different, they are acquired separately. So it is perfectly common for someone to be good at one and skip right past the other.

To make matters trickier, the more someone is strong with the physical plant, the more they tend to say, "I don't need to look at the numbers, I can tell from the leaves." I understand the feeling, but there is a trap here. There are abnormalities that the numbers tell you about first, and conversely there are abnormalities that show up in the leaves first even when every number is normal. For example, tipburn (a symptom where the leaf margins die back) is triggered when sudden growth outpaces the supply of calcium to the young inner leaves. Even when the calcium reading in the nutrient solution is normal, if the way it is distributed (the flow of transpiration) cannot keep up, it shows up in the leaves first. So with only one or the other, you miss things. Only when you watch both do the gaps shrink.

There is one more layer, separate from growth and numbers. People and the flow of work—the sense for who does what and when. There are people who read seedlings, who can track numbers, and yet who are oddly bad at giving instructions to people or laying out procedures. Conversely, there are people whose cultivation is so-so but whose organizing is outstanding. This too is not rare.

Organizing work is again a different thing. Growth and numbers deal with plants, but organizing deals with the flow of people and things, and it uses the head differently. Yet, although it looks like a world of intuition, it is actually something you can measure and put in order. When I wrote out a day's tasks, at my own site it was the harvest-related work that ate up the time. Who goes into what and when, the height of the workbench, where to place the harvested product—those things can be seen and measured. Instead of settling for "that person is good at organizing," you can look at where people are waiting and where postures are being strained, and rebuild the layout. This is a layer distinct from growth and numbers: the layer you measure and put in order.

That completes the three. The layer that reads seedlings, the layer that watches the numbers, and the layer that organizes people and work. Farm operations management runs with these three overlapping.

What to learn first—the layer you can hand over in advance, and the layer you build on the floor

Once the three layers come into view, "what should I learn first, anyway?" suddenly becomes concrete. Rather than acquiring all three at once, each has a different entry point.

In terms of order, the first thing is to get the mechanisms into your head. In all three layers, the entry point mixes "the part you can hand over in advance as knowledge" with "the part you can only build on your own floor." For the growth layer, how light and nutrients are taken up and leaves form—that pathway can be read and learned. For the numbers layer too, what EC and pH represent and what to suspect when they move a certain way—that way of reading can be handed over in advance. For the organizing layer as well, the idea of writing out and measuring the work can be taught. Up to here is the part you can hand over before someone stands on the floor.

The boundary between what you can hand over and what has to be built is fairly clear. For example, you can explain the mechanism that stronger light increases yield. But where it pays to stop depends on your own electricity cost and unit price, and that cannot be handed over as a number. The optimal EC also moves when the crop or the system differs, so you cannot just use someone else's value. So you hand over "the mechanism and the reading" in advance as knowledge, and let them build "what value to set for your own conditions" against their own site's marketable yield. Dividing along this line works well.

Next, which layer is your turn to develop. This is not decided by what you are good or bad at. You work backward from where you are actually stuck on the floor right now—where delays and rework are occurring, and which layer they sit on. If you can already see both the plants and the numbers, the bottleneck is usually the organizing part, and that is where the layer you need to develop shows up for you now. Pick up the single most visible instance of rework, see which layer's entry point it is closest to, and choose from there. That is enough.

And being outstanding at just one thing does not make the floor run. Precisely because the three layers are acquired separately, on the floor they only produce results when they mesh. Even if you can read growth perfectly, you cannot protect the marketable yield unless someone is watching the numbers and the organizing is in place. Optimizing just one layer does not necessarily make the whole optimal—this shows up in the same form at a farm of any scale.

How to read this chapter

From here, the chapter follows these three layers in order. The production plan decides the overall arrangement; seeding, propagation, transplanting, final planting, and harvest follow the process of raising the seedlings. Post-harvest work delivers quality as a product; managing and training staff, and hygiene management, set up the foundation of people and the floor. Finally, data analysis connects the records so far to judgment.

You do not have to get all of it into your head at once. Keep the three layers in mind, read from the layer where you are stuck right now, the layer that is your turn, and try it once on the floor tomorrow. This way of proceeding is, in the end, what sticks best.

Note that what we deal with here goes only as far as "the mechanism and the reading." Decisions tied directly to profit—what value to set the optimum to, how to weigh it against cost, how to sell—go beyond the scope of this book. If you feel the entrance to those questions, step into the companion volume, *172 Hints to Improve the Profitability of Vertical Farms*.

Drawing up the production plan

品目			フリル		フリル		フリル		フリル	
パネル穴数			300 穴		300 穴		120 穴		40 穴	
栽培工程			暗所発芽		育苗		生育1		生育2	
日数			1 日		12 日		7 日		7 日	
作業			播種	苗取出し	苗移動	苗取出し	移植1	苗取出し	移植2	苗取出し
12/01	水		3600							
12/02	木		3600	3600	3600					
12/03	金		3600	3600	3600					
12/04	土		3600	3600	3600					
12/05	日		3600	3600	3600					
12/06	月		3600	3600	3600					
12/07	火		3600	3600	3600					
12/08	水		3600	3600	3600					
12/09	木		3600	3600	3600					
12/10	金		3600	3600	3600					
12/11	土		3600	3600	3600					
12/12	日		3600	3600	3600					
12/13	月		3600	3600	3600					

Of the three layers, we start by deciding the overall arrangement—"what to make, when, and how much." From here, we go through the substance of vertical-farm management one item at a time. First is the production plan.

Why a production plan is needed

The conventional farming approach of moving with the seasons and the weather does not work in a vertical farm. In exchange for being able to build the environment yourself, you have

to decide in advance what to make, when, and how much.

If you run without a plan, you usually stumble in one of three ways. Demand and supply fall out of step and what you made goes unsold. Costs for electricity, water, labor, and materials go out first and no profit is left (material and labor costs are prepared before planting, so without a forecast, unplanned expenses balloon). Environmental and work management becomes ad hoc, and the finished product is uneven. All of these could have been avoided by deciding in advance.

Building backward from shipment

I have long been involved in the production and startup of leafy greens such as lettuce at a PFAL (Plant Factory with Artificial Lighting), and there is only one order in which I think about a plan: start from shipment and work back from there to cultivation. If you think, "build to use the full capacity of the equipment, and just fit shipment to that," it will not run in the first place. If you make capacity the basis, you get alternating weeks where you can make it but cannot sell it, and weeks where you want to sell but fall short.

The backward flow goes like this.

1. **Demand forecast:** read when, how much, and at what price you can likely sell. 2. **Drawing up the production plan:** from that shipment volume, work backward to the required planting quantity and the cultivation schedule. 3. **Progress management and revision:** as you run it, watch for gaps and correct them frequently.

Step 1. Demand forecast

First, grasp where, how much, and at what price you will sell. Is it a supermarket, a restaurant, or an individual; at what price does it sell through that channel; how does demand move with the season; what are competitors making the same crop doing. You read this using past sales data and market movements, but no one can know the answer to "make this and it will definitely sell." Accept that this is purely the work of forming a hypothesis.

Step 2. Drawing up the production plan

Turn the demand you read into a concrete plan. Decide the crop on three points—market needs, cultivation period, and profitability—and set a realistic target production volume from facility scale, equipment capacity, labor, and sales channels. Then match the harvest timing to

market demand, work backward through the cultivation period, and fix the seeding date.

Finally, estimate seeds and seedlings, fertilizer, materials, staff, electricity, and water. When you work back from the shipment side, this order emerges naturally.

Step 3. Progress management and revision

A plan is not finished once it is drawn up. It is something you correct as you run it. Observe and record growth regularly, check whether it is selling as planned and whether inventory is appropriate, and when a gap appears, find the cause and, if needed, revise the schedule or the production volume.

Gaps are not a matter of precision

Here is one way of seeing things I want you to hold onto while you are new. When things do not run according to the schedule, many people think, "the plan was sloppy," "I should have laid it out in more detail." But no matter how much detail you add, sometimes the gap does not go away. That is because **things moving at different speeds are mixed together** in a single plan.

Shipment is pulled by demand and wobbles finely, week by week. Cultivation is the cycle of a living thing, so it is much slower. For leafy lettuce, it is around 35 days from seeding to harvest. Even if you increase final planting today, those plants reach the shelf one cycle later. And the ebb and flow of labor moves on a peak different from either of those. If you try to put these three on the same scale of a single schedule, matching the fast wave whips cultivation around, and matching the slow cycle makes you miss shipments. So the gap is not a problem of precision but a structural problem of forcibly synchronizing things that should run separately—that is how I see it.

So what does it mean to run them separately? It means deliberately placing **buffers (cushions)** between the three. The cushion on the shipment side is the width of the right harvest window you can wait on the shelf, and the up-and-down swing of the grade you can ship. The cushion on the cultivation side is the increment of seeding and final planting timing. The cushion on the labor side is spare capacity. Fresh leafy greens keep for a short time and are hard to hold as inventory for many days, so on the shipment side you hold your cushion in "how far you can swing the harvest window forward and back" rather than "thickening inventory."

And what you watch is not the schedule itself but **how much of that cushion is left right now**. Receive the shipment wave with the width of the harvest window, and when that room is running dry, reach into the cultivation increment (the seeding and planting timing). But cultivation alone cannot wait until the buffer runs out. Even if you increase seeding after the room to receive shipments has dried up, those plants come up about 35 days later. So for the cultivation adjustment alone, you move **ahead of time**, allowing for the lead time up to harvest.

