Whitepaper:

Fit Roots for Plant Health

How to facilitate root health and -condition to get the best possible Plant Health

Preface

This white paper is one of a series about optimizing plant growth in greenhouses, which Hoogendoorn Growth Management publishes in cooperation with its partners. In previous white papers, several aspects of growing are discussed, taking one or more plant balances as a starting point. For instance, how smart use of screens supports the energy balance of the plant, maximizes photosynthesis, and keeps it active under all circumstances. And how smart irrigation in combination with the right type of substrate/slabs supports the water balance of the plant to prevent water stress. Advanced computerized process control, based on sensors and data analysis forms the linking pin to all this and ensures that all relevant growth factors are taken into account at the same time.

This white paper elaborates on the micro life in the root zone which is often underestimated in the current practice but plays a key role in plant health and resilience.

Introduction

Plant health is crucial to achieving the best possible yield and quality with the lowest possible dependence of pesticides. Although the plant root system is poorly visible, roots play an essential role in maintaining plant health.
Roots are the physical foundation of the plant in the soil or substrate, and they take up water, minerals and metabolites to be transported to the leaves, flowers and fruits. Roots also excrete carbohydrates ('sugars') and other compounds made in the leaves into the root zone to feed different types of microorganisms such as beneficial bacteria (*Bacillus, Pseudomonas*) as well as fungi (*Trichoderma, Mycorrhiza*). These beneficial fungi and bacteria have many functions:

- They form a barrier against root diseases,
- and can even act as a fungicide.
- Some of them are involved in the nutrients cycle,
- or induce resistance in the entire plant.

Together these microorganisms in the root zone – the rhizobiome – form a rich toolbox that can deliver many benefits as long as we treat them right.

A grower can do many things to make roots fit for contributing to plant health.

What is a sound root system?

Obviously, each crop has its typical root architecture, ranging from a superficial root system to deep taproots, or a combination of these. But in general, one can say that a sound root system has a whitish colour, is very much branched (many side roots) and has numerous growing root tips with lots of root hairs. The use of *Trichoderma harzianum* (Trianum) and *biostimulants* (Vidi Parva) in propagation contribute to a branched and healthy root system.

The root tip is where things happen: uptake of water and nutrients for the plant and exudation (or 'leaking') of various compounds to feed the rhizobiome.

Unfortunately, growth and condition of roots are usually poorly visible. That restricts growers to learn about the effects of their actions and growing conditions on the root system.

Is there a 'best soil/substrate'?

Good soil or substrate has specific physical characteristics: balanced portions of solid particles (minerals, organic matter), liquids (soil solution: water, dissolved nutrients) and gas (air with oxygen, carbon dioxide and other gases) (see figure 1). It is also vital that there are sufficient opportunities for both the solution and air, to refresh their composition. For instance, oxygen (O_2) must be able to move in, and carbon dioxide (CO_2) to move out of the soil/air zone.

Of course, this is a very general description, and there are many ways to create a proper substrate. That can be soil, rockwool, peat and many others. But there are significant differences even within each type of soil/substrate.

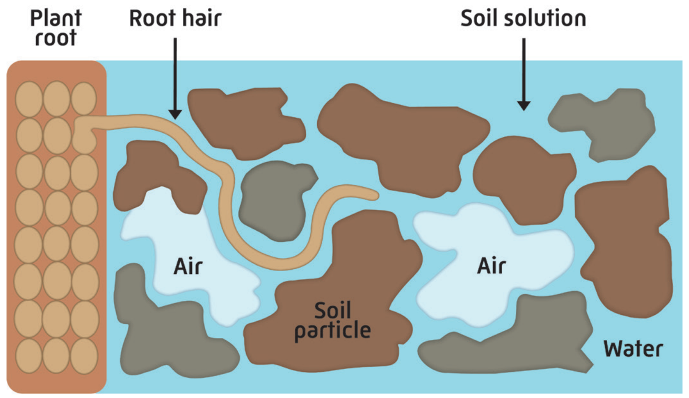


Figure 1: A good soil or substrate has specific physical parameters: balanced portions of solid particles (minerals, organic matter), solution (water+dissolved nutrients) and air (oxygen, carbon dioxide).

Optimal conditions for roots

Root temperature is an essential physical condition since it influences the metabolisms in the root zone and with that the uptake of water and nutrients. High root temperature increases water uptake; low root temperature slows down water uptake.

