Decision Support System (DSS) for prevention of Botrytis in tomato in greenhouses

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Referaat
Binnen het Interreg project 'Gezonde Kas' is een beslissings ondersteunend systeem (BOS) voor preventie van Botrytis in tomaat ontwikkeld. Deze rapport vat eerst de bestaande kennis over Botrytis in tomaat samen. Vervolgens wordt beschreven op welke wijze deze kennis in rekenregels is om te zetten. Met deze aanpak is een dynamisch computermodel gebouwd. Het model betrekt zijn gegevens van de klimaatcomputer en van eventuele handmatige metingen. Er wordt gerapporteerd hoe en wanneer het model een hoge sporendruk en een verhoogd risico op botrytisinfectie voorspelt, in afhankelijkheid van kascondities. De voorspelling wordt sterk verbeterd als de standaard meting van klimaatcondities, met meetbox, wordt uitgebreid met een meetset door sensoren die op representatieve plekken in de kas worden geplaatst. Het model is voorzien van een gebruikersschil (GUI) om het gebruik door telers te vergemakkelijken. Het gebruik van de GUI wordt met behulp van diverse voorbeelden uitgelegd. De BOS is beschikbaar voor de telers en adviseurs, en kan met of zonder overige producten van het Gezonde Kas project functioneren.

Abstract
Within the framework of the Interreg project 'Gezonde Kas' a decision support system (DSS) for Botrytis risk in tomato was developed. This report first summarizes existing knowledge on botrytis in tomato. The quantitative relationships are subsequently laid down in computer code. This code formed the basis of a dynamic simulation model to predict the risk on botrytis in a tomato crop. The model requires input from the climate computer of the greenhouse, and can also manage input from manual measurements. The report describes when and how the model predicts a high spore pressure and an increased risk on Botrytis infection, on the basis of climate conditions in the greenhouse. The prediction is highly improved when the data from the regular measurement box ('meetbox') are extended with data from a grid of sensors, positioned on representative spots in the greenhouse. The use of the model is facilitated for growers by the addition of a graphical user interface (GUI). The functionality of the GUI is explained. The DSS is now commercially available for growers and advisors, and can be used with and without other products of the Gezonde Kas project.

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Summary

Within the framework of the Interreg project ‘Gezonde Kas’ a decision support system (DSS) for Botrytis risk in tomato was developed. The DSS comprises existing knowledge on botrytis in tomato, as well as recent findings from the Gezonde Kas project. The model is based on quantitative relationships that are converted into computer code. This code formed the basis of a dynamic simulation model to predict the risk on botrytis in a tomato crop. The physiological model of Botrytis risk and tomato growth was extended with some results from the Straelen greenhouse experiments. In the model, the estimated risk is a function of humidity and temperature in the air near to the plants. This microclimate is used as a proxy of the situation in the boundary leayer of the plant where the adhesed spores are present.The model requires input from the climate computer of the greenhouse, and can also manage input from manual measurements.

The report describes when and how the model predicts a high spore pressure and an increased risk on Botrytis infection, on the basis of climate conditions in the greenhouse. The prediction is highly improved when the data from the regular measurement box (‘meetbox’) are extended with data from a grid of sensors, positioned on representative spots in the greenhouse. The use of the model is facilitated for growers by the addition of a graphical user interface (GUI). The functionality of the GUI is explained. The DSS comes both in the form of a Matlab model including all functions and as an easy-to-use web-based service. The DSS is now commercially available for growers and advisors, and can be used with and without other products of the Gezonde Kas project.

1 Introduction

1.1 Background and goal

Botrytis is one of the most harmful fungal diseases in tomato production systems. An infection by Botrytis cinerea in the stem of tomato plants creates a lesion that will kill the plant within one or more months. Moreover, an infection can result in development of new, spore producing tissues and can distribute the disease in the rest of the greenhouse. Some Dutch growers reported more then 10% loss of plants by Botrytis in some years, and an increasing need for labor to treat the plants, either to perform preventive or curative measures. The Botrytis problem has enlarged since growers tend to reduce window opening in winter to reduce heating costs. This will reduce ventilation capacity and export of humid air, thereby increasing the risk on fungal diseases that are favoured by high humidities. Details on the background of fungal diseases in vegetable crops in horticulture, with a special emphasis on Botrytis in tomato, can be found in Köhl *et al.* (2007).

The growers now face the challenge to combine the goals on most optimal crop growth, minimum requirement for labor and energy use, as well as the best approach to minimize risk on fungal infections. These goals each require a specific approach and generally result in a specific greenhouse climate, e.g. for plant growth high CO_2 levels should be maintained and window opening is thus not beneficial because the artificially added CO_2 will be lost to outside air. Since most quantitative relationships with regards to plant growth, greenhouse climte control and fungal diseases are known, we propose to use a quantitative tool to predict these processes for the near future. Such a tool can help the grower to decide which greenhouse climate to realize in order to prevent diseases and still maintain a well-growing crop. For this, a decision support system, being a computer model quantifying the most relevant processes and delivered with an easy-to-use interface, is most helpful. The English naming “decision support system”, abbreviated here to DSS, is translated to BOS (“beslissings ondersteunend system”) in Dutch, and to EHS (“Entscheidungs Hilfe System”) in German.
The aim of this project was to develop of a DSS that can advise the grower how to prevent Botrytis infections in tomato under the given circumstances of crop and climate. This DSS should consist of dynamic models on plant growth and disease risk as a function of climate and state of crop and spore pressure. Once the DSS runs in practice, its input data can be gained from the grower’s climate computer, and from sensors on spore pressure, local microclimate, plant health and infected spots. These sensors were available for the project since they were developed within the framework of the “Gezonde Kas” project, where this project was part of (see text box for more information on the Gezonde Kas project). The data were integrated and analyzed by the software on a remote computer and this resulted in an advise for the grower about which disease-preventing, climate related, or curative measures should be taken.

The Gezonde Kas framework.
The reported project was part of the Gezonde Kas project, initiated for the border region between The Netherlands and Germany, and funded by Interreg. The Gezonde Kas project comprised 26 sub projects, each conducting research on a plant health related subject within the greenhouse. Each project delivered a marketable product for helping the grower in realizing a ‘healthy greenhouse’ (i.e. ‘ Gezonde Kas’ or ‘Gesunders Gewächshaus’) that reduces the use of chemicals for plant protection while safeguarding the plant production. Partners in the Gezonde Kas project arrived from small to medium sized companies, applied research institutes to universities. For project details, see http://www.gezondekas.eu.

The specific goals in order to deliver a DSS in this Gezonde Kas project number 15, were as follows:

- Develop models for tomato growth, plant energy balance and fungal development.
- Integrate these submodels in a software environment that helps the grower to make climate related decisions.
- Establish an ICT infrastructure to connect a climate computer to the computer of the models.
- Test the models on an existing data set and make the models ready for real-time application as DSS.

This report describes the development and experiences with a DSS for Botrytis in tomato, by first presenting the existing scientific knowledge on Botrytis epidemiology. In the succeeding chapters the methods of the research will be described, will have a description of the way to model Botrytis and tomato growth, and finally, the construction of the DSS is presented. In the last chapter, the results will be discussed.

1.2 Botrytis epidemiology

Botrytis cinerea is a well-studied saprophytic fungus, and its life cycle partly takes place in a host plant (Figure 1). This Botrytis species is most common and can infest many plant species.

