Horticultural science in the spotlight

Exploring and exploiting the physiology of plants

Prof. dr *ir.* Leo F.M. Marcelis

Inaugural lecture upon taking up the post of Professor of Horticulture and Product Physiology at Wageningen University on 30 October 2014

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Esteemed rector magnificus,
Dear colleagues, family and friends, ladies and gentlemen

It is now exactly five years ago that I gave my inaugural address on crop production in low-energy greenhouses (Marcelis, 2009). The special professorship on crop production in low-energy greenhouses has given a boost to basic research on saving energy in greenhouses. I am very happy that I am now here again in the Aula of Wageningen University for an inaugural address. Energy saving will remain an important topic in our research and education, but our work will also include other aspects of horticultural science.

When I was a child I was already fascinated by growth and development of horticultural plants as well as horticultural research. And I am still fascinated. Today I will try to share some of these fascinations with you. This also explains my choice of the title of my presentation: Horticultural science in the spotlight. I want to show you how interesting and important the horticultural sector is and then in particular focus on the science. I have also chosen this title because I want to tell you about the fascinating responses of plants to light. I will show some examples what we can learn from exploring these physiological responses in plants and how we can exploit the gained knowledge in horticulture.

The horticultural sector

The government has designated horticulture as a Topsector of the Dutch economy. The horticultural sector is economically a significant sector in The Netherlands, with an export value of about 16 billion euro per year. You may wonder what is horticulture. Well, there are many definitions. Here I will only mention a few characteristics of horticulture. It is about production of plants or plant products; usually it involves a high labour demand, high capital investment, high production rates, relatively small areas.

Bulbs, nursery stock, urban farming, bedding plants and other garden plants, mushrooms, and vegetables in the open field all are examples of horticultural crops. Note that there is not always consensus about whether it is horticulture or agriculture; for instance leek and brussels sprouts used to be considered as horticultural products, but the production process has shifted more towards that of arable crops. In most countries potatoes are considered as vegetables, belonging to horticulture. This is not the case in the Netherlands. However, we are investigating new propagations systems for potatoes where propagation material is produced in greenhouses. This might be considered again as horticulture. Other examples of horticultural crops are fruits, such as apple, pear and grapes, banana, mango, and peach. We have many foreign students in Wageningen. When reading reports from students I found some interesting quotes. For instance one student wrote: "The Dutch have a very high consumption rate of mangoes and other tropical fruits." Then another student wrote "The Netherlands is the second largest producer of mangoes." Can you believe this? Of course this is not true. But why did those students think so? Well, they looked at statistical data and found that the Netherlands is among the countries with the highest import rates of tropical fruit, and it is also among the countries with the highest export. So many tropical fruits come to the Netherlands, we give them some treatment, for instance to stimulate equal ripening and then we export them again. When I talk about horticulture it is not only about the growth of plants, but also about how to treat the plant products, such as fruits or cut flowers after they have been harvested. This is an extremely relevant part of the supply chain as about 30% of all the produced products is lost in that phase without being the impact of our work if we could consumed (Gustavsson et al., 2011). Imagine the impact of our work if we could halve these losses.

In greenhouses we are producing vegetables such as tomato, pepper, cucumber and lettuce, cut flowers like chrysanthemums, gerberas and roses and pot plants like anthuriums, bromeliads, orchids, etc. Production rates are extremely high, most of the pests and diseases are controlled biologically, most of the water and nutrients are reused. It is good to realise that producing crops in greenhouses compared to open field saves enormous amounts of water. For instance, to produce a kilogramme of tomatoes in the open field in the Mediterranean costs about 60 liters while only 15 liters in the Netherlands (Stanghellini, 2014). Unfortunately the energy use in Dutch greenhouses is very high. Greenhouses use about 10% of the national consumption of natural gas (CBS et al., 2014; Van der Velden & Smit, 2014). Energy costs constitute about 15-30% of the total annual costs of a nursery (Vermeulen, 2012). Therefore the sector is putting lots of efforts in reducing the use of fossil fuel.

Trends

The world population is rapidly growing from about 7 today to 9.5 billion people in 2050 (United Nations, 2013) and eating patterns are changing. It is expected that the demand for plant food will have increased by 60% in the year 2050 (Alexandratos & Bruinsma, 2012). Furthermore, a strong urbanisation takes place already for many decades. Almost half of the world populations lives in cities. There are already 33 magacities of more than 10 million inhabitants each.