The hardest axis to move is where you can add the most cushion

The interesting thing is that cultivation, the hardest of the three to move, is exactly where you can add cushion. The cycle by which a single plant grows cannot be changed. But "when to sow" and "how many separate sowings to split into" can be changed. If you sow a large amount all at once, harvest concentrates at one point and there is no way to match the shipment wave. But if you shift the timing and sow a little at a time, plants line up on the shelf like a staircase—"plants about to enter the harvest window," "plants that will come up soon." In a week when shipments increase you go earlier, in a week you want to hold back you delay a little. That range is born. What is hard is the cycle of each individual plant; what is soft is how you scatter them along the time axis. By shifting and overlapping units you cannot move, the whole becomes a cushion.

Change the rhythm of review with the speed of the wave

How often you look can also change by axis. The width of the harvest window that receives shipments is riding the fast wave, so you peek every day or every few days at "how many swingable plants are on the shelf right now." The cultivation side gives no answer even if you measure it every week, so once every few weeks you inspect the setting itself—"is the current seeding increment right?" If you make the intervals the same, you overlook things on the fast side and needlessly wobble the slow side.

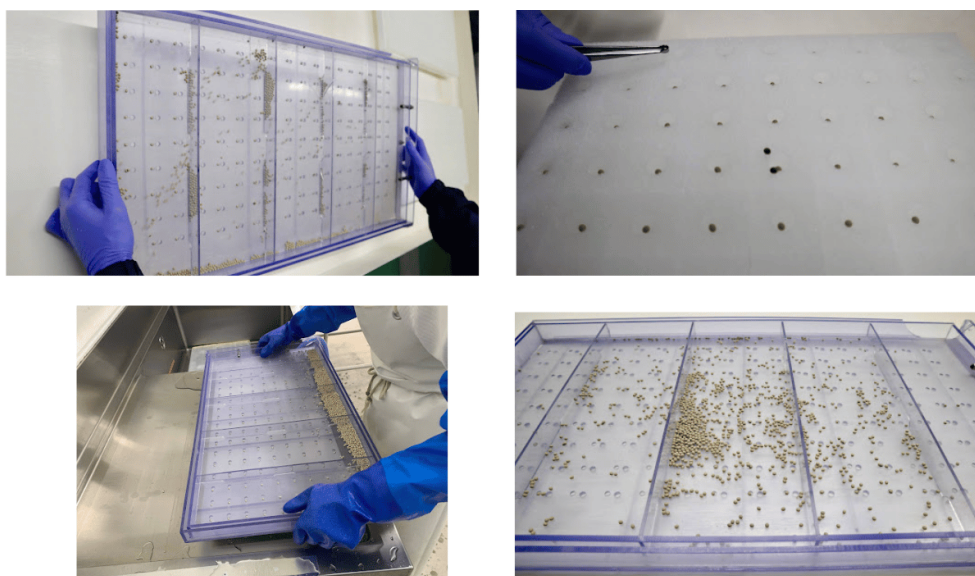
And which cushion is being depleted points directly at where the cause lies. If the width of the harvest window is always running thin, the seeding increment is not keeping up with the shipment wave. If the labor spare capacity is always tight, the staffing estimate is not absorbing the harvest peak. Rather than lumping gaps together as "a soft plan," you can separate them by which axis started to break down. This is the greatest practical benefit of

looking at things in three parts. Even the first gap becomes something you can watch calmly, not as a failure but as a signal that three clocks have started moving.

That said, building this from scratch each time is a chore. I have published the crop-schedule template I used on the floor, so use it as a starting handle for grasping how the formulas are assembled. The number of plants, the turnover, and the yield all differ by farm, so rather than using it as is, the premise is to rework it to fit your own environment.

From here on, judgments tied directly to the bottom line—"so how many days apart should seeding actually be," "how to decide planting density in light of harvest volume," "how to produce while holding down the electricity cost"—are the territory you work out with your own farm's numbers. I stop at the entrance to the way of thinking and leave the deeper judgment to *172 Hints*. The production plan is the axis that runs through vertical-farm operations.

Seeding



Once the plan fixes the seeding date, you finally enter the process of raising seedlings. From here, we go through the on-the-floor work of actually growing vegetables, in order. First is seeding—the process of sowing seeds.

Seeding is the first step of crop management. A vertical farm uses no soil. You sow into a growing medium—a material that supports the roots in place of soil and supplies water and nutrients. The flow itself is simple. Set the medium into dedicated trays and soak it thoroughly in water, then place seeds with tweezers or a seeding machine. After sowing, keep the humidity with a lid or cover to prevent drying and seed wash-out, spray water gently with a

mister, and wait for germination while managing temperature, humidity, and light. Seeding density varies by crop.

While you are new, you are probably taught to worry about the "germination rate" here. What percentage put out shoots. If close to 90% come up, you feel satisfied once: "this batch is good." That itself is not wrong. But when I look back on the batches with so-so yield at my sites, more often the thing I can point to is "back then, they weren't even," rather than a low germination rate. The shift in perspective I want you to learn here is this: **what you should really watch in seeding is not "what percentage came up" but "how evenly they got started."**

The germination rate does not reflect "evenness"

The germination rate counts only whether a seed put out a shoot or not. It is a number tallying the binary of came-up or not, and it carries no information about "when it came up." So a tray that got started all at once, evenly, and a tray that kept trickling out over three days both line up as the same 90% if they reach 90% in the end.

But these two are completely different afterward. If the germination rate is "height," then evenness is "width"—the spread in the times at which each seed put out its shoot. At the same height, whether the width is narrow or wide changes how easy the later processes are to handle. A tray that failed to come up evenly, with time gaps, becomes hard to handle from around transplanting onward. If you match the large seedlings, the small ones get left behind; if you wait for the small ones, the whole batch drags out.

Here is the important point. Seeding and germination look like a process that closes in a few days, but the evenness of the seedlings you make there drags on—through transplanting and growth—all the way to the yield weeks later. Germination is not the goal; it is the entrance to a long process that continues up to harvest. So watching evenness is less a matter of adding one more indicator, and more a matter of pushing the moment you judge seeding good or bad backward—from right after germination to the yield of the later process.

Evenness is decided at the "entrance"

So can uneven evenness be recovered in later processes? A clear line can be drawn here.

You cannot.

Evenness is not a "difference" in size but a "difference in time." A seedling whose germination was half a day late is not simply small; it is half a day behind in development. It is younger than the seedlings that got ahead. Even if you add fertilizer or light later, the whole just advances that much, and the gap between the leader and the tail end keeps moving along, still open. You cannot rewind a time gap, time and all, in a later process.

There are ways to "absorb" it through selection or the width of the harvest window: thin out the delayed individuals to line them up with the leaders, sort them by image, take a wide harvest window—these are standard floor processes, not cheating. But what they share is that they are not erasing the time gap itself. If you thin out, those seedlings get discarded; if you widen the harvest window, the shelf turnover develops a spread. In other words, a batch that looks re-evened has usually paid a cost—in yield or in labor—to absorb the time gap; the unevenness has not vanished into nothing.

So treat evenness not as "you can fix it later" but as "absorbing it later costs money." That cost does not appear on the invoice as an "unevenness charge." The labor of thinning out delayed seedlings, the replanting to fill the shortfall, the sorting labor before transplanting—the more uneven the batch, the more these invisible costs pile up little by little. Go make the evenness at the entrance. That is the surest way to reduce, in advance, the invisible cost you pay later.

Record evenness as the "width of getting started"

The width can be grasped well enough with two notes. Once a day, at a fixed time, look at the tray just once and jot down two points: "the day the first shoot came up" and "the day it was more or less all up." The difference between them is the width it took to get started. Rather than raising the precision of your observation, looking at the same time every day to keep conditions constant works far better, because it lets you compare sown batches with the same yardstick.

There is one knack. It is better to take "the day it was more or less all up" as "the day about 80% came up," not 90%. The last 10% is pulled by seeds that come late or never come at all, and the date blurs easily. And this 80% is not a number only for the record. The moisture-retaining cover (dome) you put on right after seeding is removed at about the point where 80% have germinated. If you are late removing it, light does not reach the seedlings and they get leggy and stretched, and the excess humidity makes disease easier too. The

work cue "remove the cover at 80%" and the observation cue "record the day it was all up at 80%" overlap at the same point. If you jot the date down while you are removing the cover, the operation and the record are done in one stroke.

Just by lining up, batch by batch, the difference between the first shoot's day and the 80% day, the batches that come up evenly and the ones that scatter separate out fairly clearly. Detailed observation is enough once a batch that bothers you shows up.

For the cause of unevenness, suspect temperature first

Among the causes of uneven getting-started, the one easiest to tackle on the floor is unevenness in the environment. There certainly is individual variation in the seeds themselves, and this sets the "floor" for evenness. No matter how much you even out the conditions, you cannot get more even than the seed variation. But in what I have seen in PFAL propagation, the batches that scatter more often had not had the environment pushed all the way down to that floor. The temperature and moisture after sowing are not even between the edge and center of the tray, or between the upper and lower shelves. Within the same tray, one seed is in the condition where the germination switch turns on, and another is not yet. That comes out as a time gap.