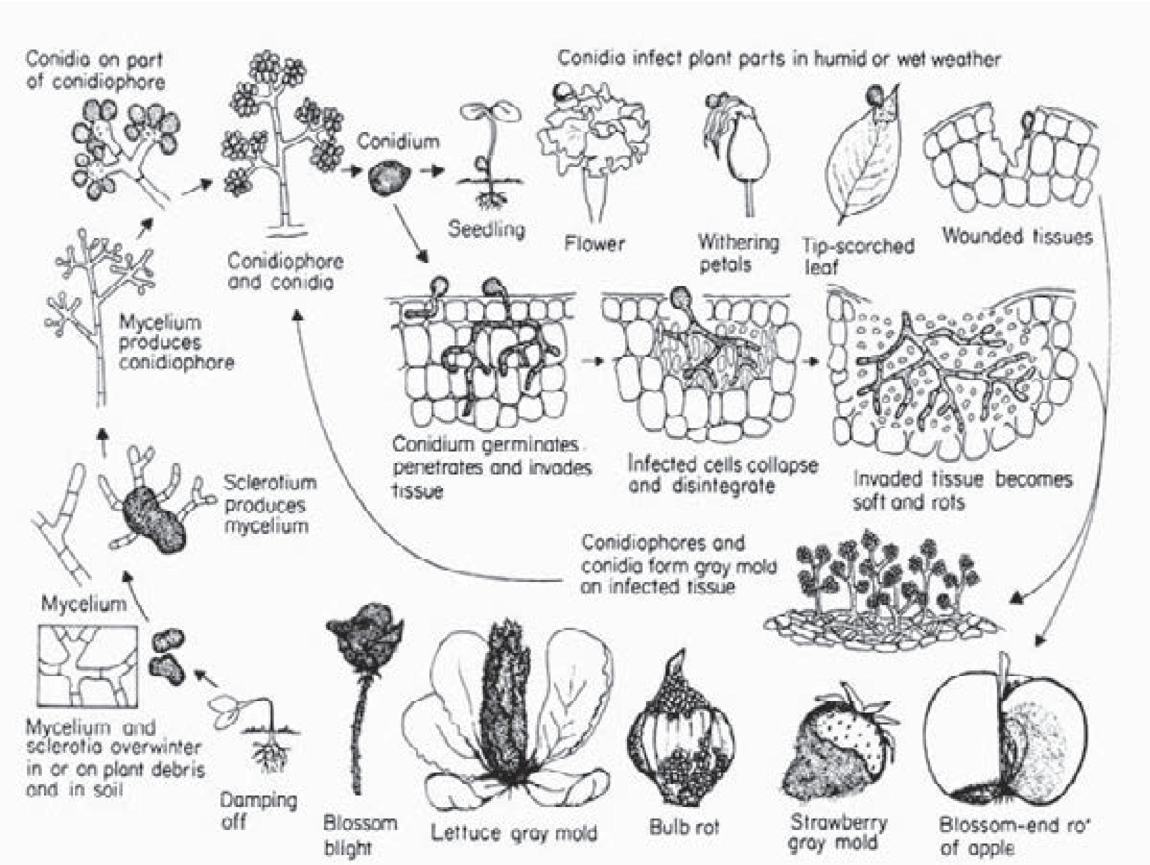


Figure 1 *Life cycle of Botrytis cinerea.*

The infection of plant tissues by Botrytis cinerea takes place by mycelial colonization and death of tissue cells, apparent as a discolored leasion. The first infection always takes place through Botrytis spores, deposited on the organ surface, and their germination, using a root like mycelial outgrowth. The germination and growth of the spores is fully dependent on local temperature and humidity.

Colonization of the host tissue is accompanied by absorption of nutrients and water, using enzymes and toxins, killing the host tissue. Colonization and growth in the host is facilitated if the host is weak, e.g. possessing weak cell membranes and a weak internal resistance (Jarvis, 1980). Tissue resistance is not only depending on the growth history and nourishment of the plant, but some tissue types are more vulnerable (e.g. flowers) or depend on their development stage (ripening and/or old).

The formed mycelium finally produces generative cells resulting in so-called conidiophores (Figure 1) that produce conidia, i.e. spores. When the conidia/spores have developed, a rapid change in humidity or a sudden movement will release the spores from the conidiophore, the spores being distributed rather close to the infected organ (max. 0.5m) unless air movement facilitates further transport. Yet, Botrytis spores are relatively big and heavy, so spread in the greenhouse will be limited unless adhesed to a carrier (pruned leaves, clothes, shoes).

2 Methods

The project was organized so as to first investigate which knowledge was currently available, which needs for a DSS were present in growers' practice, how the DSS should look like, and finally construction and evaluation of the DSS product. Some of these tasks will not be reported in this report, because the results of the tasks were embedded in the constructed DSS.

The study started with a survey and definition of the DSS:
- Kick-off with partners and invited experts on DSS for fungal diseases.
- Communication with growers on their wishes and main interests.
- Checking the technical feasibility of implementation at growers to use their data.

Subsequently, a literature survey, data collection and analysis of the Botrytis problem was carried out:
- Establishment of model relationships on basis of previous research and literature.
- Collection and organisation data of previous research.
- Analysis of data and construction of mechanistic relationships to feed into the model.

Following this desk study, we started the software development:
- Development of the model for tomato growth, plant energy balance and fungal development.
- Establishment of an ICT infrastructure to connect a climate computer to the DSS computer.
- Testing the model on an existing data set and make the model ready for real-time application.

After model construction, the DSS was tested and a commercial demo version was built:
- Functional test of the system in an experimental setting.
- Practical test in a commercial greenhouse, realizing connectivity to all possible sensors and internet.
- Finalizing the product for commercial use.

The decision support system (DSS) has been constructed on the basis of dynamic models on plant growth and disease risk as a function of climate and state of crop and spore pressure. The set-up and construction of the different sub models will be described below. As well, the required data and measurement equipment will be listed. The DSS can be , but not necessarily should be, part of the Gezonde Kas system, which will be shortly described.

2.1 Data collection

2.1.1 Botrytis

The appearance of Botrytis in greenhouses, its distribution and reproduction, its vigour or infectivity, will be related to abiotic, climatic conditions. Previous studies reported in literature as well as insights from new measurements in tomatoes will be interpreted and laid down into quantitative relationships.

2.1.2 Tomato crop growth and effects of Botrytis

Crop resistance to Botrytis is related to crop growth conditions in the greenhouse. Weak tissues are more vulnerable to infection. Adding to this, in healthy tomato plants every leaf cutting event potentially causes risks by cutting stem wounds. Data will be gathered on characteristics of wounds, their susceptibility for Botrytis and the possibilities for prevention or curation of Botrytis entering via stem wounds.

2.2 Physiological relationships in the model

2.2.1 Botrytis

A series of processes is involved in the whole chain from spore production to infection. We will shortly describe each process and formulate the quantitative relationship as applied in the DSS. The overview of the occurring processes is formulated as such that a concept for a quantitative, mechanistic and dynamic model becomes visible (Figure 2).

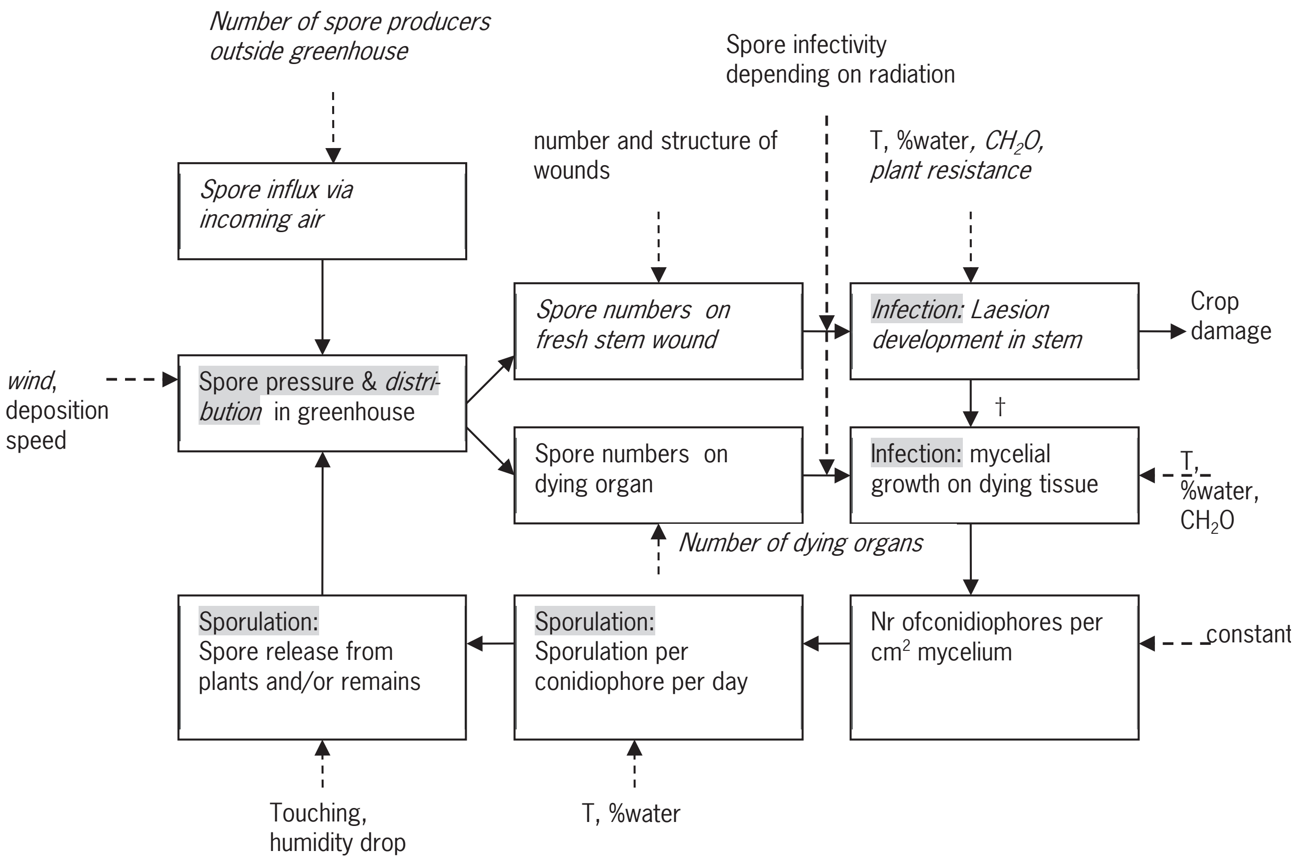


Figure 2 *Processes that play an essential role in the epidemiology of Botrytis in a greenhouse grown crop. In Italics: on these processesvery little quantitative information is present; Grey background: relationships are further described in main text.*

The following processes should be studied and deliver data to formulate a quantitative, predictive model:

1. Sporulation

Conidiophores carry the spores, and burst open as a response to abiotic conditions. The role of sporulation in the risk analysis of Botrytis in tomato will be evaluated.

2. Spore pressure & distribution

The number of spores in the air will be related to abiotic conditions on basis of historical data and new research. The movement of the spores in the air and their distribution in the greenhouse will be evaluated how to incorporate in the predictive model.