Although technical options to influence root temperature are often not available, it is nevertheless useful to measure and record the root zone temperature. Most climate management systems facilitate this. Unfortunately, not so many people use this option.

The chemical composition of nutrients in the solution influences what the roots will take up and avail to the plant. Growers can also 'play' with EC to steer the uptake of minerals and water. But that is not the only factor. The pH in the root zone solution has much influence on the availability of each nutrient in a different way (see figure 2). A pH level between 6.0 - 6.5 is the best range for most crops.

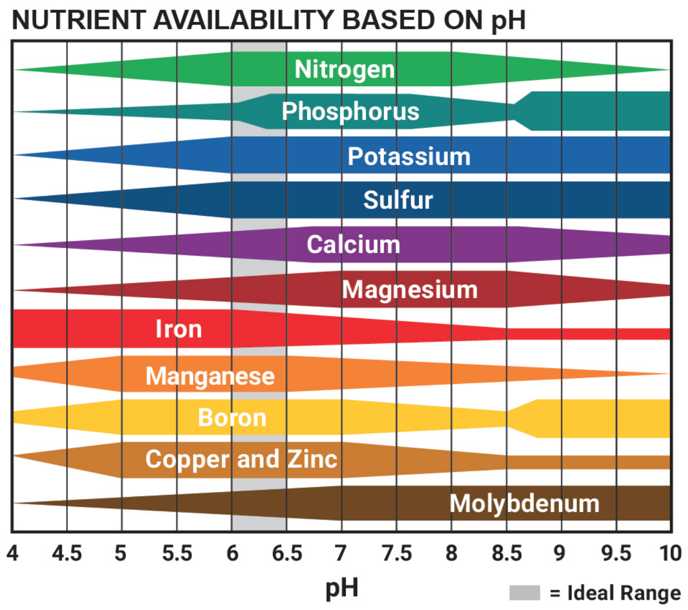


Figure 2: A pH level between 6.0 - 6.5 is the best range for most crops.

Plant roots can absorb/take up nutrients actively or passively; there are still several theories for both mechanisms. But whatever theory applies, it is always beneficial if there is sufficient refreshment of the nutrient solution. This washes out minerals accumulated around the roots and supplements the ones being depleted. Positioning the drippers as far as possible away from the drain holes in substrate bags provides the best possible refreshment in case of hydroponics. Recent research by Saint Gobain Cultilene shows that multiple drain holes in a slab give a more even water- and mineral pattern in the slab.

The composition of the nutrient solution in the root zone is frequently monitored by analysis. But only the composition of the plant sap finally tells us which nutrients the plant has consumed. There is a load of evidence that the composition of the plant sap plays a crucial role in plant health. More and more growers are using plant sap analysis regularly, to be sure the plant takes up enough Calcium, Magnesium and trace elements, and not too much nitrate. Here one could speak about the importance of chemical balance for plant health.

Mineral nutrients are essential in agriculture and horticulture because a plant growing well due to balanced nutrition has the best capacity to defend itself against plant diseases. This is an area of knowledge that is easily overlooked in the study of diseases and their diagnosis.

The biological parameters in the root zone may be the least known but are certainly just as important as the physical and chemical parameters. A diverse network of actively metabolizing microorganisms (also called the rhizobiome) is crucial for plant health and also has many functions related to plant nutrition. Such a living rhizobiome will thrive:

- after inoculation of specific components (*Trichoderma* and others),
- by feeding them appropriately (via plant root exudates, enforced by biostimulants),
- by providing the rhizobiome with a 'healthy and comfortable' working environment:
  - without toxic compounds such as chemical pesticides and disinfectants, and
  - sufficiently aerated substrate and irrigation water.

Oxygen (O_2) in the root zone deserves special attention. Both roots ánd rhizobiome need it to prosper. Too low oxygen levels can boost latent root diseases. Ensuring sufficient oxygen levels in the root zone starts with soil or substrate that facilitates air exchange. Water from irrigation/drip systems should have minimum 7 mg O_2/L, measured at the first drip cycle in the morning. The oxygenation of the irrigation water can be measured with relatively simple devices.