Production must be sustainable. In particular the use of fossil fuels should be drastically reduced. The greenhouse sector has the ambition of climate neutral greenhouses. We should be careful with natural resources such as phosphorous for plant nutrition. These resources are not endless and they may pollute the environment. We want to get rid of the use of pesticides. Light pollution from greenhouses is no longer accepted by citizens. Ground and surface water should not get polluted, which is particularly relevant in countries such as the Netherlands, while worldwide water saving is an important issue. Consumers are getting more interested in quality of the products. Quality may mean a good taste, nice shape and colour, good shelf life, but also food safety and food health. You may have noted that last few weeks the issue of healthy food has been often in the media, after the Dutch scientific council for government policy presented its study on food policy (WRR, 2014).

Urban farming is receiving an increasing interest. Urban farming has different forms and can vary from growing some vegetables on balconies in cities to large scale production units without day light (Figure 1). These production systems are often referred to as plant factories or vertical farming. Plant factories require high investments and high rates of electricity for lighting, but they would allow the highest degree of control over the production process. For bulk products this seems not an economic profitable production system, but it might be for products with high added value, for crucial production phases such as propagation, or when there is a smart marketing concept.

Figure 1. Plant factory: Production of plants under fully controlled conditions without solar light.

Developments in sensing technologies, computer science and molecular biology have been so rapid last decades that more and more crop improvements are limited by insufficient insights on whole-plant physiology with its many feed-back mechanisms. This puts a demand for whole-plant physiology as researched in our group. Furthermore, all these developments together have also opened up new tools for us as whole-plant physiologists to characterise, simulate and predict plant functioning. In other words now we have the tools to explore plant functioning and exploit the gained knowledge to improve the production and quality of horticultural products.

Mission

The greenhouse horticultural sector in The Netherlands is world leading. The sector is highly innovative and is continuously in search for new knowledge. This demands for a strong horticultural chair group at Wageningen University.
The mission of the chair group is conducting high quality fundamental research and educating students. We want to provide the scientific basis that is required for sustainable crop production and high product quality in horticulture.

We want to explore and exploit the physiology of plants. Our research focus is on how physiological processes in crops, plants and plant organs interact with the abiotic environment and how this affects crop production and product quality. Using a systems analytical approach, questions from horticultural practice are translated into fundamental research topics, aiming to explain mechanisms. These questions can be related to improving yield and pre- and post-harvest quality, energy saving, and efficient water use. In this way the research and education will also contribute to sustainably feeding the world with healthy high-quality products.

The Research

Our chair group mainly focuses on greenhouse horticulture and post-harvest quality of products produced in greenhouses as well as the post-harvest quality of tropical fruit.

We study responses of physiological processes to the environment and we aim to predict and control the phenotype of the plant and plant products. Growth and development of plants as well as product quality are studied as emergent properties of underlying physiological/genetic processes. These processes show strong dynamic regulation, many feed-back mechanisms, acclimation and interaction. An important asset of our research is that we combine experimental and simulation research.

Photosynthesis is the basis for any growth on earth. We do basic research into understanding the regulation and limitations of photosynthesis. We develop and use instrumentation that allows us to look at the biophysical motor of photosynthesis inside the leaf. Optimal photosynthesis will only lead to optimal growth if we pay attention to balancing the source and sink strength in plants. Furthermore, the partitioning of the formed assimilates over the different plant organs determines the shape of the plant as well as the yield of the harvestable organs like fruits or flowers. Via roots plants acquire water and nutrients. When it comes to studying fluxes of carbon, water or nutrients in plants, researchers often focus on fluxes of one component. However, there is a strong need to develop an integrated view on the regulation of the fluxes of carbon, water and nutrients in plants. All this research may lead to an optimized quantity of production. However, quality of the product is at least as important as quantity. Quality of a fruit, a flower, or a pot plant does not end when it leaves the grower. Neither does it start when it is bought by for instance a trading company. Quality should be studied as a continuous process from plant cultivation to post-harvest life until used by the consumers. Furthermore, if we want to control product quality we do not only need to understand the processes underlying product quality but we also need to develop methodologies for monitoring product quality.