3. Infection

The germination and growth of the spores is fully dependent on local temperature and humidity. So, the modelled mechanism of primary infection from spores should be a function of temperature and humidity, as published before by e.g. Tantau and Lange (2003) (see Figure 3).

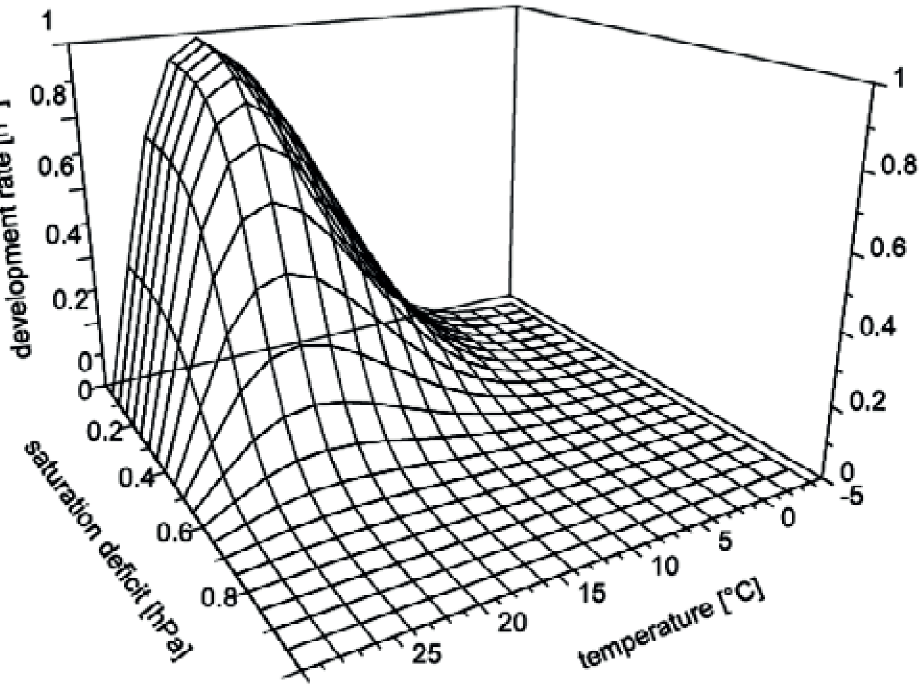


Figure 3 *Infection risk depends on temperature and humidity, as shown before by Tantau and Lange (2003).*

An infection of Botrytis happens when one or more spores have fully grown into the host tissue to enable feeding on the host's resources. This duration to infection will be investigated from literature and new research.

Only the very local environment of the spore is relevant for its germination and development. Data on this environment and the subsequent response of the Botrytis spores will be investigated.

2.2.2 Crop growth and disease resistance

A generic crop growth model, constructed in Matlab from elements of a gerbera model (De Visser *et al.* 2014), was adapted for tomato. The registration data on crop growth and fruit yield from one or more greenhouse compartments were used to parametrise the model.
Disease resistance with respect to Botrytis is not a clearly defined, measurable entity. For this project, a proxy for Botrytis resistance was used: the balance between sources and sinks of carbohydrates (SoSi ratio). A high SoSi ratio (a ratio of >1) means that the plant's photosynthesis is more then enough to fulfil it's requirements for growth. A ratio far below 1 (say <0.5) gives poor plant growth and low or neglible fruit production since most carbohydrates will be needed for maintenance respiration, prior to allocation of the remaining sugars to growing sinks.

2.3 Design of the DSS

2.3.1 Data flows

The DSS in exe format should be available and operational on the server of the company (DACOM and/or B-mex) that sells, maintains and supports the DSS software. The input data for use in the DSS should be uploaded to the server of DACOM and/or B-mex for further processing in the DSS. The developers from Wageningen UR Greenhouse Horticulture and other knowledge institutions should be able to modify and/or repair the DSS software but need to upload the latest version to the aforementioned server. An extended version of the set-up and protocols is attached in Appendix I (in Dutch).

The software should communicate with the grower's climate computer controlling and monitoring the greenhouse climate. With a time step of 5 minutes the input data on the server will be refreshed. An advise will be generated continuously, and a warning signal should be prompted if the disease risk is high. In the most extended product version the software should be able to partially control the regulation of the greenhouse in order to decrease the risk on fungal diseases.

2.3.2 Role of the DSS in the Gezonde Kas platform

All the data that will be gathered in the Gezonde Kas platform should be online available to the DSS. A data exchange platform will be constructed that should connect the data that will be inputted manually on the computer keyboard (by digital registration forms), by uploading files manually or via software packages. An exchange protocol will be constructed, tested and maintained by HvA technologies.

The data of the platform should have tags to indicate (1) time of sampling, (2) value of the measurement, (3) unit of the measurement, (4) X,Y,Z-location of the measurement.

The DSS will use these data to evaluate the conditions in the greenhouse, report the current situation back to the database and to the GUI of the DSS. The DSS will always, at every time step of 5 minutes, give a notification to the Gezonde Kas platform, indicating high risk on Botrytis, medium risk or no risk.

2.3.3 Input forms and controls

The data that will be required for the DSS to run are divided into two groups:
- Automatic data collection by hardware (sensors and controllers).
- Greenhouse climate from measurement box ('meetbox', regsitrating radiation, humidity, temperature, CO_2).
- Humidity and temperature in microclimate (wireless sensors at different spots in the greenhouse).
- Plant health by chlorofyl fluorescence.
- Concentration of volatiles, emitted by possible stressed plants.
- Status of screen opening, window opening, lamps.

Manually gathered data:
- Fruit production.
- Plant growth.
- Plant health.
- Infected spots.
- Spraying events.
- Spore pressure (if not automatized).

The automatic data recording will be available via the grower's climate computer, and the data exchange platform will have to facilitate communication with the most used climate computer systems (e.g. Hortimax, Priva, Hoogendoorn, RAM).

For input of the manually gathered data, the GUI of the DSS should have registration forms to digitize these inputs.

3 Results

3.1 Physiological relationships in the model

3.1.1 Botrytis

The succeeding processes of spore release, distribution, deposition, germination/infection, mycelial outgrowth and sporulation were all dealt with in the study. In the model not all processes were required for risk prediction, as will be explained below.

Sporulation
The touching of leaves and stems occurs very frequently when the fruits are harvested and when other plant or technical actions by personell take place. A humidity drop may occur from night to day due to heating by the sun. Both processes rather randomly occur, and the response of sporophores to burst open and subsequently shoot the spores as far as 0.5 m away happens randomly. This process is not modelled and assumed to take place daily, not restricting spore distribution.

Spore pressure & distribution
The number of spores was empirically related to vapour pressure deficit (VPD in hPa), with VPD in the night and the day having differential impact. The relationship of spore pressure on VPD is derived from De Visser *et al.* (2010):

Spore pressure = C1 * VPD in night + C2 * VPD in day + C3 * number of night hours

The values of the constants C1, C2 and C3 were determined by fitting the observed spore amounts (spores collected during 24 hour on horizontal plates) on observed VPD.

Infection
The germination and growth of the spores is fully dependent on local temperature and humidity, and is incorporated in the model as quantified by Tantau and Lange (2003) (see Figure 3).

The development rate of Botrytis at a specific climate condition results in an infection when the spore has fully grown into the host tissue. This duration to infection lasts at least 6 hours, at very moist conditions, to possibly 100 hours at less moist situations (see Figure 4). When in this period dry events occur, the drying effect results in a prolonged duration until infection. Yet, the total duration is maximally 4 days or 96 hours, when longer the spore dies.

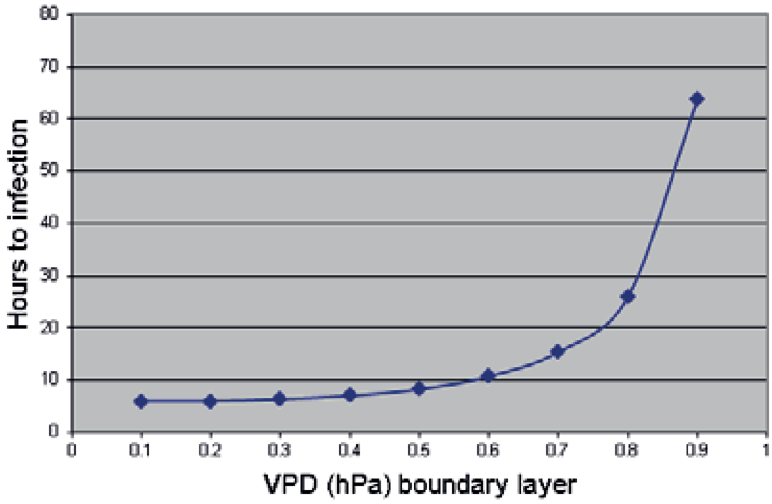


Figure 4 *Time required to generate infection, in dependance of VPD.*

Only the very local environment of the spore is relevant for its germination and development. Since spores have a size of ca. 10 nm, this layer on the leaf where the spore resides, also called boundary layer, is dealt with in infection models like the one in this report. The moisture and temperature of this layer are estimated by extrapolation from the values of the microclimate as measured by the small wireless sensors of Agrisensys. This extrapolation factor is derived from extensive tests of the model on botrytis occurrence in gerbera flowers, where infection incidences and nmicroclimate measurements were combined. Below vapour pressure deficits (VPD) of 0.1 kPa infections often occurred, and this VPD supposedly correlates with water potentials at the leaf boundary layer of 3 MPa or lower. A water potential of -2 MPa is optimal for botrytis germination, while -3 MPa slows it down considerably, and values of -7 MPa almost (but not completely) stop spore germination (see Köhl *et al.* 1992).