So far we mostly spoke about plant nutrition with inorganic fertilizers, with a risk of over-dosing nitrates which renders foliar tissues more vulnerable to pests and diseases. It is known (but long neglected) that plant roots can also take up nitrogen in other forms than just nitrate (or ammonia), namely as organic nitrogen compounds. There is increasing evidence that replacing (part of the) inorganic fertilizers by organic fertilizers does not compromise on plant growth and reduces the plants' susceptibility to pests and diseases. Microbes in the rhizobiome metabolize organic fertilizers to make them available for the plant. This process stimulates the development and diversity of the rhizobiome. Recent findings indicate that plants can even absorb entire microbes (rhizophagy), release the nutrients inside the roots, then release microbes back to the root zone.

Measurement of the composition of the rhizobiome is more challenging than the chemical and physical parameters. Around 1980, Elaine Ingham developed a set of microscopic methods to quantify the most significant groups of organisms that play a role in the rhizosphere – at that time called 'soil food web'. This method is still practiced, although it is rather labour-intensive and costly. Much progress has been made with molecular methods. These kinds of analysis give a more detailed view but are still too expensive to be used as a routine measurement.

Another method is now coming into the picture: Phospholipid Fatty Acids (PLFA) analysis. PLFAs form a part of the cell walls and characterize different groups of micro-organisms. Eurofins has developed a method to extract PLFAs from a root zone sample and to measure and quantify these compounds. The outcome then is used to assess the amounts of living microorganisms of different groups. PLFA analysis is now being developed as a relatively inexpensive method that could open the door to frequent monitoring of the microbiome.

The role of the root system within the three plant balances

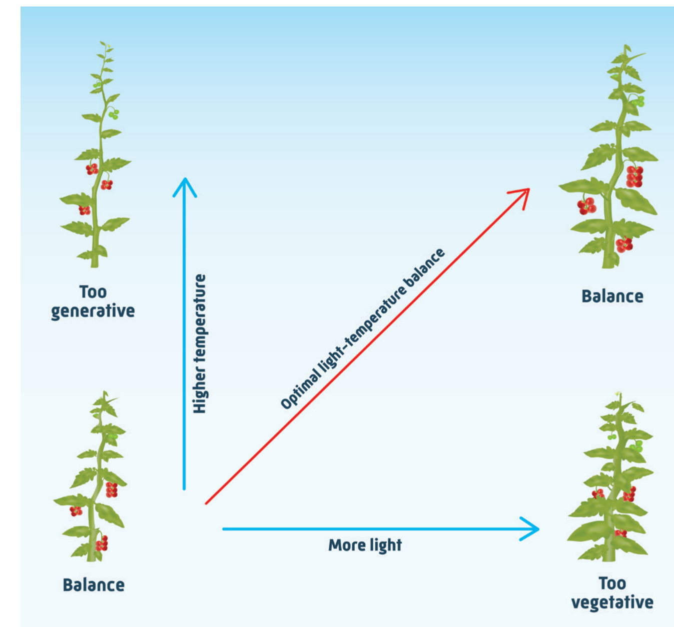
As many things in plant growth are interconnected, it will be no surprise that this also applies to the root system and the three plant balances. This role will be described below.

Roots and the assimilates balance

Developing fruits or flowers are the first to receive assimilates from the photosynthesis in the leaves, followed by growing points, and then the roots. These are the three 'sinks'. That means that in times of scarcity, roots receive the least assimilates. As a result, there are not only less assimilates available to fuel root respiration (to provide energy for root metabolisms), but also fewer carbohydrates and other compounds will be exuded to feed the microorganisms in the root zone (rhizobiome).

A balanced Ratio Temperature to Radiation will provide the best possible supply of assimilates to the root zone to feed the microorganisms.
In times of scarcity, biostimulants (like Vidi Fortum) can help to provide supplementary nutrition for the rhizobiome.

Healthy roots that can provide water whenever needed for optimum leaf temperature regulation are the basis for maximum stomata opening, resulting in maximum photosynthesis in the plants' chlorophyll. The light energy intercepted here and transformed into chemical energy in a range of compounds is not only the source for growth and production but also for feeding the rhizobiome and processes that contribute to plant resilience.



Plant balance is mainly determined by the temperature / light ratio (RTR). The advanced process control systems of Hoogendoorn enables growers to keep a steady RTR strategy on a daily basis, which stabilizes the assimilates balance of the plant. As a result, sufficient exudates are always available to feed the microbiome in the root zone.