First of all, our research is very relevant for the Dutch horticultural sector, but we are a truly international university thinking globally. And we even go beyond planet earth. Organisations on space research are very interested in plant growth in space

(Figure 2). Questions arise on how to feed space travellers with vegetables during their long travels or how to feed the first humans living on the planet Mars. I am happy to announce that in spring 2015 we will start research on plant growth in life support systems for space exploration, which we will do together with several European research organisations and companies.
In this inaugural address I would like to show you two of our areas of research. The first one is about models and sensors and the second one is about plant responses to light.

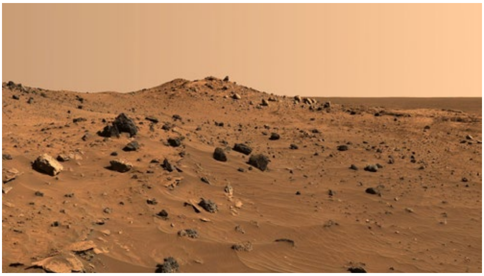
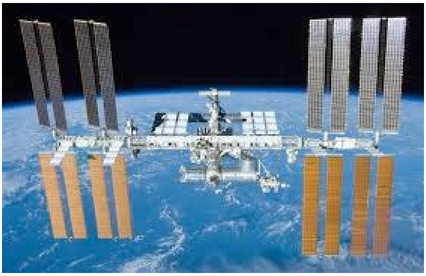

Figure 2. Horticultural research is needed everywhere.

Sensors and models for understanding, monitoring and phenotyping

Mechanistic simulation models, as a simplification of complex systems have tremendous value as a way to structure and integrate available knowledge, test hypotheses and come up with quantitative estimates of plant growth as well as product formation and quality. Our modelling concepts will focus on functional structural models (also called virtual plants) and supra-cellular systems biology models.

Computer science enables us to include 3 dimensional structures in process based models simulating growth and quality of plants and plant organs. These models are powerful tools to study the interactions between physiological processes and plant or organ structure. For instance, these models are ideal for linking water, carbon and nutrient fluxes in plants. This will cause new insights in understanding the plant's phenotype.

Most of the knowledge applied in growth models was developed in a time that molecular biology was in its infancy. For most system biologists to date the cellular level seems to be a logical upper boundary. Now it is our exciting challenge to develop models at the supracellular level that predict whole-plant behaviour using insights from omics research and genetics. Here we still have to tackle quite some challenges of up and down scaling from gene to cell, organ, plant and crop level.

Models are powerful tools in research. However, modelling without experimentation is like flights of fancy. So we also need detailed experimental work. This experimental work can often be very tedious by manual measurements of for instance the dimensions of all plant organs. Sometimes we need to develop ourselves very specific equipment (Figure 3).

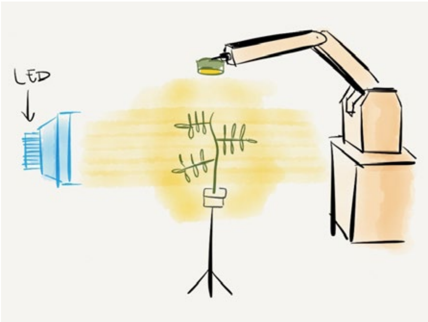

Figure 3. Schematic representation of a spectro-photo-goniometer measuring light absorption of whole plants when the light is coming from different directions (from Kalaitzoglou, unpublished).

Growers want tools for continuous monitoring of the performance of their crops (Figure 4). Several sensor technologies are becoming available. However, these sensors usually measure one specific aspect of plant functioning and often only on one specific leaf. If we really want to use sensor information for crop monitoring we need to couple the sensor data to model simulation. Then we may in the end use this in control systems for climate and fertigation in the greenhouse (Marcelis et al., 2006).

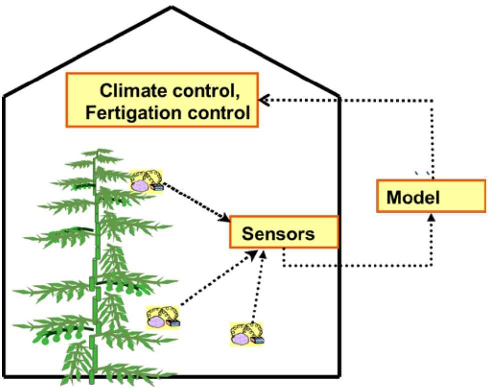

Figure 4. Sensors and models are powerful tools for crop monitoring.