Mycelial growth and formation of condiophores

Outgrowth of mycelia was not incorporated in this model. We expect that further growth of a germinated spore will always lead to a lethal lesion. Thus, the phase after germination is not relevant if the infection is already reported by the model.

3.1.2 Crop growth and disease resistance

A generic crop growth model, constructed in Matlab from elements of a gerbera model (De Visser *et al.* 2014), was adapted for tomato.

3.2 Resulting design of the DSS

3.2.1 Inputs and outputs

The minimum requirement inputs on the greenhouse climate were decided to be:
- Radiation (either global outside radiation or inside radiation, being either total radiation or PAR).
- Temperature of greenhouse air.
- CO_2 concentration in greenhouse air.
- Relative humidity or vapour pressure deficit (VPD) in greenhouse air.

The faculatative, but highly appreciated climatic inputs were:
- Temperature of outside air.
- Humidity of outside air.
- Sky temperature.
- Ratio diffuse/direct radiation.
- Wind speed outside.
- Wind speed, i.e. air movement, inside.
-

Input data on the greenhouse system that were required for the DSS to run were:
- Screen opening.
- Window opening.
- CO_2 dosing capacity.
- Spraying events.

Input data on the system that were optional, but highly appreciated, were:
- Spore pressure.
- Temperature on various spots in the compartment (via sensor grid).
- Humidity on various spots in the compartment (via sensor grid).
- Stem wound condition (humidity, chemical treatment).
- Plant management (shoot pruning, changed planting density, removal of plant head).

An overview of the data flows as used in the current DSS is presented in Figure 5.

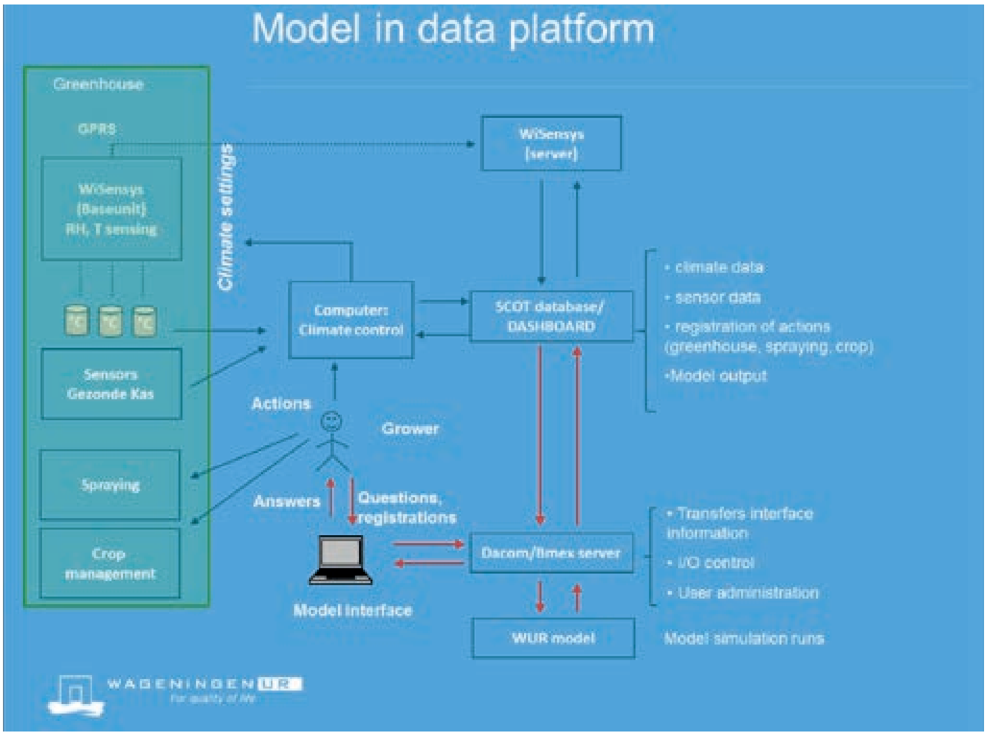


Figure 5 *Data flows in the current DSS and Gezonde Kas (SCOT database) platform.*

The software is communicating with the grower's climate computer controlling and monitoring the greenhouse climate. An advise is generated continuously (i.e. every 5 minutes), and a warning signal is prompted if the disease risk is high. In the Gezonde Kas framework, the DSS has the role of data interpreter and advisor. When monitoring data from sensors have been entered in the Gezonde Kas database (the SCOT dataplatform), they are transferred to the DSS for evaluation and advise. Both microscale (within a leaf, on a particular stem) and macroscale (sensors in the surroundings of the crop, or in the central measurement box or 'meetbox') data are input (Figure 6).

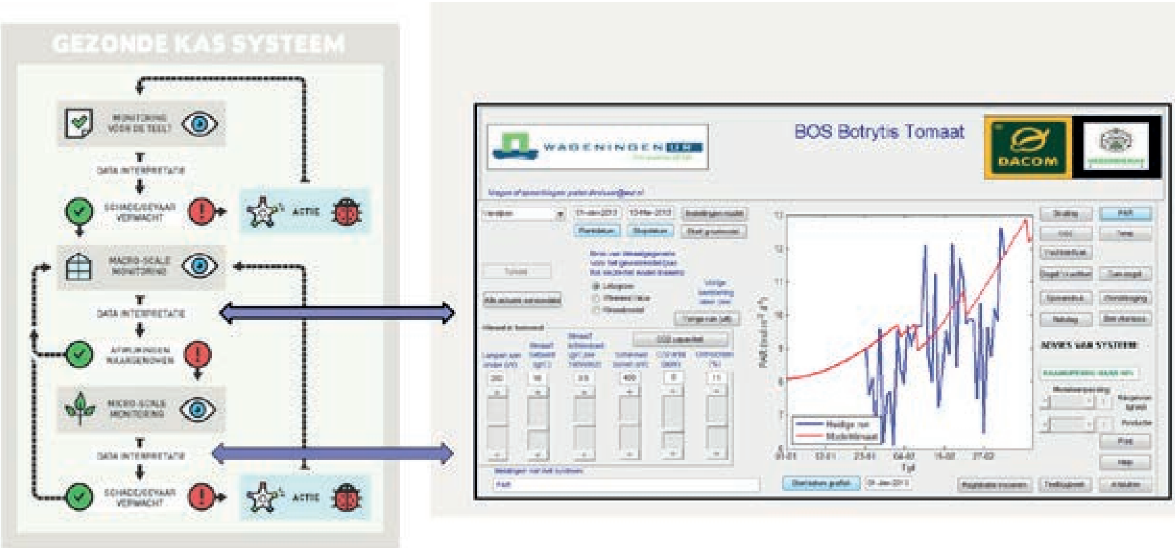


Figure 6 *Information flow between Gezonde Kas system and DSS tomato.*

3.2.2 Input forms and controls

For the model to run with the correwct settings of the climate controllers and cultivationstrategy, input forms have to be filled in. The window on the management strategy on greenhouse climate and planting pops up (Fig.7) when the button 'Instellingen model' is selected. The most relevant settings, as being agreed upon with growers, can be filled in:

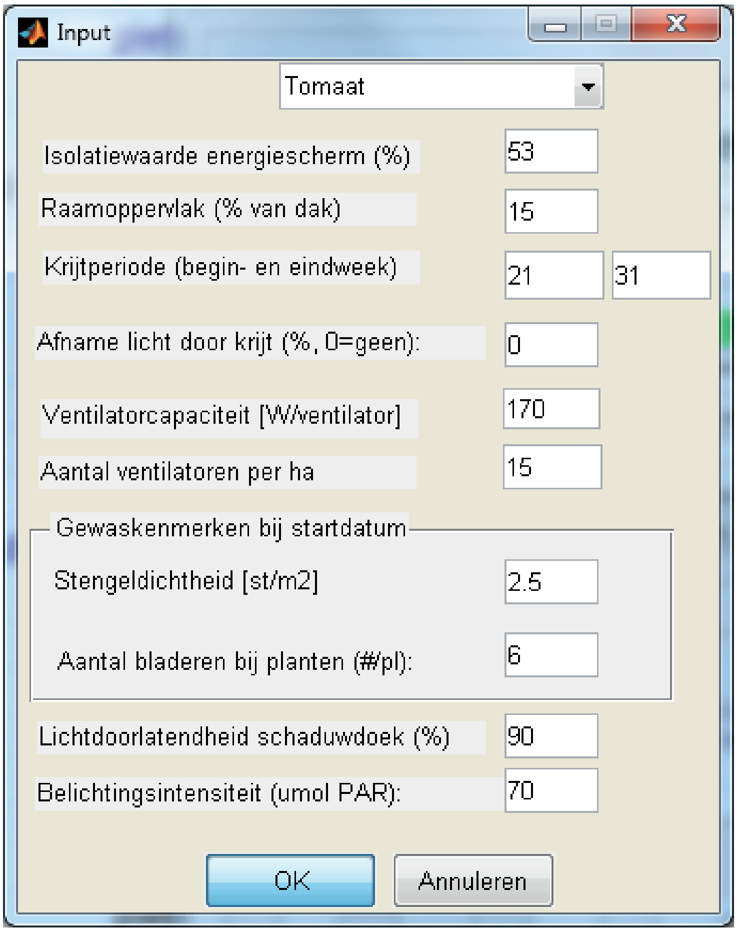


Figure 7 *Sub menu for greenhouse settings.*

A second input form is called 'Registratie invoeren' and deals with the observed yields, spore pressures and the achieved sprayings (Figure 8). These input data are very relevant for the calibration of the plant growth model, and for the current degree of disease pressure.