Roots and the water balance

Leaves regulate their temperature via evaporation by managing the opening of their stomata. But this is only possible as long as the roots provide sufficient water for evaporation. They can do so if there are enough healthy root tips to uptake the available water, ánd the root system is not restricted in its transportation function by root diseases (such as *Pythium*, *Fusarium*, etc.) that act as barriers for the water to flow upward through the xylem towards the leaves.

Calcium in plant tissue needs special attention. It travels relatively easily with the water flow through the xylem up into the plant, driven by evaporation. Much calcium goes towards the leaves because they evaporate most; little to the growing points and developing flowers/fruits. Calcium is poorly

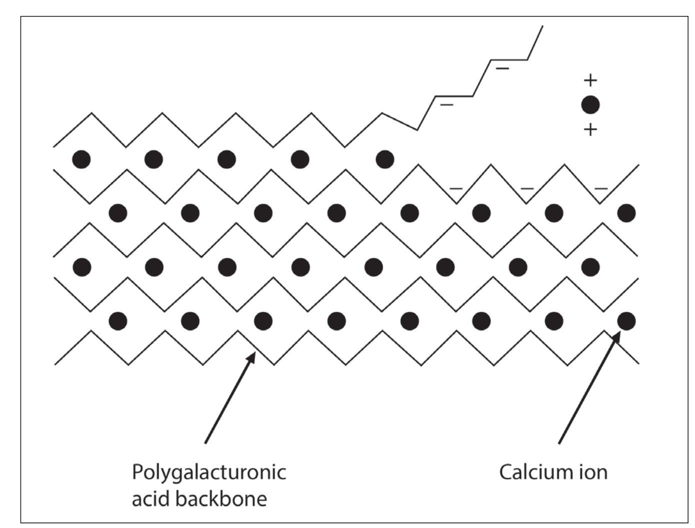


Figure 3: Calcium cements pectin layers together to form elastic and robust cell walls.

mobile in the plant, so if new cells have developed with little calcium available, there is no second chance to get it there. Calcium cements pectin layers together to form strong cell walls. Weak cell walls are prone to be attacked by pests and diseases. Continuous evaporation is the best way to provide a constant supply of calcium and to facilitate the formation of robust cell walls.

Roots and the energy balance

Evaporation is by far the most effective cooling mechanism of the plant. That is why the functioning of the roots is directly related to the plant's energy balance.

The temperature of the irrigation water can influence the root zone temperature and thus the uptake of water and nutrients.

Uptake of cold irrigation water, particularly in the morning, can lower the temperature of the stem base. If the temperature of the stem base drops below the dewpoint, moisture will condensate here, creating favorable conditions for fungal diseases like Botrytis and Fusarium on these plant parts.

In contrast, warm irrigation water will boost the uptake of water (and nutrients). If this happens while plant evaporation is low, droplets form at the edges of the leaves. This is called guttation. Sometimes the free water from guttation can promote fungal or bacterial diseases.

This demonstrates the importance of a well-controlled root zone temperature.

What some thought leaders have said about Plant Health

In 1985 Francis Chaboussou wrote (the French version of) a book called 'Healthy Crops – a new agricultural revolution'. Chaboussou was an agronomist at the French National Institute of Agricultural Research. He introduced the term trophobiosis. The theory of trophobiosis states that the susceptibility of a plant to pests and diseases depends on its nutritional state. Pests and diseases will not attack a healthy growing plant. The health of a plant is directly associated with its internal balance, which is continuously changing. According to Chaboussou, it is not just any plant which is attacked by pests and diseases, but only those which could serve as food for the insect or pathogen. In other words, pests will attack the cultivated plant only when the food that the pest or disease needs is richly available in the plant sap. Most pest and disease organisms depend for their growth on free amino acids and reduced sugars – monosaccharides – dissolved in the plant sap. Plants grown with restricted amount of nitrates, using organic fertilizers and where timely protein synthesis prevents accumulation of free amino acids.
The more plants are being cultivated in a balanced way, the fewer of these substances will be available. So, for a plant to be resistant, it is essential to manage its growth correctly. All factors which affect a plant's internal nutrition balance and functioning can lessen or increase its susceptibility to pest and disease attacks. These could be factors related to the plant (such as adaptation to the local climate, plant age, grafting) or the environment (climate, light, temperature, humidity, wind), or be associated with management practices (such as soil fertility, time of planting, spacing, tilling, pruning, type of fertilizers used).