After harvest of a fruit or flower, a similar type of methodology can be applied to monitor and control the quality. Again a sensor measures a physiological parameter and then a simulation model is used to predict the quality until it is used by the consumer (Figure 5).

Figure 5. Based on colour measurement at harvest a model can predict shelf life of cucumber fruits. From Schouten et al. (2002; 2004).

If we want here truly predictive models for the quality of horticultural products, we should develop models that simulate quality formation as a continuous process from pre-harvest to post-harvest.

Most models simulate an average plant or an average fruit or flower. However, even in a greenhouse where only one hybrid cultivar is grown, there is quite some variation among individual plants and also among the different organs on a plant (Wubs, et al., 2011). If we want a precise control in a greenhouse, we should take the challenge that our models can deal with this variation. For predicting post-harvest behaviour of fruits it has already been shown that we can learn from the variation among fruits within one batch (Schouten et al., 2004).

Another application where we can use models is for exploring which phenotypic characteristics would lead to optimal yield. For instance our model calculations predict that if we would breed tomato plants with a more open structure, for instance by longer petioles and internodes crop photosynthesis can increase by about 10% (Figure 6; Sarlikioti et al., 2011). Knowing that there is a lot of genetic variation on these plant parameters, this may give guidance to breeding programmes.

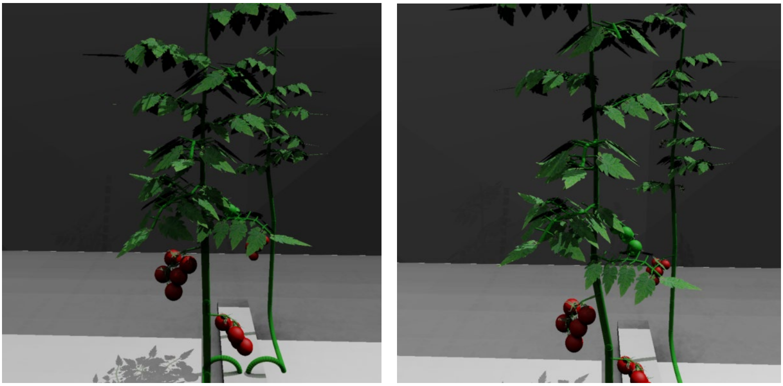

Figure 6. Model calculations indicate that about 10% improvement in crop photosynthesis of tomato is possible if crops would have a more open canopy structure (right figure) compared to a dense structure (left figure). From Sarlikioti et al. (2011).

Phenotyping is a key factor in breeding, for which world wide many millions of euros are invested. Our chair group has a lot of expertise for phenotyping plants. In particular, fluorescence, reflectance and vision are suitable techniques for phenotyping (Figure 7). However, it will soon be recognized that phenotyping needs to be more than measuring plant characteristics with a sensor. First of all, fundamental knowledge of the relevant physiological processes is needed to define conditions at which plants should be phenotyped. Furthermore, physiological crop models will be needed for evaluating sensor data.

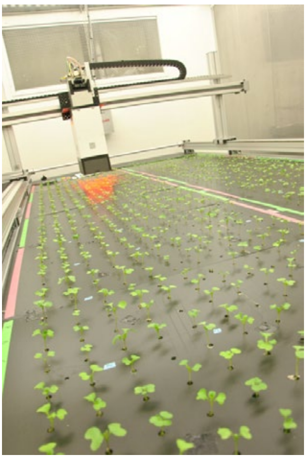

Figure 7. Phenotyping is a key factor in breeding, requiring high throughput measurements on plants.

I advocate a huge joint effort of Wageningen groups with expertise on phenotyping and breeding to invest in phenotyping technology and methodology, not only for model plants such as *Arabidopsis*, but also for horticultural and agricultural crops.