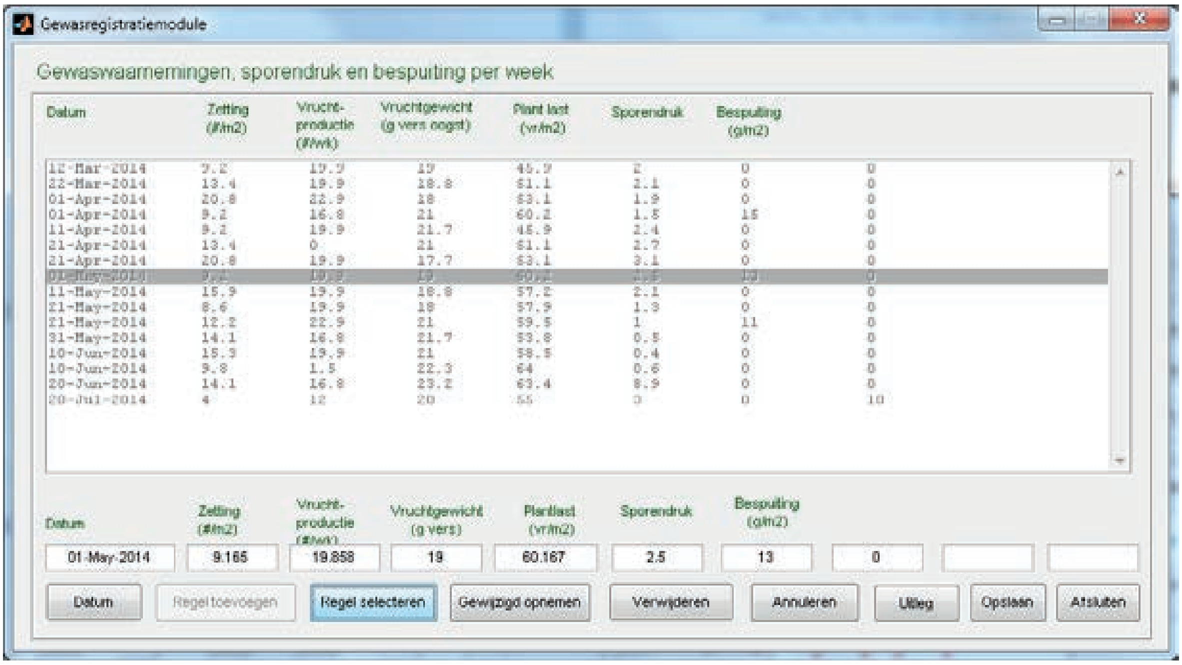
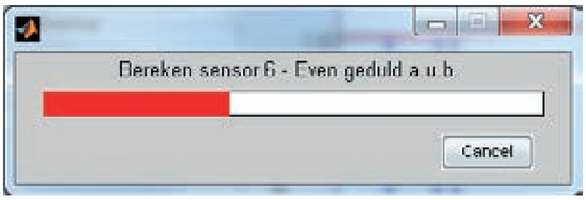


__Figure 8__ Sub menu for inserting crop production data, spore pressure and spraying events. The last, right-most column can optionally be attributed to a variable of interest.

3.3 Functioning of the user interface

3.3.1 Running the model

For each of the sensor locations the model simulates crop growth and botrytis development for the given time interval. A progress bar indicates the progression of the model, that runs a simulation for each sensor location:



When all sensor locations have been simulated, output is stored in a virtual Matlab data file. The output can be viewed in a number of ways:

1. Time course for a selected sensor location.
2. A grid, representing a 2D map of the greenhouse compartment.

Ad 1:
For every sensor location one of the twelfth output variables at the right side of the GUI can be selected. Directly after clicking the already present data file on the chosen variable is plotted in the graph window. The time course pf the variable's value will be shown.
The starting and finishing date for a simulation run were already selected (else the model will use the previously used dates), and the output can only be extended to a wider time frame if run again at newly set dates.

Ad 2:
In the graph pane the sensor grid is shown with modelled risk or current temperature or humidity per sensor. The variable can be selected in the box left of the graph, called 'Sensorgrid in de kas':

For the current end point of the simulation (14 June 2014 in Fig.9) the risk level and required action is presented, being 'ADVIES VAN SYSTEEM' in a white text box at the right side of the interface. The sensor with most severe risk level is indicated, if risk is at hand. Optionally, the 2D grid can be converted to a risk map, showing the contours of the sensor output (Figure 10).

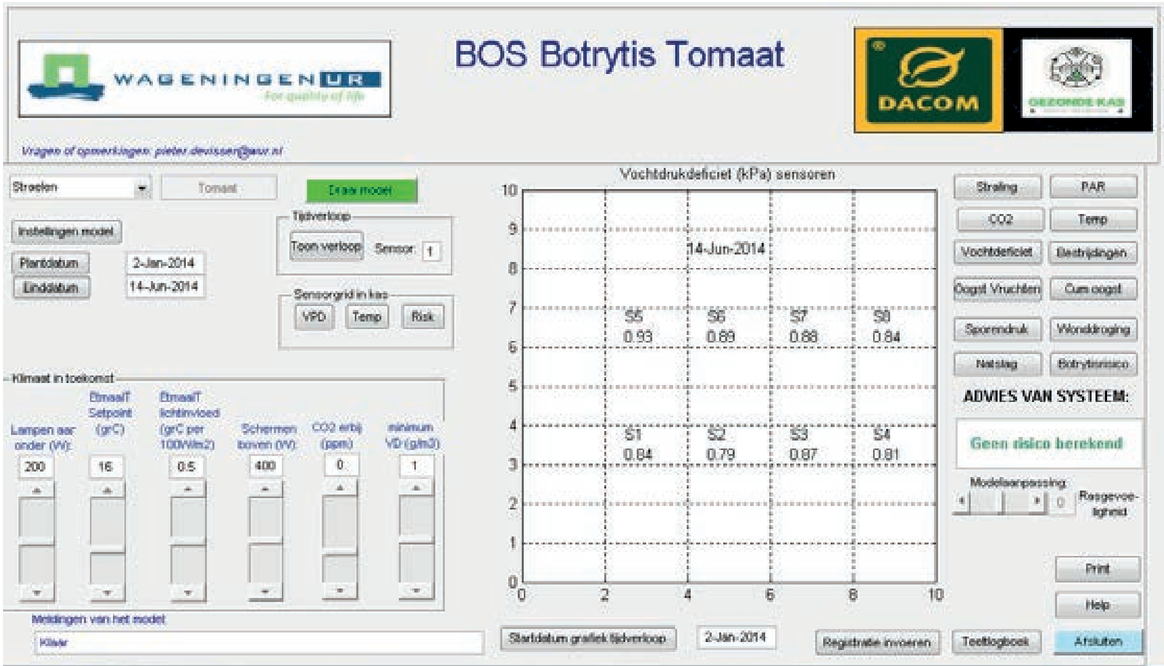


Figure 9 *Simulation result showing the sensor grid and current value of observed temperature or humidity, or modelled botrytis risk. The advice of the system is shown at the right side of the interface.*

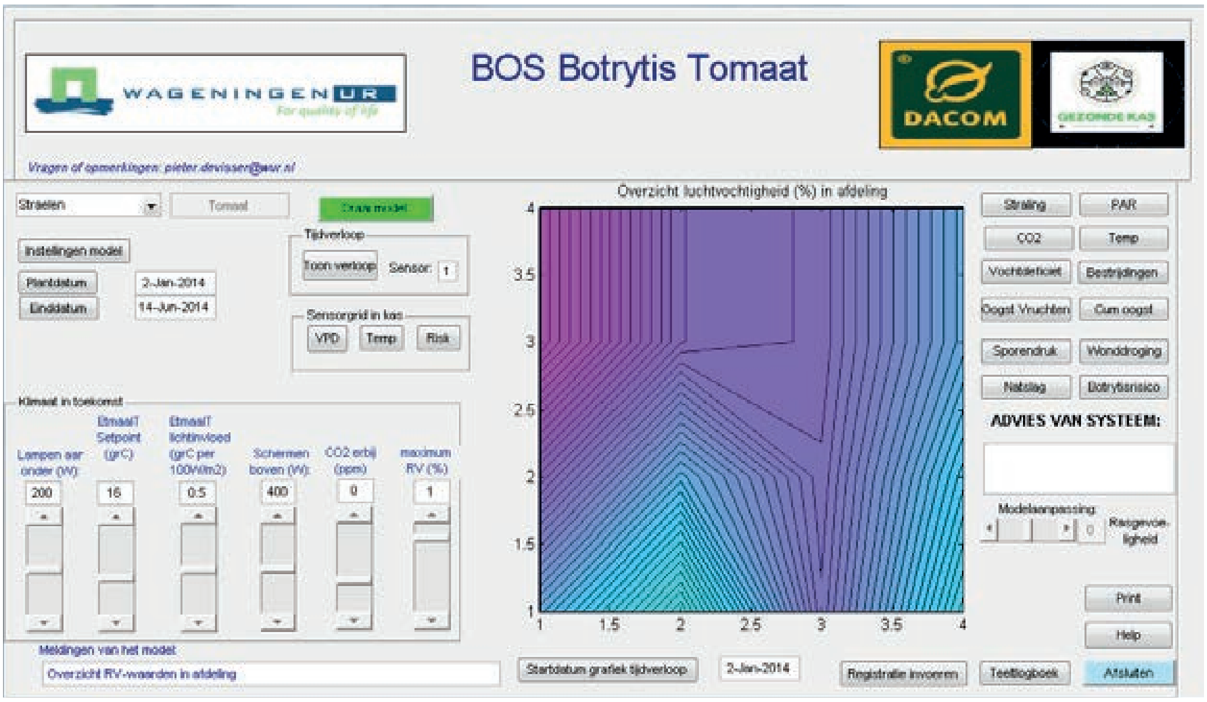


Figure 10 *Contour plot of the humidity in the greenhouse compartment, as observed with the sensor grid.*