So in terms of order, first crush the environmental unevenness. To get a quick bead on it, start with temperature. The optimal temperature for germination differs by crop; in my feel from raising leafy greens, komatsuna and mizuna get started evenly in a slightly higher band than lettuce—about that much of a difference. Rather than memorizing fine numbers, when germination is delayed it is worth first suspecting whether you have strayed from the optimal band of the crop you are currently using. Moisture unevenness also affects evenness, but temperature and moisture are linked—warm spots dry out easily—so if you look at temperature unevenness first, you can more or less guess the moisture too. Moisture in the water-uptake period especially matters, so soak it well early, and lower it a little once germination is confirmed. If this raising and lowering is uneven by location, it too leads to differences in getting started.

You do not need to measure everything for where to look. Just the two points where a difference is most likely to appear. For a shelf, the upper and lower levels; for a single tray, the edge and the center. These are structurally the places where a difference appears easily.

Place one thermometer at each and match it against the width of getting started. If the batches that tend to lag are biased to a fixed level or fixed position, that is the identity of the unevenness. After that, it is just raising the temperature of the lagging level, swapping the placement, and for unevenness you still cannot even out, moving the air with a circulation fan—and then repeating batches with the same yardstick.

The menu of countermeasures itself—crushing temperature unevenness and reviewing the seed lot—is no different from usual. What is different is the timing. Until now, you tended to notice temperature unevenness only after the seedlings scattered and gave you trouble at transplanting—too late, after the fact. If you watch the width of getting started at the entrance, you can play the same hand ahead of time, before the seedlings have grown up. That is the practical benefit of holding onto the single perspective of evenness.

The unevenness that remains even after you push it—that is a matter of the seed lot. Even after you crush the temperature unevenness, some unevenness remains. That is the floor of the seed's own capability, a wall you cannot cross by how you sow. If batches keep scattering even after you push it that far, it is no longer a matter of how you sow but a matter to look at on the seed-lot and procurement side. It is better to keep the line drawn between floor countermeasures and matters to look at in purchasing and lot selection.

For that reason too, keep storage basically low-temperature, low-humidity, and shaded; thoroughly practice first-in-first-out, using older stock first; and note the lot number. Seeds can lose vigor without any change in appearance, and that shows up later as poor germination. When evenness scatters, to separate whether it was the sowing or the lot, nothing starts unless there is a record of which lot was used when.

That is the perspective I want you to acquire in seeding. How far to push the optimal germination conditions and seed selection and turn them into profit—that judgment is territory you solve site by site, so in this book I stop at the entrance. The deeper judgment I leave to *172 Hints*.

Propagation



Once seeding is done and shoots have come up, you enter the period of raising those shoots into seedlings that can withstand transplanting. This is "propagation." As a process it is the plain stretch sandwiched between seeding and transplanting, but the quality here almost decides the subsequent growth results. While you are new, harvest and transplanting look more conspicuous, but from a feel built over long years on the floor, a section that stumbled at the seedling stage often cannot be recovered to the end. Some farms set up a dedicated propagation room or propagation racks and build the environment carefully just here.

Why go to such lengths over the seedlings? The reason is simple: a sturdy seedling makes everything afterward easier. A seedling with firmly spread roots settles into the environment at the transplanting destination easily, and establishes quickly. Growth then proceeds smoothly as is, so the period up to harvest shortens. A seedling in good nutritional condition is also strong against disease. Conversely, if you send out a thin, weak seedling as is, it scatters after transplanting, disease appears easily, and in the end it affects yield. Think of propagation as an investment to raise the final yield.

The thing to be most careful about in raising seedlings is not letting them get leggy. Legginess is when the stem alone grows thin and long and becomes weak. The cause is mostly insufficient light and too-high temperature. After germination, in the period when the cotyledons open and begin photosynthesis, if lighting is late, they get leggy all at once. If you run without light during the germination period, start lighting once the cotyledons open, before it is too late. The timing here is a point to nail down on the floor.

The environmental points to hold are continuous with those at seeding—the four of temperature, humidity, light, and nutrient solution.

- **Temperature:** match it to the crop and growth stage. For lettuce, it is common to manage the propagation room's air temperature (not the water temperature) at around 25°C during the day (since you want to suppress legginess, lower it a little at night to tighten them up). Small seedlings are weak against low temperature, so do not lower it too far.
- **Humidity:** too high makes disease appear easily. Around 60–70% relative humidity is the guide.
- **Light:** what matters for preventing legginess is light. Many varieties do not need light for germination itself, but once the cotyledons open, secure an appropriate light level. If the start of lighting is late, that alone makes for weak seedlings.
- **Nutrient solution:** while the seedlings are small, keep the nutrient solution concentration (EC) low and raise it as growth proceeds—that is the basic. That said, in my experience, if management is difficult, running at a low, fixed EC works fine in practice (this does not mean keeping it constant at the same high EC as the main cultivation area, but keeping it constant at a low-to-medium value).

What you aim for in raising seedlings is not merely large seedlings but even seedlings. If growth scatters within the same tray, you cannot match the transplanting timing, and the subsequent management stays troublesome the whole way. Uneven watering, uneven light or temperature by shelf position, uneven seeding density—the causes of unevenness are mostly around here. When you pull out a single tray, be able to create, every time, a state where the seedlings' height and leaf expansion look even. This is where propagation skill shows.

Once the seedlings grow and their leaves begin to overlap with their neighbors', that is the sign for the next process, transplanting.

Transplanting & final planting



Seedlings that have finished propagation are moved to a wider space. If you leave seedlings whose leaves have begun to overlap with their neighbors', light does not reach them, the roots are cramped, and they cannot take up enough nutrients. By moving them to a wider space, the light received per plant returns and growth accelerates again. Repeating this move step by step, the last one—planting at the spacing that carries them through to harvest—is final planting.

Decide plant spacing not by "planting convenience" but from "shipment"

At final planting, are you deciding "how many plants to put in per square meter" by the convenience of the work in front of you—whether you can plant fast, whether losses come out? How many panels one person can handle, how few you lose at establishment. That yardstick itself is important. But density alone, if you decide it by that sense of speed, quietly shaves the harvestability and the salable weight per shelf down the line.

At planting it feels good to pack them in fast, but the harvest slows down at your hands later. A packed shelf looks densely full and seems to have good yield, yet each plant comes up on the small side, and when you weigh them, "plants that reach the target size" turn out fewer than you thought. The planting spacing affects not only the convenience of the work in front of you but the salable weight you finally weigh.

Why does this happen? The amount of light falling on the shelf does not increase even if you raise the density. In the end, that fixed light is just being shared among the number of plants. So when you increase plants, each plant's share decreases and it comes up small. Here is where it is easy to get it wrong: the total harvest per unit area—the gross weight—actually keeps rising up to a certain density as you increase the number of plants. What plateaus is not the total but "the weight that reaches the target finished size and can be shipped as grade—the salable weight." Looking densely full while the usable weight is not growing is usually proof that under-grade small plants are increasing.

Conversely, if you take plant spacing too wide, you cannot make use of the limited cultivation space, and the harvest volume per unit area drops. A vertical farm is a system that raises production efficiency by stacking grow beds vertically, so you want to use the space fully. But if you pack too tight, growth suffers. Reconciling these two is the crux of final planting.

So reverse the order. First, place the finished size you aim for per plant and the gap where the hand slips in comfortably for harvest. Work backward from there to decide the spacing, and reconcile the planting speed last. "Not the upper limit of the planting side, but drawn from the harvest side and the salable weight per shelf"—thinking in this order changes how density looks quite a bit.

Note that this "packing too tight is a loss" assumes head-forming leafy greens or large-head leafy greens shipped by the finished size of a single plant. For items sold by count or total volume, like baby leaf, the loss of a plant falling under grade is less likely, so the just-right density leans toward the more packed side. It is simply that the balance point differs by item.

See it not by count but by "the circle each plant spreads"

Even so, the hands on the floor tend to be pulled toward "if I pack a little more, I can earn more count." This is not because they are greedy. How many you planted can be counted on the spot, but the seconds each harvest takes and the weight that reached grade do not come out until much later. They are just being reined in by the number close at hand.

So what you should keep at hand is not the count but the image of "the circle each plant spreads." When planting, picture, one plant at a time, the circle of leaf spread at the size you aim for, and watch only how much that circle overlaps with its neighbors'. When the circles collide and begin to bite into each other, that is borrowing in advance against both "fighting over light and falling under grade" and "the harvest hand not fitting in." If you want to keep a bit more as a physical marker, draw a single circle on the final-planting panel with the same diameter as the leaf spread of your target size. Each time you plant, compare that circle with the plant spacing in front of you, and make it a mark that tells at a glance—if it is packed tighter than the circle, you are borrowing against the future. Even if the hole pitch is fixed and cannot be moved on the spot, it becomes a guide when you decide which panel to use next.

Level differences, yield, and automation are a separate story

Let me touch on one common snag. "Even planting at the same spacing, the upper and lower levels come up a little differently." The culprit of this difference is usually not light. A PFAL rack is normally designed on the premise that the same panels are fixed at the same height on every level and that light is even regardless of level. What remains and takes effect is unevenness in temperature and airflow—heat tends to accumulate on the upper levels, and

the way the wind and CO₂ circulate is not even by level or position. So if a certain level always comes up small, trying to catch it up by tweaking density level by level tends to make final planting and panels complicated to manage while the crucial cause stays untouched. That is a matter to fix not with plant spacing but with HVAC, air supply, and equipment.