Figure 8 shows how important crop models are for proper phenotyping. In phenotyping studies often photosynthesis parameters of a leaf are measured. Usually, the maximum quantum yield or parameters for maximum rate of photosynthesis are measured. But what does a measurement of photosynthesis of a leaf tell us about photosynthesis of a crop under different conditions? We could do many experiments to investigate that, but that is not very practical. We can use a physiological crop model to estimate the consequences for crop photosynthesis under varying growth conditions. A 10% increase in maximum quantum yield leads to about 9% more photosynthesis in winter time (Poorter et al., 2013). However, in summer time when light intensities are much higher, photosynthesis is less affected by the maximum quantum yield and is the effect on crop photosynthesis only 6%. In contrast the parameters for maximum rate of photosynthesis are not so relevant under low light conditions of winter, while their impact is larger under summer light conditions. This simple example nicely illustrates that measuring one physiological parameter is usually insufficient for phenotyping. The impact of the measured values should be evaluated under different conditions by a crop model.

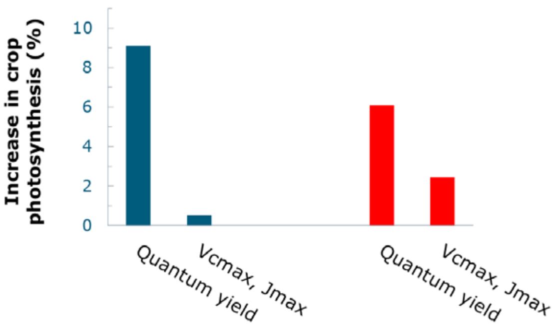

Figure 8. Efficient phenotyping combines sensor information and physiological crop simulation models. The graph shows simulated consequences when a sensor has measured 10% increase of photosynthesis parameters for maximum quantum yield or for maximum rate of photosynthesis (Jmax and Vcmax). From Poorter et al. (2013) by permission of John Wiley and Sons Inc.

Light on plants

Light is the driving force for plant growth. When growing plants in greenhouses we should realise that the light that we get from the sun is for free (Figure 9). Let's use this efficiently. This starts with a high light transmission of the greenhouse. Only if we have used all the solar light efficient, then we may add lamps for further improvement of production or product quality. Still it occurs that on the same day during some moments the lamps are on, while at some other moments of the same day the sunscreens are closed. Here are clear possibilities for improving production and energy efficiency.

Figure 9. Make use of natural light in greenhouses: it is for free.

On a clear day you can find in a greenhouse many light flecks and shaded spots (Figure 10). When I started 27 years ago with my research, I worked on crop models together with my former colleague Hans Gijzen. At that time our models predicted already that we could improve crop photosynthesis and therefore crop growth if the light could be made diffuse by using a glass on the greenhouse that would scatter the light (Spitters et al., 1986; Gijzen, 1992). At that time this knowledge could not be applied as all the glass that diffused light had a very poor light transmission. So, there was also no possibility to test the theory in an experiment. Since a few years glass exists that makes the light diffuse and that does not reduce the light transmissivity. In most crops we have shown that by using diffuse glass we can improve yield by 5-10% (Hemming et al., 2008; Dueck et al., 2012; Garcia et al., 2012; Li et al., 2014a). I find this a very nice example of how theoretical model calculations can help to substantially improve production even though it may take a number of years before it is technically possible. It is also a typical example of first exploring the physiology and finally exploiting this knowledge.

Figure 10. Diffuse light can improve crop yield by 5 to 10%. On the left: Plants in a greenhouse with clear glass, where typically light and shade flecks occur. On the right: Plants in a greenhouse with diffuse glass, where the light is more uniformly distributed over the leaves.

In many pot plants, like anthuriums or orchids, growers often apply sunscreens as they are afraid that too high light intensities may damage the crop. When we use diffuse glass on a greenhouse, less peaks of light occur on the leaves. Where a grower of anthurium would not allow more than 5 mol m^{-2} d^{-1} PAR light in the greenhouse, we allowed up to 10 mol m^{-2} d^{-1} of light before closing the sunscreen. Production rate of the plants doubled and quality of the plants was very good (Van Noort et al., 2013; Li et al., 2014b). I am happy to see that when now a new greenhouse is built, often diffuse glass is used and that growers of pot plants dare to allow more solar light in the greenhouse.