3.3.2 Botrytis prevention by setting future climate

The grower usually has a number of operators to adjust the greenhouse climate. These operators are presented as sliders in the GUI, and comprise (1) lamp light, (2) average day temperature, (3) screening, (3) additional CO2, (5) humidity. Apart of these slider controls, within the settings menu the following controls are possible: (1) screen transmissivity, (2) percentage light reduction by chalking of glass cover, (3) ventilator numbers and their power, (4) power of the lamps. All the aforementioned controls affect future climate to a certain extent, depending on the time in the year (in summer lamp light does not have much effect) and their combination (chalking AND a dark screen will seriously reduce light reaching the crop and possible botrytis spores).

A standard weather year is used to simulate the outdoor abiotic conditions. This particularly important for predicting future indoor conditions, in the greenhouse So, future clmate is fully dependent on (a) the standard weather year input, (b) the values of all the slider and settings as mentioned above. In that way, the grower can manipulate future climate and is . For simulation of past growth and botrytis, the standard weather calculation is overruled by observed data on indoor conditions, measured by climate boxes (dutch: 'meetbox'), unless these data are missing.

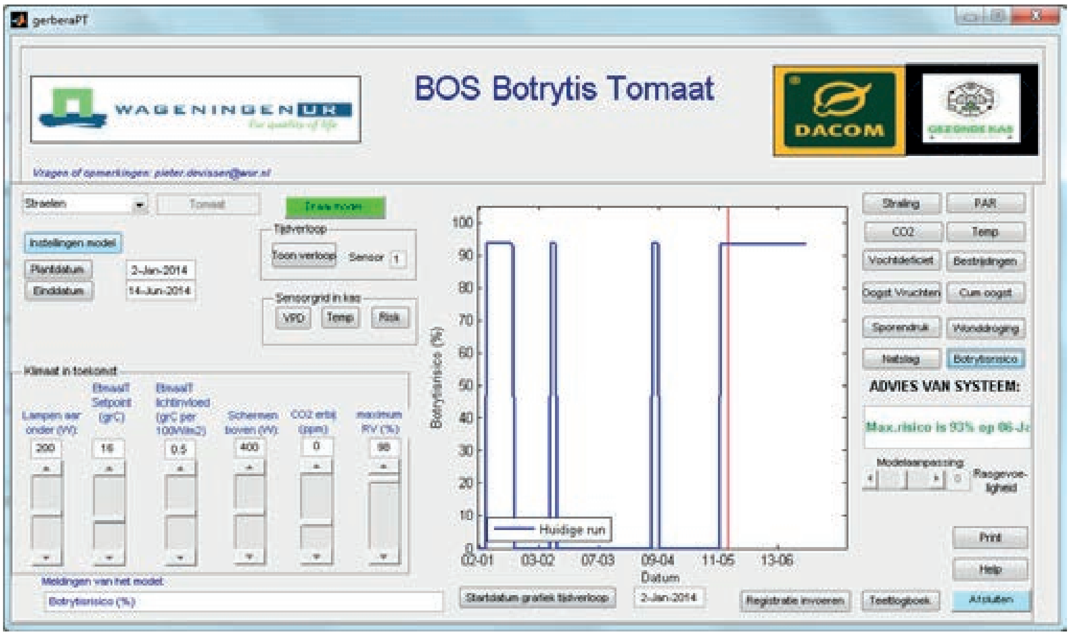
In the graphs, the start of the future is indicated by a red, vertical line (Figure 11).

3.4 Modelling climate and resulting infection risks

3.4.1 Humidity and infection

Botrytis germination and infection is favoured at humid conditions. We selected a dry and a wet scenario to show the capabilities of the model. When in the settings for future climate a maximum value of 98% is introduced, 4 times an infection risk is predicted in the current time series (Figure 11). The 4th incidence is quite obvious, since this occurs in the future, when the humidity is fixed at this constant value of 98%. Yet, also three past moments of 98% had occurred because indoor measurements were missing and the set humidity thus replaced the not available data, leading to a, theoretical, high risk.

11a



11b

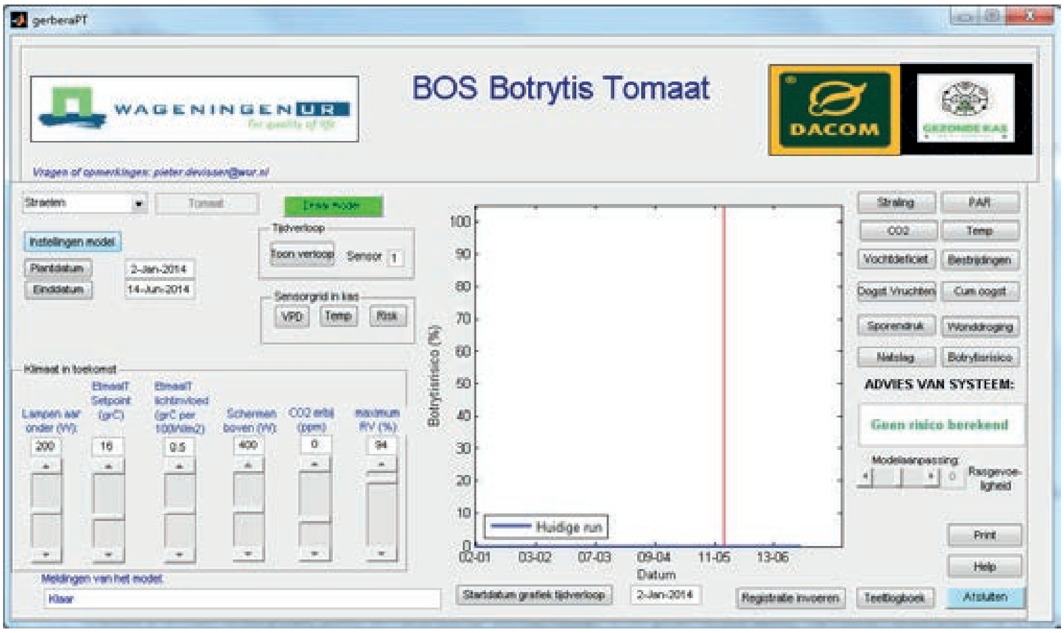


Figure 11 *Interface with simulation of past and future infection risk. Moment of calculation is 15 May, and right of the vertical red line the future period is shown. 11a. Output at maximum humidity set at 98%; 11b. Maximum humidity set at 94%.*

3.4.2 Model performance

The crop growth model was adapted from a generic growth model made in Matlab. The parameters for fruit production were tuned on basis of observed yield in the tomato compartment in the Straelen greenhouse. When the moment of start of generative phase was inserted in the model, the modelled yields nicely agreed to the observations (Figure 12). Since source strength of this tomato cultivar was known, and yield agreed to the observations, the surplus or shortage of sources could be estimated, and thus source/sink ratios could be modelled. The SoSi ratio was generally around 0.8 during the modelled time frame.

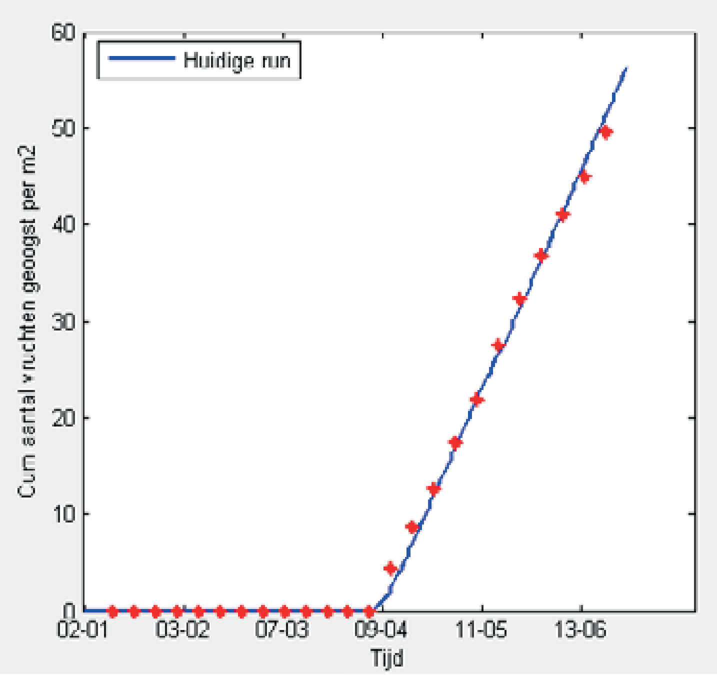


Figure 12 *Cumulative fruit yield (nr of fruits per m² per week) nicely fits the observed yield in Straelen in 2014.*

The risk on Botrytis strongly depends on the degree of wetness of the fresh wounds on the stem after cutting or breaking of the leaves. In Figure 13 the estimation of wound drying is shown. The drying is quantified by:

Fraction dried stem wound = 1 – (daily exudate from root pressure – daily wound transpiration)/200;

Th exudate flow depends on the abundance of assimilates, derived from the SoSi ratio, and root temperature. Just before fruit sinks strongly appear, before end of March, wounds dry too little, probably due to excess sugars pushing root pressure, whereas evapotranspiration is still minor.