One more thing: when you pack them and the leaves interlock, the air that promotes transpiration reaches the inside of the plant less easily, and depending on the variety, the tips of the inner leaves die back—tipburn-like symptoms increase. Varieties whose leaves stand upright and leave gaps in the plant spacing hold up even when packed somewhat, but varieties whose leaves lie down and curl in have their centers close up easily and are weak to packing. So "the more prone-to-collapse the variety, the larger you see the circle, and stop before they overlap." The judgment to pack density and the choice of variety are things you look at connected.

When labor cost starts to weigh on you, the talk tends to turn toward "why not just automate transplanting," but it is safe to look at this with your expectations lowered a notch. What a machine is fast at is "planting speed," and the light-receiving area and the harvest gap that determined the yield—the quality of the arrangement—do not improve on their own just because you plant fast.

Finding the optimal plant spacing, the investment decision on equipment to fill level differences, whether transplanting automation pays—this area is territory you can judge only after you actually measure with the yardstick of shipment weight per shelf. The procedure for measuring the three outputs (weight that reaches grade, the seconds each harvest takes, yield) in linkage, sorting by variety, and a realistic evaluation of automation are dealt with in detail in *172 Hints*. As a new hire on the floor, first just take home the momentary habit of comparing the panel's circle with the plant spacing in front of you each time you plant—that is enough.

Harvest & trimming



When the finally-planted plants have grown out, comes the last process of cultivation—harvest and trimming. It is the moment when the seeds you sowed yourself are finished as vegetables, but at the same time it is the starting point of a new process toward sale.

I have been involved in the harvest of leafy greens at PFAL vertical farms for over ten years. The consultation I receive most in this process is the tug-of-war: "cut fast and quality drops, work carefully and the count does not come out." Build a line that cuts fast, and by the time it is on the store shelf the leaf tips are damaged. Ease your hands so it does not get damaged, and this time the day's yield does not reach the target. Many people will recognize the sense that whichever you prop up, the other collapses.

But this only looks like a two-way choice because you have put efficiency and quality on a single scale. Look closely and harvest has several knobs you can turn separately. **When to cut, how to move, what to cut with**—once you separate them out, the number of moves increases. Even setting aside the big machinery like light and temperature for now, with only what you can move on the floor starting today, the story is no longer a single "speed or quality."

Before turning the knobs, level the floor of hygiene

Before turning the knobs, there is one more thing to place first. The "floor of quality." Washing and drying the tools and harvest crates, frequently clearing water and debris from the harvest area—for hydroponic leafy greens, this becomes the foundation of quality before the cut. If you pack with water still on them, it becomes an entrance for mold and rot. This is what I have repeated till I'm hoarse on the floor.

Washing, drying, and clearing up cost no money, can be done starting today, and can be redone. That is why it is also a knob you can turn first of all. If you talk about the cut while this stays loose, your footing stays hollow. The idea of hygiene itself we handle together later in "thoroughgoing hygiene management," but on the harvest floor, rather than "cutting off bacteria from somewhere," the stance of not leaving water and residue behind, not increasing them, not spreading them, is enough.

When to cut—time of day and the day of the cut

First, the time of day within a day. At the sites I have seen, once the afternoon came, fatigue set in, and what was cut turned out later, at the boxing stage, to have rough cut surfaces and uneven lengths. Conversely, from the start of work through midday, concentration held, and even at high speed it was even.

However, which time of day gets rough differs by site and by person. There are surely sites where hands and eyes are cold first thing in the morning and the first hour is the roughest. So rather than fixing the time of day, watch when things get rough at your own site, and steer just that band back toward evenness. Once you know the rough band, treat that time as a separate thing: lower the speed knob for a while and concentrate only on making the lengths even.

When you are in the zone, evenness holds even if you raise the speed. Even within the same harvest, you split the aim by time of day.

The interesting thing is that once the quality of the rough band stabilizes, the speed afterward actually rises too. Since the rework of fixing things at the boxing stage decreases, the later process gets faster. Rather than pitting speed and quality head-on, if you decide in advance which to prioritize by time of day, there is a band where both follow along on their own.

There is also something that matters at a slower level—"the day of the cut," which day you cut on. You shift the planned harvest day by one day, and whereas the previous day had small plants mixed in, the next day they were even and both cutting and boxing finished smoothly. Have you had that experience? But if you just shifted a day by hunch, it does not become a reproducible arrangement. In the first place, plant evenness is largely decided by the density at final planting, by earlier processes, and, going further back, by the evenness of germination, so it is not just a matter of the cutting side. Even so, choosing an even day to cut is something you can do on the harvest floor.

How to move—the evenness of the cut surface changes with your motion path

In the afternoon, when fatigue sets in, you are snipping with just your wrist. As you pile up what you cut in your left hand, the motion of reaching for the next plant is somehow awkward. Yet in the morning, when you are in rhythm, you turn your whole arm—your whole body—to face the plant. The same person, mind you. That "how you move" affects the evenness of the cut surface.

Wrist-snipping gets rough probably because the cutting range is too wide and you are reaching only with your hand toward distant plants. So in situations where you move the plants to a workbench or conveyor to process them, set the workbench height so the elbow bends slightly, and narrow the reach to within a single step. Cut only within reach, then bring your whole body in. Then the angle at which the blade enters is even every time, so the cut surface is less likely to scatter—a feel I have seen many times on the PFAL leafy-greens floor.

That the postural load drops is itself something measured in research. In a report that did motion analysis of leafy-greens harvest at a vertical farm, compared with standing or a high workbench, sitting with the workbench set to elbow height and narrowing the work range reduced both the angle of tilting the neck back and the angle of thrusting the shoulders forward. However, this measured the case of sitting at an independent workbench, so it does not directly apply to cutting on the spot on the upper levels of a multi-tier rack. Where it takes effect is in situations where you move the plants to a bench or conveyor to process or sort them.

What to cut with—the constancy of the motion, more than the tool

The matter of tools. When cutting leafy greens, some people use scissors, others draw through smoothly with a knife-like blade. Rather than scissors-or-blade deciding evenness, for both it is "does the blade enter at the same angle in the same position" that matters more. Scissors make the closing position easy to fix, so length is easy to even out. A draw-cut can give a smoother cross-section. It is not a matter of which is superior, but the idea of choosing whichever suits your own motion path.

There is one more thing around tools where hygiene comes in. Knives, scissors, and harvest crates—wash and dry them promptly after use. Beyond maintaining the edge, it is a floor basic for cutting off the contamination you do not want to bring into hydroponic leafy greens.

Trimming—the finishing process that creates product value

Once you finish cutting, comes trimming. Trimming is the work of finishing the harvested vegetables. It is not merely a matter of appearance but bears on product value itself. A vegetable with a neat shape and clean trimming looks fresh and appetizing, gives a sense of reassurance, and conveys an impression of high quality. For leafy greens, you drop a few damaged outer leaves and the base, and leave the clean inner leaves. Standards for the number of leaves, length, weight, and shape are sometimes finely fixed by the farm or the sales destination.

What you want to be conscious of here is that trimming works against you if overdone. It is the work of dropping damaged outer leaves and the base, but if you remove too much, the salable weight drops as is—it works in the direction of lowering yield. Conversely, if you nick or tear leaves, product value drops. And sloppy work produces rework and takes time in the end. So decide the size and quality standards in advance and sort into grades, and the judgment will not wobble from person to person.

What looks like a difference in skill, and what design can raise

Finally, one realization remains. When a difference in harvest volume or quality appears between a veteran and a new hire, you tend to settle it with "that person's skill isn't there yet." But in light of the talk so far, it may not be a skill problem but simply that the workbench height does not fit, that the arrangement of the cutting day is not even from person to person, that the hygiene procedure has not been handed out.

Here we separate two things. Design—workbench height, the arrangement of the cutting day, hygiene and trimming procedures—raises the "floor" of both veteran and new hire. If the procedure is handed out on a single sheet of paper, the new hire's minimum line rises. On the other hand, the "ceiling"—a skilled person's output, judgment in difficult situations, the adjustment of force—that is decided by skill. Evening out the design does not erase it, nor should it be erased.

Confuse them and it becomes a waste. If you settle a level difference that design could actually fix with "that person's skill isn't there yet," you overlook a gap a single sheet of paper could have filled. So first raise the floor with design, and only what remains after that do you, for the first time, call skill. The order is like that.

Note that from here on, there are also knobs that cannot be moved from the harvest floor alone. The preparation of tightening fertilizer a few days before cutting to lower the leaf nitrate, the trade-off where raising yield lowers nutritional value—as with light and nutrient solution—and the judgment of whether to bring in automation machinery: all of these are deep dives tied directly to yield and the bottom line, requiring the judgment of "how much makes it worth it." Since these are beyond the entrance to harvest, I place only the entrance to the way of thinking and leave the details to *172 Hints*. Improving the harvest process, in the end, affects the whole farm's profit.

Post-harvest work



Cut vegetables are not something you can just leave sitting. A vegetable loses freshness from the moment it is harvested. In appearance it loses its juiciness and wilts; in taste the flavor fades and bitterness and harshness increase; and nutritional value drops too. The chain of work up to shipment decides how far this freshness can be protected.

Post-harvest work is broadly four things. **Conveyance** from the cultivation area to the work area (keeping temperature during transport, absorbing shocks with containers and carts).

Weighing and sorting to align size, shape, and weight to grade. **Packing and packaging** into bags and packs. And **storage**, resting them at appropriate temperature and humidity. As a procedure, it flows in this order.