In winter time often lamps are used to improve growth and quality of plants. The most common lamps are high pressure sodium lamps. However, at this moment an LED revolution has started. This was accentuated earlier this month when the Nobel prize for physics was granted to the invention of blue LEDs. LED technology is developing very rapidly. The latest LEDs are about 25% more efficient in converting electricity into light compared to high pressure sodium lamps. This opens opportunities for energy saving. Even more interesting, is how plant growth and quality can be controlled by LED light. Important features are for instance the manipulation of light colour, the separation of heat and light, distribution of light in the canopy. If we would fully understand the response of plants to light spectrum, timing, direction and intensity, we could use light much more efficient. 50% saving on energy costs should be easily possible. To realise this ambition, we will start a large research programme called 'LED it be' in 2015. 'LED it be' is a programme in which several Wageningen groups, universities of Delft, Leiden, Utrecht and Eindhoven, as well as 10 companies participate. In this research programme 11 PhDs and postdocs will be appointed.

In textbooks you can find already quite some information on effects of light colour on plants. The widespread availability of LEDs provides plant scientists opportunities for efficiently studying light responses. I expect that within five to ten years we have obtained so much new information, that these text books can be rewritten.

We can measure the response of photosynthesis of a leaf to light spectrum. However, we should never forget that a leaf is not yet a whole plant and a whole plant is not yet a crop. Measuring the spectral response of a whole crop is quite complicated. Simulation models can help here. The response of a crop to light colour is not identical to that of a leaf, even when the crop consists of all identical leaves (Figure 11; Paradiso et al., 2011). The simple explanation for the difference shown here is that on a single leaf a large fraction of green light transmits through a leaf and is not used in photosynthesis. However, in a crop this transmitted light is used by the leaves down in the canopy. This makes that on a crop basis green light is better used than expected from measurements on single leaves.

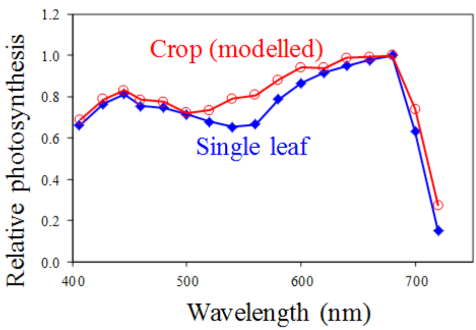

Figure 11. Spectral effects on photosynthesis of a single leaf (closed symbols) and crop (open symbols). The crop with a LAI of 3 consists of leaves which all have the same properties as the single leaf. From Paradiso et al. (2011) by permission of Elsevier.

The morphology of plants is strongly affected by light colour. This can be applied in ornamentals where shape of the plant largely determines their economic value. Furthermore it can have enormous effects on the growth of plants. When cucumber plants were grown under different lamps, large differences in in plant size appeared, which were due to effects of the lamps on plant shape and thereby the absorption of light (Figure 12; Hogewoning et al., 2010a). In fact the photosynthetic properties of the leaves of the big plants were poorest.

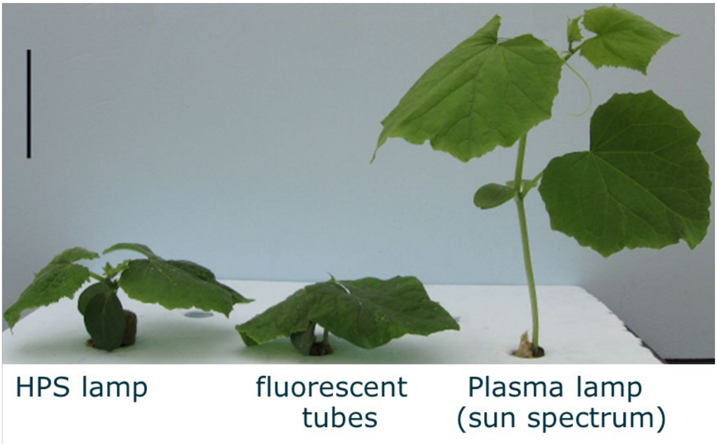

Figure 12. Spectrum of lamps can substantially alter plant development. From Hogewoning et al. (2010a) by permission of Oxford University Press.

The spectrum of the light is not necessarily kept constant during a day or growing season. We can speculate on manipulating the light spectrum during the day and how that would affect the physiological response of plants.

In our research on light colour we often find unexpected responses. For a long time it was known that if we enrich solar light with blue light we can reduce elongation of plants. However, if plants are grown under blue light alone, without any other colour, plants elongate very strongly (Hogewoning et al., 2010b). This is just one example indicating complex interactions between different photoreceptors.