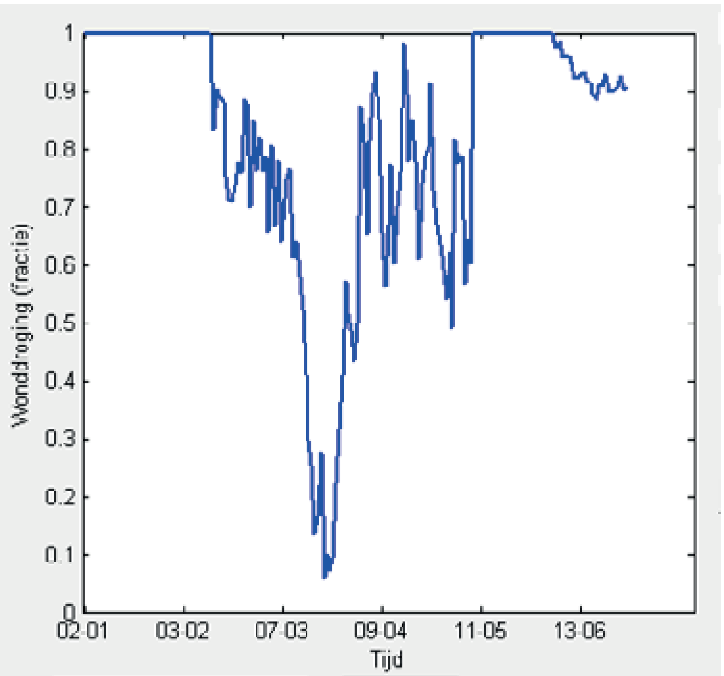


Figure 13 *Indication of wound drying.*

A partly wet wound is an attractive entry point for Botrytis spores. The exact water potential of the stem wound surface could not be determined experimentally. Thus, a sound model on water potential and associated spore germination could not be constructed. Moreover, a possible entry of spores in the stem vascular tissue was too complex to investigate. Spores that enter in internal tissue can in due time cause an endemic infection, on a moment when nutritional status for the spores has improved.

3.4.3 Botrytis alert is the Web-based Service of the model

The principal model for Botrytis risk estimation is also copied and converted into a web-based service. This web service can be reached by any computer, tablet or smartphone where ever in the world. Thus, a grower can always check the webservice for possible Botrytis risks in his greenhouse. Like the Matlab version, the web version allows to view the output as a time series or as a 2D grid of the greenhouse compartment (Figure 14). The 2D grid only is relevant if a set of sensors is present in the greenhouse and connected to the data platform. The demo of the model uses realtime data from the Straelen tomato greenhouse and is found at the url http://149.210.153.146/BotrytisAlert

The service is being sold by the Dutch company B-mex.

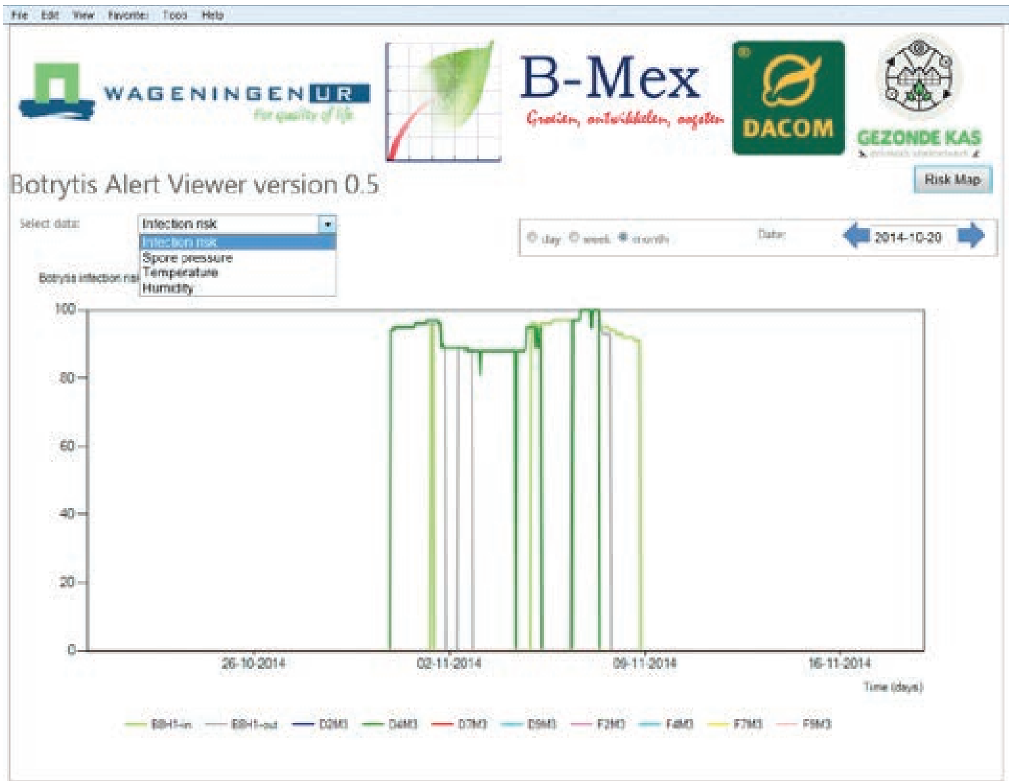


Figure 14 *Botrytis alert in the form of a web service, available on the internet. Model risk and sensor data can be displayed within a grid of the greenhouse (Risk map in top window) or as a time series (bottom, where the drop-down box to choose the output variable is shown). Risk is reported for sensor B8H1 in both windows.*

4 Discussion

A physiological model of Botrytis risk in tomato plants in greenhouses was constructed on basis of literature data and extended with some measurements in the Straelen greenhouse. The estimated risk is a function of humidity and temperature in the air near to the plants. Although this microclimate may resemble the situation in the boundary leayer of the plant where the adhesed spores are present, there are possibilities to improve the model. If more research would be done on the condition of the boundary layer, especially at the surface of fresh cut stem wounds, the model would increase in realism. The role of the boundary layer in Botrytis risk prediction is frequently mentioned in literature (see e.g. Köhl *et al.* 2007). A recent study suggests that humidity of the stem wound is not relevant but the signaling cascade to trigger defense mechanisms (Beyers *et al.* 2013), yet the most common signaling molecules do not seem to be the main triggers. Despite the scientific debate, a very practical solution of the Botrytis problem in tomato crops has been suggested in the project of the Katholieke Hogeschool Leuven (2015 or earlier), with a website that indicates that a good hygiene and a careful leaf pruning technique may almost eradicate the Botrytis risk. The accompanying advisory model Bomodly does not seem to be supported anymore.

The DSS reported here can easily be used by growers and advisors. The webservice version 'Botrytis alert' is even easier to use and runs without need of user interaction. Yet, the alert programme notifies the user when Botrytis risk is calculated. It is envisaged that in the future, the most extended version the DSS software will be able to automatically, partially control the regulation of the greenhouse in order to decrease the risk on fungal diseases.