But there is one thing here I want to shift the view on.

The moment you confirm quality, and the moment the customer confirms it

You weigh, package, inspect, and ship. You run each step properly. And yet, after shipment, a complaint comes: "the leaves were wilted," "it was damaged by water droplets." Weighing was to grade, packaging and inspection were by the procedure. And yet you are told this at the destination.

Think about it and the last moment you confirm quality is at the inspection table, while the first moment the customer confirms it is when they open the delivered box. Between them lies, in its entirety, the transport time, temperature, and shaking. If you overlook water droplets at inspection and pass them, inside the sealed box that moisture has no escape and steams the leaves the whole way there. Even if there is no problem at the shipment point, by the time it arrives it is damaged.

In other words, post-harvest work is not a process that merely confirms the current state; it is a process that, right here, decides the state hours or days later. So the inspection standard too gets redrawn—not just "is it within grade" but working backward from "what will it be like when opened."

The first step of that backward reasoning is to become the customer yourself. Pull one box from today's shipment. Instead of leaving it on the shipment shelf, rest it for the same transport time, in the same temperature band, and open it yourself at the hour the other side will open it. Then "no problem at boxing, water droplets after half a day, wilting after one day"—what happens at the exit of your own process lines up on a time axis. This does not predict beyond the logistics that follow. It is a very cheap verification to isolate only the damage you built in within your own process, before handing off to logistics.

The three types of damage

Damage that appears with time is better not lumped together as "freshness dropped." Touch it with your hands and it separates into several types. Because the physics at work is different for each.

Wilting (dehydration) has leaves with no firmness and is light. Weigh it and it should be lighter than at shipment. This is a sign that, before the cooling stage, water is escaping from the leaves. When wilting appeared at my sites, usually the time the leaves were left bare in dry air—between harvest and pre-cooling and packing—had grown long. The moves are: do not let them dry before cooling and before packing, and tighten up the processes that leave the

leaves exposed. If wilting tends to appear before packing, humidifying to suppress the dryness around the leaves is also effective. But note that this humidifying works only "before packing, on the wilting side." If you let dampness build up after bagging and sealing, this time it swings to the next two sides. Even for the same "moisture," the move reverses by situation.

Water droplets (condensation) appear as beads on the inside of the bag. It is the type of sealing them up while still warm. If you put leaves not chilled to the core into a bag and seal it, the inner moisture loses its escape and becomes dew on the inside. The moves are: drop the temperature all the way before sealing, or switch to a packaging that lets it escape.

Conversely, if you seal after chilling to the core, sealing can even work in your favor by retaining moisture. It is not that sealing itself is bad, but that sealing before chilling to the core is what takes effect.

Rot (steaming) tends to appear at the bottom tier and center of the box. It is the type where you stacked them up before they cooled to the core and the central heat could not escape.

The moves are: drop the core temperature before stacking, and stack in a way that lets air pass through. There is one more route here that temperature and stacking alone do not explain. Rot is also affected by the number of bacteria that were on the leaf surface to begin with. If the tools or crates are dirty, you pick up bacteria there, and then the dampness and temperature inside the bag advance it. So rot countermeasures are not about bringing in special sanitizing equipment—first, the ordinary cleanup of washing and drying the tools and crates you used, wiping the water off the workbench, and not letting the debris pile up.

Bacteria are everywhere to begin with and cannot be made zero. So rather than "keep them out," "do not increase them, do not spread them." This is the hygiene routine that belongs to the floor of quality, before you even talk about types.

At what temperature and how many minutes a type crosses over shifts by crop, by packaging, and by logistics conditions. You cannot make a flat assertion here. Following one box at your own site and confirming where the type appears is the sure way.

Order the moves as "operation → consumables → equipment"

Once you have laid out moves by type, this time line them up on another axis. By the size of the effort and money it takes to change them, the moves separate into three layers.

The first is the **order, timing, and motion path** layer. The order of cooling, how you stack, the time leaves are exposed—these can be changed by operation starting today. No money, just decide and run it. The order of releasing inventory is here too. First in, first out. If you break this and let old inventory stagnate on the shelf, you give it that much more time for dehydration and rot to advance. The hygiene of washing tools and clearing water lines up in this free layer too.

The second is the **consumables and jigs** level. Switch the packaging material to one that lets moisture escape, change the shelf height, add coolant packs. You can try it with a small investment, and it stays within the range of consumables.

The third is the **equipment and contracts** layer. The pre-cooling chamber, the packaging machine, the temperature band of the logistics carrier—these are matters you take upstairs.

What matters is the order. First push the first-layer operation all the way. Types that vanish with that need no equipment. Reverse the order and buy a pre-cooling chamber first for a type that operation could have erased, and the type will not vanish no matter how much money you spend. That said, this does not mean "everything vanishes with operation alone." There are types that operation tweaks alone cannot reach—the speed of dropping the core temperature, the way of sealing. So the reason to start with operation is not that everything vanishes with operation, but to cheaply isolate, before you buy, "which types vanish with operation and which need equipment." And if you have a record from the first layer sorting the types, then when you take an equipment or contract case upstairs, you can say "to stop which damage, how much." The material for the decision is in hand.

Damage you can prevent post-harvest, and damage decided upstream

Even after packing it down layer by layer, there is still a question that remains. Post-harvest work does not decide "everything."

The way to tell is this. Follow one box: no problem at shipment, and after half a day or one day a type appears. Wilting, condensation, steaming. This is the side you can change post-harvest. Damage that appears with time is created by your own handling. Conversely, the cut surface is already brown from the moment you open it, the leaves already have damage, the firmness was weak to begin with and they wilt right away. This did not appear over time; it was in there from the start. The choice of variety, the timing of harvest, the way of cutting—it

was decided at harvest itself or before it, and no matter how carefully you handle it post-harvest, you cannot recover it. Damage that entered upstream, return upstream.

Post-harvest work is not the place to shoulder everything. The traits decided upstream, and the price and the brand, cannot be changed here. But the range you are finalizing here—the state when the customer opens the box—that alone you build to completion cleanly. Whether a load once bought gets chosen again, or becomes a complaint and the business thins out—what divides them is whether it arrived in the promised state when opened.

Note that if you have an outlet that routes leaves that did not reach grade to cut-use or processing feedstock rather than disposal, the portion you could not fully prevent with operation does not remain a pure loss. How far you can recover it depends on how you build your sales channels, but this outlet design, and the judgment of which type to route equipment investment toward, are decisions tied directly to profit. I place only the entrance to the way of thinking here and leave the deeper working-out to *172 Hints*.

Managing and training staff

Up to here the focus was on seedlings and numbers. From here we enter the last of the three layers—the layer of people and organizing work. Technology and equipment alone do not make a vertical farm run. What runs it is people, and how you raise people quietly governs the floor's results. Compared with capital investment it looks plain, but in fact this is where it takes effect most.

When teaching, the first wall is "that person's intuition." Yield is not stable. Trace the reason and it always ends at a particular someone's judgment. The floor changes depending on the day that person is there or not. Add people and reproducibility does not come; try to teach and the person themselves cannot put it into words well—at the root of this anxiety is probably a single assumption. The premise that intuition is an individual's experience and ingenuity, entirely their own, and cannot be taken out. Let us take off that premise once.

Intuition can be divided into three layers

A veteran decides on the spot when to harvest. How do you hand that judgment to the next person? It is not a matter you can settle by making a manual, but neither can "watch and learn," because the floor stops the moment that person quits.

Try asking "what did you look at to decide," and what comes back is usually "just a feeling." But observe closely and the color of the leaves, the posture of the plant, the difference in growth by rack level—the person is looking at several things. They just cannot verbalize it; they are looking at fixed cues. This "just a feeling" is neither a lie nor laziness—it is probably a fact—but "cannot put into words" and "cannot be made into a form" are not equal.

I think about a veteran's judgment in three layers by ease of standardization.

- **First layer: values an instrument reads.** They remain as numbers, directly, without passing through the person's senses. However, how to read those numbers—whether it is calibrated, where it was measured, how to handle level-to-level differences on a multi-tier rack—is already the next layer's story. Even for PFAL leafy greens, in the same room, growth differs between a level where airflow stagnates and one where it does not, and a single number misses the real state.

- **Second layer: judgment that branches by condition.** The branching part—if the leaf color is like this, at this stage, for this shipment destination, then harvest. Even if the person cannot say it, if you ask "why didn't you harvest just now" many times alongside them, candidate cues start to come up. But an after-the-fact explanation can diverge from the actual judgment, so cross-check across multiple times and multiple people.

- **Third layer: the feel of the hand.** The part that is genuinely hard to quantify and remains in the hand to the last.

The key is not to try to make everything into a form from the start. Because you lump the three layers together as "intuition," it becomes hard to hand over. If you pick up first the part you can verbalize in the first and second layers, a good deal of intuition can be brought toward ordinary handover items. What remains is only the third layer, the part that stays in the hand. Because you say "watch and learn all of it" without separating that out, it stops the moment the person quits.

Judging the harvest timing is exactly a scene where these three layers overlap. There is a guide close to an instrument—the days of growth from sowing and final planting (first layer). But in the end you look at the appearance—the color of the leaves, the posture of the plant—and decide whether to harvest now or wait a day. This reading of appearance cannot be fully put into words and tends to remain in the hand (third layer). Laying the numbers as the foundation while handing over the final judgment on the spot by demonstration—separated

out, it organizes this cleanly.