Light spectrum can affect stomatal regulation in plants. It would be a challenge to lower the stomatal conductance such that we reduce transpiration at moments we don't want it, while we increase it at other moments. For instance in summer time, a high transpiration can prevent too high leaf temperatures. On the other hand in winter time reducing transpiration at night or at moments of high heating demand can substantially contribute to saving energy. However, this should be done in such a way that it does not reduce photosynthesis. This can only be achieved by a thorough understanding of the physiological regulation of stomatal opening, transpiration and photosynthesis.

Plant responses to light are not only relevant for growth, but also for their tolerance to diseases like mildew and botrytis (Ballaré, 2014; Van der Velden & Hofland-Zijlstra, 2014. This is an avenue not to forget.

Interestingly, with light we can also affect the quality of harvestable products. For instance affecting colour of flowers and leaves, which is relevant for ornamental crops but also for some leafy vegetables. Spectacular improvements were found in vitamin C content of tomato if LEDs were placed close to the fruits while growing on the plant (Figure 13; Labrie and Verkerke, 2014). At this moment we are studying in more detail how the vitamin C content responds to light treatments and how this is regulated physiologically. There seems to be some interesting links with photosynthetic and mitochondrial electron transport. Manipulation of vitamin C and other health related compounds by light or other growth conditions in greenhouse horticulture, is not sufficiently explored yet. If we would explore this further, this may lead to interesting possibilities for exploiting the physiology of plants. Greenhouses could become a source of healthy products. Or using the Dutch metaphor 'Kas als apotheek'.

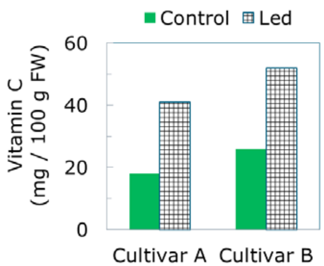

Figure 13. LEDs close to the tomato fruits during their development on the plant, increased vitamin C content of of the tomatoes. From Labrie and Verkerke (2014).

Not only during cultivation but also post-harvest the use of lamps provide tools to control the product quality. For instance applying low intensity light on fresh-cut lettuce improved its shelf life by triggering the sugar and vitamin C production (Schouten and Woltering, unpublished yet).

I hope that my lecture, has made you aware that light has tremendous effects on plant functioning. For detailed understanding of these effects, in experiments we usually vary only one factor at a time. However, if we want to optimize the efficiency of the used light we need to adapt other growth conditions simultaneously.

Responses of plants to the environment are seldom linear and show many interactions. furthermore, short and long term responses can be very different due to acclimation and feed-back mechanisms. Though reductionistic research analysing separate factors under constant conditions is still highly valuable, we should now also go one step further and analyse multiple interacting factors in fluctuating conditions. So far this approach is hardly seen in physiological research.

Education

There are several rankings of universities. I am proud Wageningen University is ranked number one in the agricultural research (National Taiwan University Ranking; Figure 14). In rankings of general universities we are usually within the top 100 or 150. And there is more good news on education. We are also ranked by students as the best university for full time bachelors in the Netherlands for 10 years in a row. Our BSc programme Plant Sciences is rated as the best BSc programme for 3 years in a row. This year 56 students started the BSc programme Plant Sciences. In the master programme Plant Sciences some 70 extra students join in; these students come from all over the world. In our chair group we have at the moment 30 MSc students doing a research project of 6 months. This is a huge research capacity and a huge brain potential with many highly talented individuals. I see it as my responsibility to create an academic and motivating atmosphere for these students. We are very happy with the growing numbers of students, but now we have to take action to deal with these larger numbers in order to be able to maintain the quality of education.

Figure 14. Wageningen University has good scores in several rankings.

Attracted by the world leading position of Dutch greenhouse horticultural sector, there is great interest from countries all over the world in academic education in greenhouse horticulture. At this moment a considerable fraction of the international MSc students Plant Sciences choose to specialise in Greenhouse Horticulture. I am convinced that this number of students can be increased substantially, if there would be a study profile better adapted to greenhouse horticulture. I propose to develop a new multidisciplinary course on greenhouse horticultural production, including e.g. soilless cultivation, labour and automation, IPM and robustness of greenhouse production systems, post-harvest technology, etc. Co-operation with other chair groups and the DLO groups Wageningen UR Greenhouse Horticulture and Food and Biobased Research is essential to develop this course. Furthermore, these courses will not only be interesting for MSc students, but these courses can also be offered to employees of companies or other universities or schools. In fact we have already started some initiatives together with Wageningen Academy.