In short, trophobiosis describes the symbiotic association between organisms where food is to be obtained or provided. The term trophobiosis is also used for a theory of pest resurgence on crops to which pesticides have been applied, where the breakdown of proteins to amino acids (proteolysis) causesing a change in the composition of leaf tissue, making the leaves more attractive for pests and diseases. This results in increasing dependence upon pesticides.

We can conclude that Chaboussou has left a legacy that can transform the way we think about plant health.

John Kempf has taken this on board and developed the Plant Health Pyramid™: an integration of plant physiological research knowledge and practical experiences on how soils (or growing substrates) and crops evolve to a higher level of pest and disease resistance and higher levels of plant health. Several of these insights are very much connected with the Plant Empowerment balances, as will be demonstrated in the next section.
When soils and crops are exposed to regenerative farming practices, they pass through a continuum of 4 stages of increasing plant health. The progression to better health restores the natural and biological abilities of the plant and soil/substrate system to its highest potential. During this process, plants will show increasing immunity to soil and airborne pathogens, better resistance to insects, improved production of lipids leading to stronger cell membranes for tastier fruits with better shelf life, and higher nutritive value.

Levels 1 and 2 of plant health are purely a function of nutritional integrity and are usually not difficult to achieve with most crops and most soils/substrates, especially when we provide balanced mineral nutrition, where foliar applications of plant nutritional supplements can play an important role.
Levels 3 and 4 are not as straightforward to accomplish as the first two levels. For reaching level 3, it is essential to have a healthy, vigorous soil digestive system (soil food web or rhizobiome) capable of providing a significant share of the plant's nutritional requirements. Without this microbial digestive process in place, the plants will never have the surplus energy required to achieve high levels of lipid production and energy storage.

In the first two levels of the Plant Health Pyramid™, changes are taking place in the plant chemistry. The third and fourth stages involve changes in biology in the rhizosphere.