Dissolve verbalization into the everyday daily report

Getting the outline of the second layer by listening alongside dozens of times takes considerable time and hands. And you have to do it while the veteran is still on the floor, or you will not make it in time. Yet the floor tends to start in a panic only after it is clear the person is leaving.

So rather than setting it up as a special project, dissolve it into the daily work. If you stop the floor, sit the veteran down beside you, and take testimony, the person braces themselves and it does not last. Instead, on one line of the daily report or handover, add one reason **only on days the judgment split**. "Today I didn't harvest, because the leaf color wasn't there yet." If you try to write on every day, it gets cut first in busy periods. One line runs as an extension of daily work.

As for who writes, rather than making the veteran themselves verbalize, it runs better for the young worker working next to them to jot down "what, when, how" in one line. Since the person can only say "just a feeling," the side holding the question records it. But the "why" part cannot be filled unless the veteran gives a one-word answer on the spot, so proceed while it is still peacetime and they are cooperative. Once it accumulates, occasionally reread the recurring reasons to rebundle them as condition branches, and have the veteran later confirm in one word whether the young worker's line is "right in that understanding." Rather than making it in time, you are creating a state, in peacetime, of being in time.

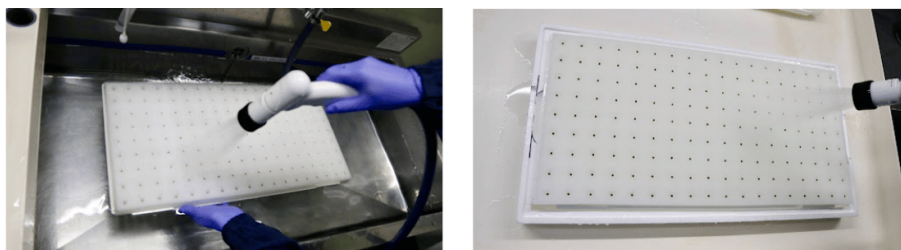
New-hire training also rides on top of this separation. The basics go to everyone—the difference between a vertical farm and conventional agriculture; the basics of crop management such as temperature, humidity, light, CO₂, and nutrient solution; the procedures of each process; hygiene management; quality control; safety management. Once you join the work, a minimum of knowledge is essential, and hygiene and quality especially get emphasis. The specialties beyond that—cultivation technique, equipment management, data analysis—are handed over in stages to people who have finished the basics. This specialty part is exactly the territory packed with the second and third layers from earlier.

There is one thing I want to set down honestly. Before asking "how do you hand over intuition," there is also the move of asking whether you can get by without handing it over at all. Increase

the part measurable by instruments and push the second layer up into the first. Redesign the work to reduce the scenes that require judgment. Simplify the standard so it lands on the same procedure whoever does it. If you can reduce the total amount of intuition itself this way, the effort of handing over becomes unnecessary too. This is the right direction as the main line, and where you can, it is better to lean that way. But the parts that automation and standardization cannot fully reach inevitably remain. So here we handle "having leaned what you can, how to hand over what still remains." How far to lean on systems, and where to spend people and cost—that judgment is the very judgment of cutting opex, and the deeper way of thinking I leave to *172 Hints*.

Once you can make this separation, intuition is no longer "something that vanishes with each person."

Thoroughgoing hygiene management



Once you have set the people in order, you move to the foundation of the floor where those people work—hygiene. The vertical-farm floor always comes with a relationship to pathogens and pests. The thing new hires stumble on most is this hygiene management. Because if you are stuck on the assumption that hygiene is a matter of the volume of cleaning—"how much you wash"—you will inevitably, someday, hit the wall where no matter how much you wash, the numbers do not come down. Let me set down my position first. Bacteria cannot be made zero. No matter how much you isolate the building, some come in mixed into the tap water and the nutrient-solution water, and where temperature and water align, they are always somewhere. So I feel little meaning in pinning down "where" the bacteria came in from. There are only two things to hold. Whether you are creating a place (a breeding ground) where those bacteria increase. And whether you are spreading contamination that has grown concentrated in one place to a place that ought to be clean. Hygiene management starts from switching your head over: it is not the work of increasing the number of washes but the work of not increasing,

not spreading.

Why it bottoms out even if you increase the number of washes

"I increased it from three times a week to every day, yet the bacteria numbers in the cultivation area are the same as before." You thicken the procedure manual, add places to wipe, and still it bottoms out at the same number. While you are new, you tend to worry here that "my cleaning is sloppy," but usually it is not a problem of cleaning volume.

Walk the floor and you notice something odd. The bench you wipe every day is reasonably clean, while under a shelf people rarely touch, or a pipe joint—places not in the cleaning procedure—the bacteria numbers are worse. The place you are washing and the place bacteria are increasing are, to begin with, out of alignment. Rather than washing being insufficient, I see this as because bacteria settle easily in places where condensation and organic matter accumulate and do not dry. Leafy greens use water. Inevitably, in low spots, joints, and around drains, leftover water and nutrient solution accumulate. There the temperature and humidity are convenient for bacteria too. Thicken the procedure manual and add places to wipe, but if the breeding ground for multiplication itself remains, it bottoms out—I have seen this many times on the floor. So what you look at first is not the cleaning schedule but "where does water stop and not dry." If it is designed to dry, it does not come down to a contest of the number of washes in the first place.

In hydroponics, there is one more thing to watch. There is a point that the very fact of the nutrient solution circulating through the facility can become a structure that boosts the multiplication of bacteria that can move within water. But this is a place easily misunderstood; circulation itself is not evil. As long as you secure sufficient flow and run it normally without stagnation, it is my read that circulation does not spike the risk. What becomes a problem is the places where the flow stops and water stagnates, the places that never dry. Whether bacteria multiply easily in the nutrient-solution system depends greatly, before the number of washes, on the structural side—whether the water is flowing properly, whether it is stagnating.

Do not carry concentrated contamination into the clean zone—seedlings and the movement path

Once you have held down the place where they increase, what takes effect next is where you concentrate those bacteria and where you spread them. The bacteria themselves are

everywhere, thin and few. The problem is whether a route remains in the facility where the supposedly-thin bacteria grow concentrated in one place and are carried into the supposedly-clean cultivation area.

There are broadly two carriers. One is the seedlings. The medium and around the roots are, to begin with, concentrated places with more bacteria. If you put them into the cultivation area as is, you place concentrated contamination in a place that ought to be clean. No matter how much you wash the room, the portion that clings to the seedlings does not decrease with the number of washes. The other is the movement path of people and things. Propagation, transplanting, harvest, packaging—rooms that ought to differ in cleanliness get crossed back and forth by carts and people. The cart wheels, the boots, the gloves carry the concentrated bacteria of the dirty side straight to the clean side. So the point to hold is the structure of fixing the place that receives seedlings to a single point, and organizing the movement path one-way from higher cleanliness to lower. Do not let it flow back, do not let it return. Do not bring the bacteria of the concentrated place into the thin place. Hold that down by design, and the cleaning afterward gets a good deal easier.

When inspecting the movement path, dividing the facility once by cleanliness into three helps you see where things cross.

| Zone | Cleanliness | Main places | Point to hold | | --- | --- | --- | --- | | Contaminated zone | Low
| Facility entrance, office, restroom, break room | Stop contamination brought in from outside | |
Transition zone | Medium | Material prep room, changing and handwashing area | Do not
move contamination into the clean zone | | Clean zone | High | Seeding, cultivation, and
harvest areas | Keep this cleanest |

Fix the movement path one-way: contaminated zone → transition zone → clean zone. Before entering the clean zone, always pass through the transition zone, and enter after dropping the dirt with a change of clothes and handwashing. The basic is: do not enter the clean zone straight past the transition zone. If you look at your own facility, the points are more or less fixed. Are people and things going properly one-way from higher-cleanliness rooms to lower ones? Is there any scene where a cart or a person flows back from the lower side to the higher side? Is the seedling reception point fixed to a single spot, or do they come in from here and there? Just making the boundaries visible with floor color-coding and signs changes how people move. With employees merely "being careful," the hygiene environment quickly falls

apart. Setting it in order with rules and structure is realistic.

Problems you erase with structure, and problems you move with operation

Up to here, both the place where bacteria increase and the route by which concentrated contamination spreads have come into view as being on the structural side of the facility. Then what takes effect next is drawing the line. Is what is in front of you right now "a problem that won't vanish unless you fix the structure," or "a problem you can reach by changing how you clean and disinfect"?

What is useful here is the order of "hit it first." Even if you talk structure first, the walls of the existing facility cannot be moved right away. So first try changing the washing and drying methods that cost no money and can be moved starting today. If the numbers come down obediently, it was a problem operation reaches. Conversely, if doubling the cleaning still faithfully recurs at a specific place, in a specific season—for example, coming back to the same south-side line only in the rainy season—I see this as a sign of the structural side. Hit it and hit it and it comes out in the same place; that very bottoming-out tells you the breeding ground is on the structural side. Another cue is whether it comes out the same way in the same place even when you change the person in charge. If it changes when the person changes, it is the worker side; if it comes out in the same place whoever does it, it is the structural side—that is the separation.

