Model-Based Decision Support for Protected Cultivation of Sweet Pepper

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Abstract

A crop growth model for sweet pepper was applied to simulate quantity and timing of fruit set and harvest. Climate input for the model was organised by means of online data platforms, linking directly to climate computer sensors. This information was processed and made available as model-input automatically via an ftp-server. Additionally, regular registration of fruit set and harvest was routinely performed on a weekly basis at the companies and entered manually into online data platforms. The processed model-input for registration was made available via the same ftp-connection. The model was complemented with a user interface, allowing instant simulation of simple climate scenarios. This provided the grower with information on the consequences of changes in greenhouse climate for fruit set and harvest. Initially, model results were solely supplied through a partnership with a cultivation advisory firm, acquainting the grower with the possibilities of the model-application. Later in the project, experienced growers used the application locally, allowing them to use the tool more frequently as support in their decision making.

INTRODUCTION

Crop growth modelling has long remained an exclusive activity of academic crop physiologists. Although results from these models are often interesting from a general point of view, in order to obtain valuable information for commercial growers, output (and thus input) has to be company-specific. Technological progress now allows swift and easy information exchange through the internet, which has taken away a significant boundary for making model output more company-specific, (semi-) real-time and thus more applicable to commercial growers. In this paper we report results from three years of applying a sweet pepper model as a decision support tool for growers.

Sweet pepper is one of the most important greenhouse vegetable crops in The Netherlands (production value of 289 million euros in 2009, Borgdorff and Schutter 2010). Year-round greenhouse production of sweet pepper can be tricky, as vegetative and generative growth need to be balanced. This balance effectively represents a compromise between cultivation goals in the short-term (few weeks) and long-term (season). Keeping the crop in balance is complicated further by fluctuations in climate, in particular incoming irradiance.

Fruit Set

Fruit set is an important characteristic in sweet pepper cultivation as it is the determinant of the number of harvestable fruits. Growers usually strive to keep fruit set as stable as possible. However, as flowers and young fruits have relatively low competitive ability as a sink for assimilates, sweet pepper growth is characterised by frequent abortion of young fruits and flowers during periods of low assimilate availability. These periods can occur due to high fruit load or low light intensity. The resulting irregular fruit set pattern causes yield fluctuations to occur (e.g. Heuvelink et al., 2004; Wubs, 2010). These yield fluctuations tend to propagate through oscillations in fruit load, due to the feedback effect on fruit set, and are synchronised by low light levels, leading to periodic oversupply (yield flushes) and accompanying low prices.

Crop Growth Modelling

Protected cultivation in greenhouses offers growers a variety of options to influence crop growth and development. The greenhouse climate can be manipulated and crop management actions like leaf picking or pruning can also be used to manipulate biomass growth and allocation. Crop growth modelling can be used to analyse the effects of influencing factors on the growth and development of crops. Many crop growth models for sweet pepper exist, which simulate crop growth and harvest as a function of time in various levels of detail (e.g. Marcelis et al., 2006; Schepers et al., 2006; Buwalda et al., 2006). Academically, these models can be useful in assessing the magnitude and importance of general effects, such as the behaviour of fruit set as a function of absorbed light. From a crop management point of view, model predictions are particularly useful when they are based on up-to-date company-specific input data. In this way the current situation can be assessed and predictions for the future can be made using scenario calculations. In this project we aimed to improve crop management by informing growers with crop growth model predictions based on company specific data.

MATERIALS AND METHODS

Crop Growth Model

Only few models are able to predict fruit set and yield fluctuations as an emerging property within the model (Schepers et al., 2006; Buwalda et al., 2006) The model by Buwalda et al. (2006) was chosen, because the discrete time step aided model-data integration with discrete data sets from commercial nurseries. For the complete model description we refer to Buwalda et al. 2006. Input data for average 24-hour temperature, daily light integral and average CO_2 concentration during the light period were a combination of realised company-specific time-series, and seasonal sinusoid functions, which extrapolated the running average of the realised time series.

Commercial Nurseries

The project ran over three years, with model applications for 3, 6 and 12 commercial nurseries in 2009, 2010 and 2011, respectively. Each consecutive year, the commercial nurseries from the previous year chose to stay involved with the project, leading to a mix of experienced and un-experienced users. The model runs were initiated by destructively measuring aboveground dry weight of 10 starting plants at each nursery.

Calibration

If available at the start, quantitative information about the sweet pepper cultivar at each nursery was used to pre-calibrate specific model parameters for each company (e.g. parameters for Richard’s growth curve or temperature sum to mature fruits). For new nurseries or cultivars a standard parameter set was used as initial value. Parameter estimation was subsequently performed once after the first registered peak in fruit set had appeared in the realised harvest to match predictions with observations (for each new nursery/cultivar).

Technical Set-Up

The full scheme of the information flow is shown in Figure 1. Datasets from commercial nurseries were made available through the internet via specialised internet sites LetsGrow.com (LetsGrow.com, Vlaardingen, The Netherlands) and Priva Fusion online (Priva B.V., De Lier, The Netherlands). These company-specific time-series (5 minute timestep) were processed into the climate input required by the model (mentioned above) and made available through a ftp-server. In this way, the model application could always obtain the most recent input data for each company, requiring only a working internet connection.

Graphical User Interface

We specifically aimed to improve the accessibility of the model predictions to untrained users. Therefore we developed a graphical user interface, allowing various simple climate or management scenarios to be run and compared to a base run. The most relevant model output of each run was visualised within the user interface, through a selection of output graphs (Timeseries of: Climate inputs, fruit set per m^2, fruit load per m^2, harvested number of fruit per m^2, harvested fruit fresh weight per m^2 source/sink ratio and average fruit fresh weight), which could be visualised in a central figure in the user interface. Figure 2 shows the central figure and the sliders to create simple scenarios. The model has a time-step of one day, whereas growers prefer a weekly time-step, because most of the company data (fruit set, harvested number of fruits, etc) is only registered on a weekly basis. Therefore, to allow easy model-data comparison, model output was integrated per week and results were plotted on a weekly basis.