5 References

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Appendix I. Notulen overleg met DACOM en HvA web solutions 6 sept. 2012

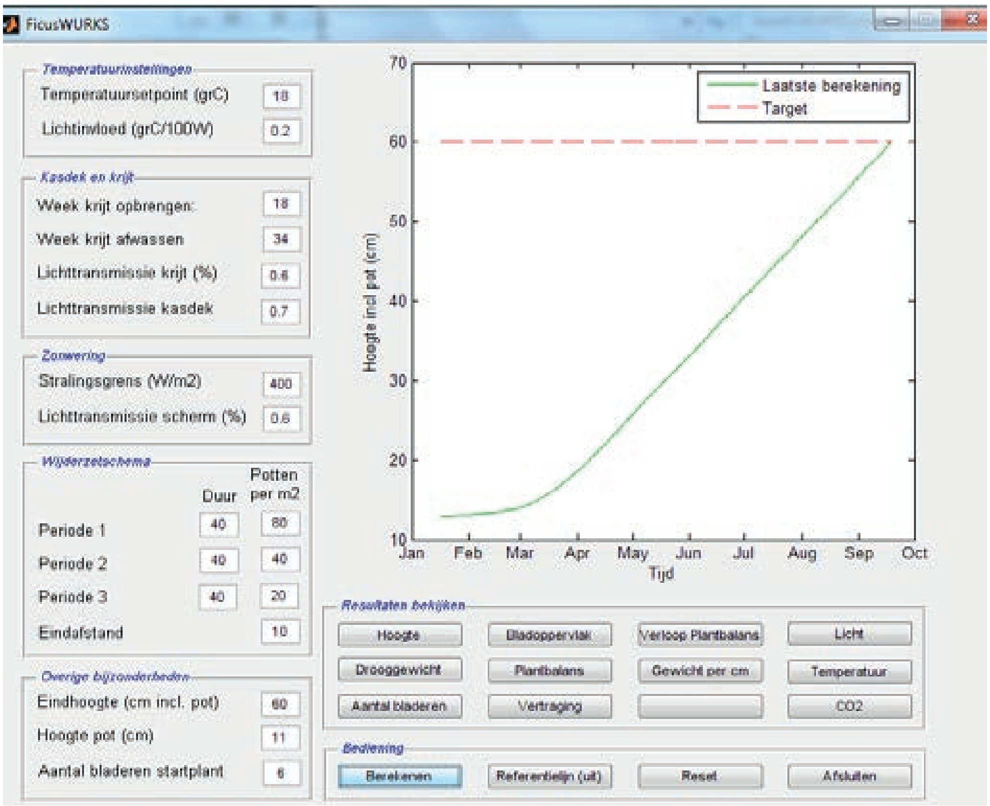
Onderwerp: Gezonde Kas – Product 15 – BOS Botrytis in tomaat
Datum: 6 september 2012
Aanwezig via Skype: Hans van Bokhoven (HvA), Louis Nannes (DACOM), Pieter de Visser (not.)

Status:
Pieter meldt dat er enkele contacten met o.a. de Duitse partners in het GZ programma zijn geweest, maar dat aan model afgelopen tijd geen wijzigingen zijn geweest.
Hans meldt dat hij met Siebert (DACOM) overleg heeft gehad over de procedure voor data extractie van sensoren. Inmiddels is dit duidelijk, en kunnen we dit in een proefkas gaan testen. Zijn vraag:"welke kas met tomaat gaat het worden?". Pieter: onzeker: afdeling in Straehlen of in Bleiswijk. Laatste optie is niet aantrekkelijk want kost veel (huur)geld. Straehlen is ook veel beter omdat Wireless value daar sensoren heeft hangen die we in de test mee kunnen nemen. Pieter gaat dit na (Actie).
Vraag van Hans: wil je in de BOS de data van de draadloze sensoren (RV, Temp) vooraf middelen en dan model invoeren? Pieter: nee, ik wil PER SENSOR een simulatie run doen, want er is per sensor verschil in infectierisico. Gevolg: per sensor komt er een datafile die in de naam aangeeft welke positie de sensor heeft (bv. R3_20_2, oftwel Rij 3, 20cm hoog, herhaling 2).
Acie: Pieter stuurt correspondentie aan Hans/Louis die hij had met Jos Balendonck t.a.v. dit protocol
Louis meldt hij overleg met Hans afgelopen tijd heeft geïnitieerd maar het technische deel aan de Dacom-technici heeft uitbesteed (zie ook boven).

Technische opzet van ICT systeem t.b.v. BOS tomaat:
Pieter schetst de opzet zoals dat in het WURKS-project draait (zie Figure onderaan doc): (1) een WUR applicatie staat op een server bij Alterra, kan door WUR onderzoeker zo vaak als ie wil ge-update worden en gecheckt worden op functioneren (via log files), (2) de 'klant' heeft een interface/GUI op zijn/haar PC met allerhande knoppen en een grafiek-deel, en doet een rekenopdracht die de WUR applicatie doet draaien, (3) de applicatie stuurt een xml file terug met louter reeksen getallen die bestaan uit een tijd-stempel en een output-waarde, en elke afzonderlijke output wordt grafisch zichtbaar als je de bijbehorende button klikt in de GUI.
Actie: Pieter stuurt deze opzet naar Hans en Louis ter beoordeling.
Louis vindt deze WURKS-opzet niet geschikt voor DACOM, want er is dan iemand die aan onderdeel van de BOS prutst (onderzoeker op de server…), en er zijn teveel servers/platforms/systemen die moeten communiceren. De WUR applicatie (een afgeschermde executable) kan toch gewoon op hun server, en kan altijd wel eens ge-update worden. Klopt. Akkoord.
Actie: Pieter stuurt voor week 39 (uiterlijk 24 sept) een exe en input en output files naar DACOM.
Actie: Louis zorgt dat die exe via een GUI van DACOM aanroepbaar is en output laat zien.
Hans geeft aan dat hij voor meerdere projecten binnen Gezonde Kas de techniek van de data stromen ontwikkelt, en dat dat niet perse altijd via letsgrow moet, want dat is slechts één van de data locaties. Er komt een universeel protocol dat per situatie met lichte aanpassingen blijft werken. Het lijkt er wel op dat alle data van telers met GZ systeem in één centrale database worden beheerd.
Hans meldt dat er contact was met Innosieve om de meting van sporendruk regelmatig (frequentie is nog niet afgesproken) te uploaden: ik meen dat er handmatig een csv-file op de teler/gebruiker PC wordt gevuld, en deze wordt ge-upload naar de centrale database van GZ.
Actie Hans: binnen 4 weken zijn de data van de RAM klimaatcomputer, en van Wireless value, beschikbaar op een server. Zodat DACOM het proefmodel (bovengenoemde exe) hiermee kan testen.
Actie Pieter: vraagt Innosieve of ze nu sporendruk gaan meten in Bleiswijk en of dat bij tomaat is; Pieter houdt in proefversie van de BOS al rekening met een dagelijkse meting van de sporendruk.

Design van klantgerichte interface
Pieter en Louis zijn akkoord dat DACOM de interface bouwt, en dat WUR hiervoor het motortje (de exe) aanlevert in Emmen. Dit betekent dat DACOM een design bedenkt dat een aantrekkelijk, verkoopbaar product oplevert. Hiervoor moet de interesse bij tomatentelers gepeild worden. Om te beginnen bij een gemotiveerde, meedenkende teler. Hans suggereert de gebroeders (o.a. Eric) Vereijken, die over meerdere bedrijven beschikken in de grensstreek, en die enthousiast waren over een eerder DACOM product. Het toeval wil dat Pieter hem gesproken heeft m.b.t. PPS Botrytis Tomaat (maar niet hij, maar Pieter van Dijk, en Leo Verbeek, zitten in de PPS) omdat hij met Climeco heeft samengewerkt, en in de landelijke cie tomaat zit. Als hij overtuigt is van de BOS volgen er vast meer.
Actie: Pieter belt Vereijken, en probeert een datum voor bezoek, samen met Louis, te regelen. Na week 38.
Volgend overleg
Over ruim een maand weer Skype overleg. We hopen dan Vereijken te hebben gesproken, en de exe getest te hebben met data van Straehlen.

Bijlage 1: Illustraties:



WURKS interface op locale Client-PC die exe op Alterra server aanroept via knop "berekenen"

Bijlage 2:

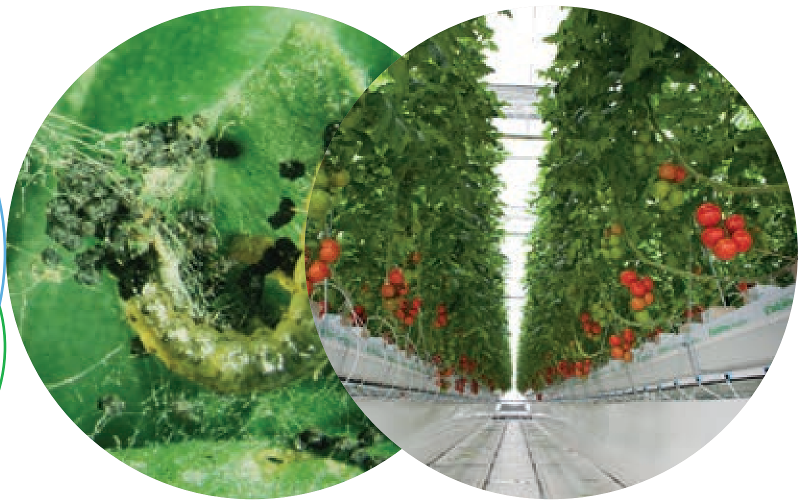
Afspraak protocol voor transfer van data draadloze sensoren: Prod15 & Prod 7,8,9:
From: Visser, Pieter de
Sent: vrijdag 22 juni 2012 16:07
To: Balendonck, Jos
Cc: Zijlstra, Carolien
Subject: MS15.1

Dag Jos,
Hierbij de afspraken t.a.v. Milestone 15.1 i.e. "Specification of requested data (RV and T) for product 15, the DSS Botrytis tomato".

Product 15 ontvangt van Product 7 de RV en T met volgende specificaties en format:

- Minimaal met nauwkeurigheid in % RV en 0.1 graad temperatuur.
- Elke sensor levert per 5 minuten een 5-min gemiddelde waarde.
- Het vaste sensor-grid is conform de procedure bij Wireless Value, dus de gridpunten bestrijken max. 1 ha kasoppervlak.
- We gaan uit van 3 hoogten in het gewas (onderin, in midden, in top).
- De mobiele sensor geeft bij elke meting ook zijn X,Y,Z-positie (dataformat nog in overleg met Letsgrow) door.

To explore the potential of nature to improve the quality of life



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