Even once you know it is the structural side, redrawing partitions or gradients in an existing facility becomes close to a rebuild. You cannot put a hand in right away. In that case, make operation work "in place of structure." Fix the place you bring seedlings in to a single point, and separate carts between the high-cleanliness and low-cleanliness sides so they do not mix. Even without a physical wall, you can hold down carry-in and crossing that way. Or divide by time. Group clean work in the morning and dirty work in the afternoon, creating one-way flow by time. But unless you insert cleaning and drying to reset after the afternoon dirty work, that dirt carries over to the next morning and the one-way flow breaks. Dividing and then always resetting once is one set. For the water side too, even if you cannot fix the gradient or drainage right away, just draining and drying the pipes and tanks that go unused after work, and the pooled water in low spots, greatly weakens the portion that stagnates and multiplies.

Disinfection is not a cure-all—normal circulation management over sanitizing

There are scenes where you place disinfection (ozone, UV, chlorine treatment of the nutrient solution) on top of cleaning and drying. Cleaning is the process of physically washing away dirt; disinfection is the subsequent process of killing, with chemicals, the pathogens that remain even after washing. You must not swap the order. If you spread disinfectant while organic matter and plant residue remain, the effect drops greatly.

But there is something I want to say strongly here. Disinfection is not a cure-all move where you install it and you are done. Chlorine-based agents, chlorine dioxide, UV, ozone—these disinfections can indeed reduce bacteria. But how they work changes greatly with the type of the target bacteria and the concentration and contact time of the agent, and there is no single standard treatment that works on everything. Moreover there are side effects. Ozone treatment can lower iron and manganese in the nutrient solution, or reduce not just the targeted pathogens but also the beneficial microbes doing useful work within the nutrient solution. You can reduce the targeted bacteria, but you shave away the "raising side"—the nutrients in the nutrient solution and the balance of microbes.

So I stand on the side of thoroughly practicing normal circulation management rather than suppressing with sanitizing equipment. Secure sufficient flow, run it normally without stagnation, wash and dry. On top of that foundation, place only as much disinfection as needed. The order is firmly this. Rather than leaning entirely on disinfection, add disinfection as an aid where you have cut off the breeding ground and the route by structure. Not "safe because we installed sanitizing equipment," but "kept clean because it is running normally"—think in that order.

The three layers the word "safety" bundles together

Push hygiene management far enough and you eventually run into the question "are our vegetables safe?" Scenes come up where buyers at shipment destinations and consumers ask you that. Here is one thing I want to sort out while you are new. The single word "safety" actually bundles together three layers of a different nature.

The first is the **pesticide-free layer**. This is the story of "what you did not put in at the entrance," and it is close to a product label. It speaks only of the single point that no pesticides were used. About water, about insects, about hygiene, the words "pesticide-free" guarantee nothing. "Safe because it's pesticide-free" is just pasting the easiest-to-say phrase over all the

worries.

The second is the **microbial layer**. It is the operational risk that bacteria increase within the facility and can spread along the water channels. A vertical farm is often said to be safe because it is closed, but being closed also means that when something happens inside, everything is connected through the water and the HVAC. If bacteria appear on one shelf, they can ride the water channel and circulate to the next line. The unit for viewing safety becomes not "one plant" but "the range connected by the water channel"—that is this layer. However, this is not a story of "closed = necessarily total wipeout." If anything the reverse: a hydroponic facility that circulates normally with sufficient flow and is properly managed has, to begin with, a low risk of pathogens running rampant. The point is that how you partition that water channel and how you keep the circulation normal is what is asked.

The third is the **contract layer**. When something happens, back to which lot do you recall? When equipment stops and a whole area is ruined, how do the contract and insurance move? What the shipment destination truly cares about is usually not the presence of pesticides but this—the arrangement of who bears how much when it spreads.

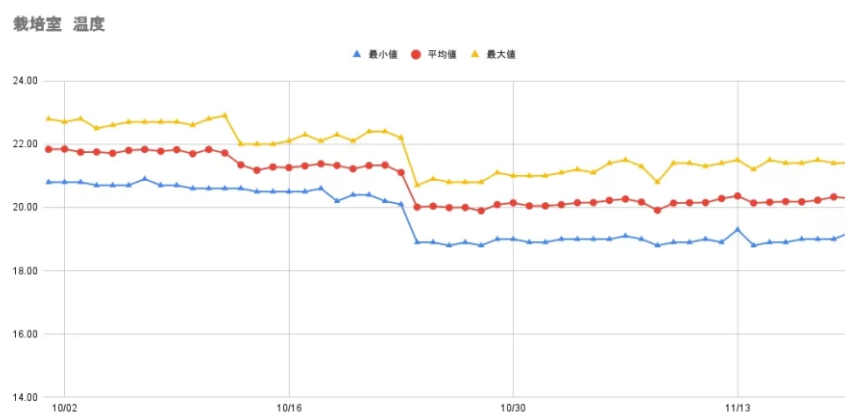
The same word "safety" actually bundles three of a different layer. So if you answer them mixed together when asked, it does not mesh. When a consumer is saying "somehow it feels artificial and I'm uneasy," and you return the technical substance "we separate the water systems," you can end up making them more uneasy: "do you have to manage it that much or it's dangerous?" What I want you to acquire while new is the stance of drawing out the one axis the other side is worried about and returning facts about only that axis. Asked about pesticides, "we don't use them." Asked about water, "it's a nutrient solution with fertilizer dissolved in it, and we manage the concentration and replacement like this." Asked about hygiene, the talk of zoning and drying. Rather than asserting flatly that it is safe, laying out what you do and do not do reaches the other side's unease properly.

And remember too that the range you can answer in your own words and the range you should hand to inspection are separate. The nutrient solution concentration and replacement frequency, the harvest date, the cultivation environment—these are your own records, so if asked, you can answer in your own words. On the other hand, residual-pesticide test values, bacteria counts, and the traceability of origin—even if you say "we do this" or "we don't use that," that is only your own word, not evidence the other side can use as a basis for the

transaction. This is the range you should hand to third-party inspection and records. Conveying early that "we don't handle that" for what you cannot produce ends up more trusted than forcing it through with "it's safe."

Leafy greens are often shipped without washing after harvest, so the hygiene environment during cultivation becomes the hygiene state of the product as is. Hygiene management is plain, endless work. Neither the point of getting certified nor the point where an inspection came back negative is the goal. First wash, dry, and hit it, and read the remaining bottoming-out as a structural sign. Cut off the place bacteria increase and the route concentrated contamination spreads, separate what you can erase from what you move, and keep watching where it repeatedly comes out. This plain stance is what takes effect in the end. Note that how to compose inspection items in the three stages of cause, result, and attitude, what to thicken by shipment destination (mass retail, food service, institutional catering), and the working-out of procurement-specification thresholds, contracts, and insurance are matters that enter the territory of business design rather than farm operations management. I place only the entrance to the way of thinking here and leave the deeper practice to *172 Hints*.

Data analysis



The processes up to here have left records as you ran them. Finally, data analysis connects those records to judgment. When you hear "analysis" you may brace yourself, but the starting point is not buying a new system; it is much closer at hand. This is the talk of the order to hold before a vendor tells you "first, add sensors and collect data."

The records pile up, yet you look only after an incident

You put temperature, humidity, and harvest volume on the daily report every day, and record the electricity cost every month too. That itself is sustained—many sites are like this. The problem is after you put it down. Whether anyone is properly looking at it is doubtful. Only when harvest drops do you trace back for the first time and realize after the fact, "back then the numbers really were off." The electricity cost too ends at glancing and "that's high." The data is already plentiful at hand, yet looking at it is always "after something happens."

What is lacking is not a new sensor. Who looks at what you already have, and when—that is what is missing. There are two ways of looking: "after the fact," tracing back after an incident occurs, and "periodic inspection," looking at fixed points in normal times when nothing has happened. After-the-fact is too late, so it only serves as an answer-check for the cause.

So what you decide before buying a new system is who looks and when—that is all. One approach I sustained on the PFAL leafy-greens floor: for fifteen minutes in the morning, one person reads yesterday's daily report aloud. Temperature, humidity, harvest volume—every morning, even when there is no abnormality. Then "higher than usual, isn't it?" catches at the stage of a small sense of discomfort, before it becomes an incident. The electricity cost too, just by glancing weekly rather than once a month, "only this week is oddly high" comes into view as HVAC overrunning or a door left open. At a PFAL that runs lighting and HVAC constantly in a closed environment, at my sites this area came out earliest.

The same number is a mere record if you look after it happens, but if you look every day in normal times it becomes a yardstick measuring "the difference from usual." Data utilization advances greatly just with that switch first.

Make the width of normal a yardstick, and do not put judgment on one person

What is the minimum set of records to line up? Lined up from the viewpoint of being the basis for management judgment, three kinds: production (daily harvest volume and, if possible, yield), cost (electricity cost and the use of labor and materials), and quality (the grade of shipments and how much off-grade came out). These are usually left scattered across separate ledgers and receipts, so rather than starting to measure something new, line up what already exists in the same place. Making the minimum set starts there first.

Keep up the fifteen-minute morning reading every day and, after a while, the reading becomes a ritual. It gets familiar, it flows past. In what I have seen, this happened almost without fail. So two devices are needed.

The first is how to make the initial yardstick. What is "different from usual" no one knows at first. So at the beginning, resolve not to judge and just do the one thing of lining up numbers. Line up the temperature at the same time and same place every morning, and "ours is around here" naturally comes into view as a width. Write that width down on paper in one line—"the morning temperature is around here"—with the actual values of your own site. Once you put the width of normal into text, the yardstick leaves individual sensation and becomes the same whoever reads it. The knack is not trying to decide the correct standard from the start.