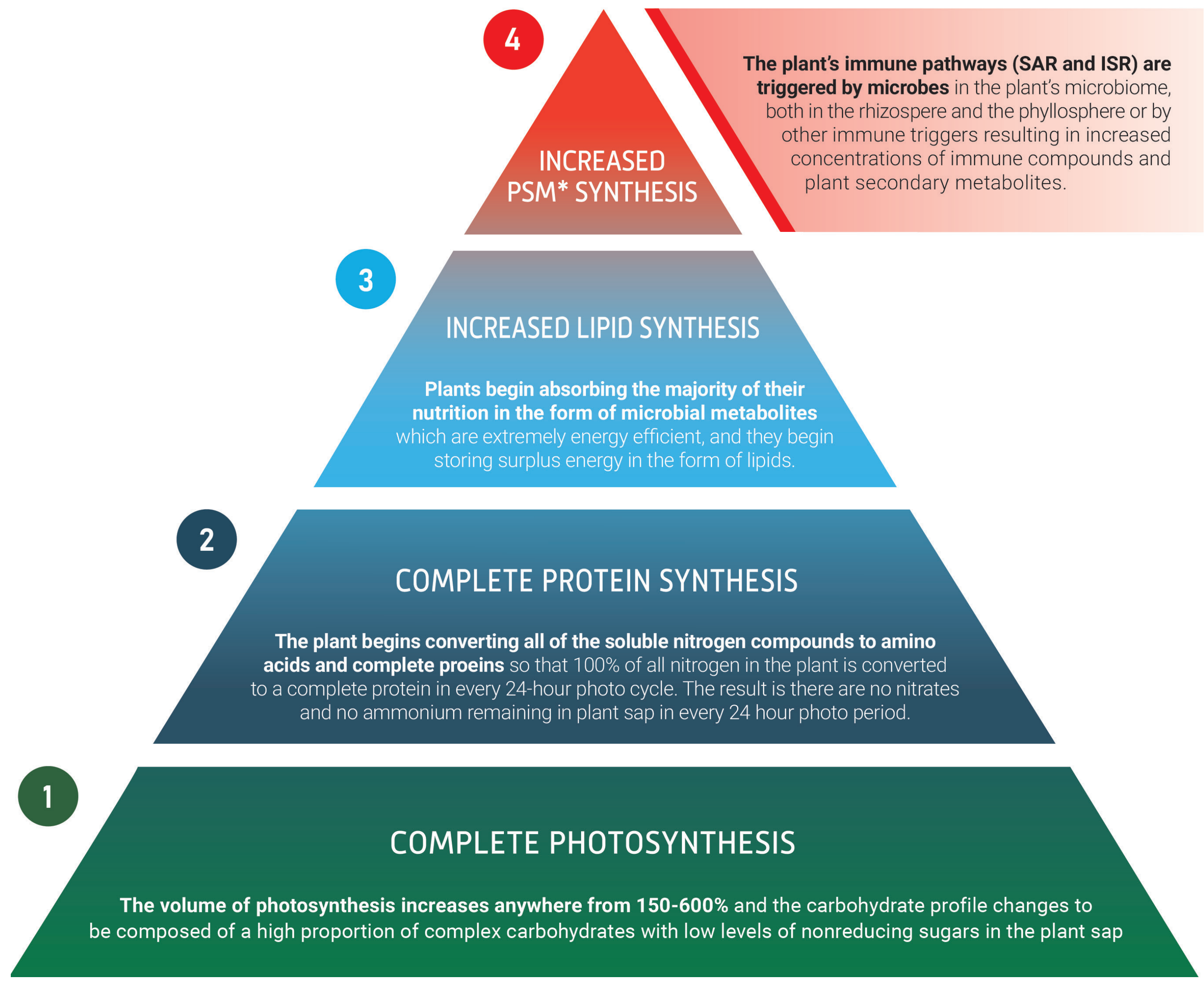


Figure 4: Infographic Plant Health Pyramid (source John Kempf)

Level 1: Complete Photosynthesis

Plants require adequate levels of magnesium, iron, manganese, nitrogen, and phosphorus to reach this stage of health. Phosphorus is not directly involved in photosynthesis but is required for photosynthetic metabolism.
The volume of photosynthesis increases to the plant's potential and the carbohydrate profile changes to more complex carbohydrates with low levels of non-reducing sugars (such as glucose, fructose and sucrose) in the plant sap. Plants develop resistance to soil-borne fungal pathogens such as *Fusarium, Rhizoctonia, Pythium, Phytophthora,* and others. An even assimilates balance contributes to this level of plant health.

Level 2: Complete Protein Synthesis

To reach this stage of plant health, plants require adequate levels of magnesium, sulfur, molybdenum, and boron.
The plant should quickly convert all of the soluble nitrogen compounds to amino acids and complete proteins so that all the nitrogen in the plant is converted to complete proteins. As a result, no nitrates and no ammonium remain in the plant sap. Analysis can prove if this has been achieved. If so, plants become more resistant to insects with simple digestive systems, especially larval and sucking insects such as cabbage loopers, aphids, whiteflies, thrips and leafhoppers. This connects with Chaboussou's theory.

A good **water balance** and uptake of the crucial minerals will prevent water stress and allow the best possible protein synthesis in the leaves. Application of appropriate biostimulants (such as Vidi Terrum) can mitigate the effects of abiotic stress on protein synthesis.

Level 3: Increased Lipid Synthesis

Plants begin absorbing the majority of their nutrients in the form of microbial metabolites which is extremely more energy-efficient than taking up mineral nutrition. This is also a positive contribution to the assimilates balance. Then they start storing the 'saved' surplus energy in the form of lipids. This is also a positive contribution to the assimilates balance.
All this helps plants to develop increased resistance to airborne fungal pathogens such as downy and powdery mildew and bacterial pathogens which land on the leaf surface and release pectolytic enzymes to digest cell wall pectin. The waxes and oils on the leaf surface serve as a shield to prevent these enzymes from working their way through the leaf surface.
A very active plant microbiome in the rhizosphere enables plants to absorb the majority of their nutrition in the form of microbial metabolites, which is a precondition to reach this level of health. *Trichoderma* (Trianum) and other beneficial microbes help plants to reach this stage.