Simulation models for plant functioning are not only powerful tools in research, but can also be used as an efficient educational tool. Furthermore, new information and communication technologies have changed the way young people gather information and it allows new ways of teaching. E-learning and distance learning will increase in importance. These are also tools to reduce costs for foreign students, which increases the attractiveness to study at Wageningen University.

Students are expected to conclude their thesis study with a report containing many pages. However, for most academic jobs it is important to be trained to write concisely. Therefore, I would prefer to abandon the writing of long MSc theses. Students better write the final report as a scientific publication. Simultaneously students have to store their data in a database such that they are easily accessible for later use.

Education programmes will be more and more at the European level or even world level rather than at national level. Further co-operation with other universities needs to be sought. In particular budgets from EU might help in realising these programmes.

Conclusions

Now I come to the end of my talk. I hope that you have got an impression of the dynamic world of horticulture. How fascinating it can be to explore the physiology of plants. And if we understand the physiology of the plants, how we can exploit that knowledge to improve the yield and quality of horticultural production, such that we make the production more sustainable and contribute to feeding the world with healthy high-quality products and providing people with beautiful ornamentals. In this way we contribute to the quality of life.

Word of thanks

I am very happy to be surrounded with a large number of stimulating, cooperative and knowledgeable people, who have helped me a lot. Without them I wouldn't have been here today. I can't mention them all, but a few persons I would like to thank in particular.

I would like to show my gratitude to the confidence put in me by the Selection Advisory Committee headed by Harro Bouwmeester and in which a number of respected colleagues took seat. Similarly I would like to thank the Wageningen University Board. In particular I would like to thank rector Magnificus, Martin Kropff. Dear Martin, thank you for your confidence in me which has led to my appointment as professor of Horticulture and Product Physiology. I admire how you can motivate and make people enthusiastic about research and education.

Ernst van den Ende and Ton van Scheppingen, directors of the Plant Sciences Group. Thank you for your support and for your constructive discussions and advice.
Hugo Challa, who passed away too early, and Siebe van de Geijn were my teachers while working on my PhD thesis. They trained me in conceptual thinking, analysing and concise formulating.

Dear colleagues of the chair group of Horticulture and Product Physiology. We have made a new start and at times a new start can also be challenging. I very much appreciate the cooperation with all of you and I admire you for the high quality education and the very interesting research. It is very inspiring for me to work with such a well-qualified group of people.

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For seven years I have worked as team leader at the business unit Wageningen UR Greenhouse Horticulture. I would like to thank my team members from who I always got a lot of support. Although I find driving in a car not an efficient use of time, I liked very much to be on the two locations in Wageningen and Bleiswijk. I would also like to thank the management team of the business unit and in particular the business unit manager Sjaak Bakker. We have had 7 good years. I hope we can continue our good cooperation in the future.

I cherish the fruitful cooperation with many colleagues from different groups of Wageningen UR as well as other universities. I find this cooperation very stimulating and hope to continue on that.

Throughout the years I have cooperated with many different companies: growers of all type of crops, plant breeding companies, automation companies, advisory organisations, lighting companies, etc. I find this cooperation essential to realise impact in the horticultural sector. A special word of thanks also to the programme Greenhouse as Energy source (In Dutch: Kas als energiebron). This programme has stimulated tremendous efforts on energy saving in greenhouses and has given me the opportunity to conduct research relevant for the horticultural sector.

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Prof. dr *ir*. Leo F.M. Marcelis

'The greenhouse horticultural sector in The Netherlands is world leading. The sector is highly innovative and is continuously in search for new knowledge. This demands for a strong horticultural chair group at Wageningen University. Our research focus is on how physiological processes in crops, plants and plant organs interact with the abiotic environment and how this affects crop production and product quality. Using a systems analytical approach, questions from horticultural practice are translated into fundamental research topics, aiming to explain mechanisms.'

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