The second is that when the viewer is one person, the sense gets biased. Have one person do the reading, but do not let one person do the judging. The reader can be fixed daily. Just, only when they think "this feels different from usual," toss it on the spot to one more person: "what do you think of this?" This is actually also what prevents it from getting familiar and flowing past. Since perfect concentration every day is impossible, make it a rule to voice it and pull in a second person only when something catches. The idea is that even a skim-read is fine as long as it is a structure where, if one thing catches, you can stop.

Getting familiar is a premise. Keep it in a form that catches even after you get familiar.

Operation that relies on perfect concentration does not last, first of all. Deciding the viewer and the judge separately is plain, but it is a point that takes effect.

Adding measurement comes after you hit the wall of separation

Once the morning reading and the weekly electricity cost let you catch "different from usual," the next wall inevitably comes. The wall where the difference is visible, but why it happened cannot be separated by the records at hand. For example, harvest dropped and the electricity cost also rose, but the daily-report temperature is within the width of normal. Here you cannot name "is it HVAC, is it water, is it something else." The separation stops at the records at hand. That is the first sign to "add measurement." Conversely, if you add sensors before hitting that wall, since there is no habit of looking, you end up just glancing and done. The order is reversed.

Where this order works obediently is in a closed environment like PFAL leafy greens. Because the variables are relatively few and the daily report and electricity cost pick up much of it. In a greenhouse buffeted by outside air and sunlight, or in the fruit-vegetable territory with many variables, there are surely scenes where it does not even work without multiple measurements from the start, so please take it that what I have in mind is only the closed-environment side.

One more thing: when adding measurement, look together at whether "who reads it, and when" can be put on operation. Measurement you can add as one line to the fifteen-minute morning slot lasts. Something you cannot see without opening a dedicated screen separately every day will, however high-function, eventually go unwatched by everyone. This too I have seen many times on the floor. So when you add, always consider whether you can drop one old line. The reading slot is fixed at fifteen minutes; do not increase the line count either. If the temperature you lined up early on stabilizes at "around here" and does not stray for a long time, you no longer need to voice it every morning. You can drop it to occasionally checking weekly. Do not increase the slot; swap the content. The decision to add and the decision to drop are a set.

Measurement to run on a separate track—fault detection and calibration

Up to here has been the talk that "measurement for separation comes after you hit the wall," but separate from that, there is also measurement to run from the start.

Abnormalities like faults and disease, where by the time you notice it is too late and irrecoverable, cannot be caught in time by normal-time reading. Measurement that monitors continuously and raises alerts is something you place without waiting for a problem. During hours when human eyes do not reach—overnight or when short-staffed—do not try to fill it with manual operation; leave it to continuous monitoring.

The other is the calibration of the yardstick itself. If a sensor returns an off value, even the width of normal you took the trouble to write down warps, and you create "after-the-fact" on the data side. Retake, periodically, as a premise of operation, the guarantee that the instrument outputs correct values. Along with that, update and hand over the paper with the width written on it each time a person changes. These two are the typical places where person-dependent operation breaks down, so it is easier to decide them from the start.

The beginning is not a sensor but a single sheet of paper

"We haven't installed sensors or IoT in the first place, so data utilization is still a ways off."

Some people feel this and stop at the entrance, but the beginning is not a sensor; it is a single sheet of paper. If you are not recording anything yet, before going to buy IoT, choose just one number you already care about and jot it down at the same time every day. Just the thermometer value and harvest volume, or even only the electricity bill that arrives monthly, is fine. The easiest place to start is the electricity cost. Since it arrives every month as an invoice, all you do is change "glance and file it away" to "write this month's number next to last month's, lined up in one place." That is already fine data utilization. The question "who looks, and when" begins the moment the numbers to compare become two.

The power to read lined-up numbers grows even if you narrow the items. What I often watched on the PFAL floor was the proportion of waste that comes out at trimming. If you end it at "there was a lot of waste today," nothing remains, but from the same number you can read several facets—the care of that day's work, some flaw somewhere in the cultivation process, whether the plants are packed too tightly. Even a single number, just by lining it up against the width of normal and asking "why is it high today," changes the range of moves you can play. Before higher-grade equipment, this way of reading takes effect more.

Finally, an honest line. What operating the records at hand can cover is the range of "notice a difference and take a move yourself." The temperature is different from usual, a door was open, you forgot to turn off the water supply—the cause is inside your own daily operation, and if the difference is visible you can reach out and fix it. That is where this method takes effect most, and it is broader than many people think.

There are only two places where you let go. One is the wall of separation. When the difference is visible but the records at hand cannot separate the cause, and missing it on a hunch really costs money. There, for the first time, add measurement, and if possible bring in a specialist who reads such data for a living. The other is talk touching electrical capacity, wiring, chemicals, structure—safety and the equipment itself. There you do not experiment at all with your own yardstick. Because the price of failure is not "harvest drops" but something irrecoverable. The guide is this. If you read the number and understand "what to do," keep it in your own frame. If what you understand from reading is only "someone more knowledgeable than me is needed," that is the boundary. And being able to notice that boundary early is itself one of the things the habit of looking every day teaches you.

Note that if you are at a loss from scratch over which items to line up and how, I hand out, as is, the recording formats I have used on the floor as "13 farm operations management templates." Rather than something to apply exactly, I think it is better to look at them as a checklist that shines a light on what your own site is lacking and what is excessive. Talk that steps into finding the optimum and judging cost reduction I yield to *172 Hints*. Once you can turn the records at hand into a yardstick, read it as the next step.

Chapter 3 summary

- Farm operations management divides into three layers: reading seedlings, watching the numbers, and organizing people and work. They are acquired separately, and only when they mesh does the floor run. First get the mechanism and the reading into your head, and start with the layer where you are stuck now.
- Build the production plan backward from shipment. Shipment, cultivation, and labor are three clocks of different speeds, so hold buffers (cushions) separately, and for cultivation alone move ahead by the lead time.
- What you should watch in seeding is not the germination rate but "evenness." The width of getting started is decided at the entrance, and absorbing it later costs money. For unevenness, suspect temperature unevenness first.
- Propagation is an investment in the final yield. Do not let them get leggy; create evenness over size. When the leaves begin to overlap, that is the sign for transplanting.
- Decide the plant spacing at final planting not by planting convenience but backward from shipment (the target size and salable weight, and harvestability).
- Harvest is not a two-way choice of "speed or quality." Separate out when to cut, how to move, and what to cut with, and first level the floor of hygiene. Raise the floor with design, and only what remains do you call skill.
- Post-harvest work is the process that decides, right now, the state when the customer opens the box. Tell damage apart by type, and order the moves operation → consumables → equipment. Damage that entered upstream, return upstream.
- A person's intuition can be divided into three layers; the values an instrument reads and the judgment that branches by condition can be dissolved into the peacetime daily report and handed over. Lean what you can onto systems, and hand over what remains.

- Hygiene is not "block the entrance" but "do not increase, do not spread." Cut off the breeding ground (places that do not dry) and the carriers (seedlings, movement paths), and manage with normal circulation rather than leaning on sanitizing equipment.
- For data analysis, "who looks and when" comes before a new sensor. Make the width of normal a yardstick and catch the sense of discomfort before an incident. The beginning can be a single sheet of paper.

The knowledge that forms the foundation of the floor is now, roughly, all in place. From here, make the basics you have learned solid at your own site, and build on top of them "how to create a farm where profit remains"—that concrete way of judging I leave to *172 Hints to Improve the Profitability of Vertical Farms*, compiled with a focus on profitability. First, make this chapter's basics familiar to your own hands and eyes.

Afterword

Up to this point, we've walked through the whole of the work that is vertical farming — from the future of the industry, to the fundamentals of cultivation, to the realities of the floor. Now that you've read this far, you are no longer the newcomer who stands on the floor with no idea what's going on. Whether you're looking at the equipment, at the numbers, or at how people organize their work, you should now have a rough sense of where each of them sits within the whole. First of all, give yourself credit for having come this far.

That said, let me be honest with you. This book is only a foundation. What's written here — just reading it will get you only halfway. The other half comes only through repetition: tomorrow you try something once on the floor, it doesn't go the way you expected, and you try it again. Knowledge becomes your own only once you put it to use. That's why I wrote this not as a book to be finished at your desk, but as a book to be carried onto the floor and worn down with your own fingerprints.

And when you reach the stage of building on that foundation — of working out how to build a vertical farm that turns a profit — the more advanced, hands-on know-how that bears directly on profitability is gathered in the companion volume, *172 Hints to Improve the Profitability of Vertical Farms*. Where to set the optimum, how to weigh it against cost — it picks up right at the line this book kept drawing, where it said, "from here on, this is territory you pin down with the numbers of your own floor." And if you find you can't work it all out on your own, or you'd like a set of eyes on your own operation, we can also work together directly through my consulting. Which way you go is something your own floor, as it stands today, will decide for you.

One last thing. People sometimes say that vertical farming "doesn't pay." But having spent more than ten years watching over leafy greens on the PFAL floor, I'm convinced there is still ample room to do better, depending on how you go about it. Time and again I've seen a small improvement come back as a difference far bigger than anyone expected. On the floor where you're about to stand, too, there is always room that no one has touched yet. Finding it and setting it in motion — that is the work from here on.

Now, off you go. I'll be waiting for you out on the floor.