Level 4: Increased Plant Secondary Metabolite (PSM) Synthesis

Extremely poor growing plants can produce PSMs when under stress, but since these plants lack energy, this may lead to low production and quality.
Healthy plants with a good assimilates balance use their surplus energy to fuel the plant's immune pathways (SAR [Systemic Acquired Resistance] and ISR [Induced Systemic Resistance]). These are triggered by microbes in the plant's microbiome, both in the rhizosphere and the phyllosphere (the outer layer of foliage) or by other immune triggers. This results in increased concentrations of immune compounds and PSMs. At this level plants develop increased resistance to pests with a more sophisticated digestive system (beetles, bugs, root rot nematodes) and viruses.
Plants require the correct microbes in the plant microbiome to trigger the immune response to reach this stage of health. Again *Trichoderma* (Trianum) and other beneficial microbes applied to the root zone or foliage help to achieve this advanced level of plant health.
High temperature often increases the production of PSMs . As Growing by Plant Empowerment generally leads to higher greenhouse temperatures, this could promote the production of most PSMs in plants.

Conclusion

Many growers are in transition from a reactive problem/solution strategy to a more proactive, holistic approach. They apply new insights as from Growing by Plant Empowerment, aiming to grow crops with minimum dependence on pesticides and fertilizers, hence minimal impact on the planet. With this approach, they achieve more with less and often reach better financial results.
The above explains how to make roots fit for plant health, the links with Growing by Plant Empowerment principles and some scientific insights in plant health management. The following practical recommendations can be extracted from this:

1. Make sure your irrigation water contains enough oxygen. Oxygen is very important for the rhizobiome ánd roots functioning.
2. Choose a substrate that 'accommodates' the rhizobiome. Learn about additives that help to create a better 'housing' for these workers.
3. Continuously measure and record root zone temperature.
4. Start adding beneficial microbes right from the start. *Trichoderma harzianum* T22 (Trianum) is very strong in protecting a plant against various soil borne pathogens, ánd it promotes plant growth in several ways.
5. Avoid oversupply of nitrates that make the plant very attractive to pests and diseases — especially when using plant growth promoting microorganisms like *Trichoderma* that boosts nutrient uptake.
6. Strive to the right cation balance in the root zone that leads to the right balance in the plant sap. Check if high phosphate levels in the root zone do not impede uptake of trace elements. Use the insights in the water- and energy-balance to achieve continuous uptake of calcium.
7. Frequently measure the nutrient composition of the plant sap to verify the plants' nutrient uptake.
8. Do not kill the invaluable rhizobiome with the thoughtless application of incompatible pesticides. Once you start using pesticides, there is no way back, or at least it takes considerable time.
9. Support the microbiome (around roots and in soil) in stressful situations, that means in periods with high Ratio Temperature to Radiation when availability of sugars to feed the roots is reduced, when the rhizobiome suffers "starvation".
10. Apply biostimulants to help plants to withstand abiotic stress.

In short: a focus on soils/substrates, irrigation water quality, varietal features, biodiversity in the root zone, plant nutrition, climate control, use of biological pest and disease control and biostimulants is essential to grow healthy and resilient crops.

Epilogue

Hoogendoorn Growth Management creates sustainable and user-friendly automation solutions for every kind of horticultural business worldwide. It provides growers with a complete solution to efficiently manage the greenhouse climate, irrigation, and energy usage, regardless of the greenhouse structure, location, and equipment. The intelligent controls enable growing high-quality crops and achieve maximum crop yields with minimum use of scarce resources such as water, energy, and nutrients. The principles of Plant Empowerment are completely integrated within these controls. The main focus is on growth, continuity, and innovation.

Koppert Biological Systems produces sustainable cultivation solutions for food crops and ornamental plants. Together with growers and in partnership with nature, we work to make agriculture and horticulture healthier, safer, more productive and resilient. We achieve this by using natural enemies to combat pest infestations, microorganisms to control pests and diseases, bumblebees for natural pollination, and biostimulants that support and strengthen the crops both above and underground. Restoring and protecting vital ecosystems in a natural way is the basis for healthy crops and a balanced environment. Add our quality, know-how, and consultancy services to this and you will understand why an increasing number of growers regards us as a partner with whom they can realize their ambitions.

hoogendoorn
growth management

Westlandseweg 190
3131HX Vlaardingen
The Netherlands

T +31 10 460 80 80
Info@hoogendoorn.nl

KOPPERT
BIOLOGICAL SYSTEMS

Veilingweg 14
2651 BE Berkel en Rodenrijs
The Netherlands

T +31 105 14 04 44
info@koppert.com