Model Implementation

The model and graphical user interface were implemented in Matlab 7.7.0 R2008b (The Mathworks, Natick, MA, USA).

RESULTS AND DISCUSSION

Model Application

During the first year of the project, the model output was discussed with growers, during regular visits. Additionally, in the final year of the project, the application was also installed locally, to allow growers access to the model predictions at any time. At the beginning of the season, the full season was calculated using smooth sinusoid functions for the climate input. As the growing season progressed, this climate was increasingly being replaced by the realised climate. However, the graphical user interface offered the possibility to undo this replacement up to any date in the past, to allow assessment of the influence of realised climate on the model predictions. As any offset between simulated fruit set and actual fruit set increases uncertainty in future predictions, the model application also offered the possibility to use realised fruit set instead of simulated fruit set for the historical part of the run. In this case, for each time step, the simulated fruit set in the model state was corrected for the observed fruit set. This feature was implemented as one of the settings, accessible for the user through the graphical user interface, and could be changed to any date in the past, to assess model predictive power for fruit set, based on realised climate.

Prediction Accuracy

The original model by Buwalda et al. (2006) was based on *Capsicum annuum* L. 'Ferrari'. After parameter estimation, when sufficient realised time-series data was available (as described in Materials and Methods), the model exhibited appropriate predictive power for most cultivars. Some general reservations are however in place. At the beginning of the growing season, predictions with respect to the timing of the first fruit set, were less accurate than later in the season. As the harvested fruits of the former period are generally sold for better prices than later in the season, this was considered a weak feature of the model. Also, prediction accuracy was generally better for cultivars with no significant differentiation in fruit outgrowth kinetics. This differentiation can occur due to positioning of fruits (main stem versus side shoot). Also, breeding efforts have focused on removing the abscission zone to reduce abortion in some modern cultivars. This results in fruits, which would otherwise have been aborted, to remain on the crop. However, these fruits often show an outgrowth pattern which is very different from the average fruit. Due to the fact that the model uses the same temperature sum and descriptive Richard's growth function for computing fruit growth and development for all fruits on the crop, this detailed differentiation could not be captured.

Use of Model Application in Practice

Due to limited space, the description of the use of the model in practice remains exemplary. The model was generally used in a number of different ways. First of all, at the start of the season, the predicted seasonal yield pattern was assessed and in some cases compared with results from the same cultivar/greenhouse combination in previous years. However, due to the strong influence of weather conditions on the yield fluctuations, this simulation run had limited predictive value. Secondly, the most intensive use of the model focused on influencing the timing and extent of the short-term fruit set (1-4 weeks ahead).

An example scenario is shown in Figures 3A and B. In the example, the effect of a 4-week period with relatively low light levels on weekly fruit set is being assessed. The light input for the model starts with the realised light intensity (in Fig. 3A) and uses the smooth sinusoid line (in Fig. 3A) for the remainder of the growing season. The period with lower light intensity is pointed out by the arrow. In Figure 3B the scenario is first computed without the period of reduced light intensity (reference line) followed by the calculation using the input light levels shown in Figure 3A (prognosis line). Note that the realised fruit set (observed line in Fig. 3B) is used to overrule the simulated fruit set (model line in Fig. 3B) for past time points to improve future prediction accuracy.

It was found that for 2009 and 2011, the sequence of periods with high light intensity followed by periods with low light intensity, caused the sweet pepper crops at most nurseries to exhibit the previously mentioned oscillations in fruit set and yield. The model application was able to predict these, but no realistic scenarios of climate or crop management could be found to overcome the oscillations. In 2010, the weather pattern was less pronounced, which meant that fruit set, fruit load, and assimilate availability could be kept more constant, and were also more responsive to the available crop management tools. In this year, many growers remarked that the use of the model had allowed them to make more informed decisions.

CONCLUSIONS

In order to use crop growth models for decision support in commercial cultivation, company-specific output is necessary, which requires the use of company-specific up-to-date input data.

Short-term scenario calculations from the model application allowed growers to make more informed decisions on crop management strategies and climate settings.

In years with pronounced relative light or dark periods, it was still very difficult to maintain a regular fruit set pattern. As a result, in 2009 and 2011, yield fluctuations were still considerable.

ACKNOWLEDGEMENTS

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Literature Cited

Borgdorff, A.M. and Schutter, R. 2010. Product-info Paprika. Kwantitatieve analyse van productie, handel en consumptie van paprika. Dutch Horticultural Product Board Report. PT2010-38.

Buwalda, F., Van Henten, E.J., De Gelder, A., Bontsema, J. and Hemming, J. 2006. Toward an optimal control strategy for sweet pepper cultivation 1. A dynamic crop model. Acta Hort. 718:367-374.

Heuvelink, E., Marcelis, L.F.M. and Körner, O. 2004. How to reduce yield fluctuations in sweet pepper? Acta Hort. 633:349-355.

Marcelis, L.F.M., Elings, A., Bakker, M., Brajeul, E., Dieleman, A., De Visser, P.H.B. and Heuvelink, E. 2006. Modelling dry matter production and partitioning in sweet pepper. Acta Hort. 718:121-128.

Schepers, H., Kromdijk, W. and Kooten, O. 2006. The conveyor belt model for fruit

bearing vegetables: Application to sweet pepper yield oscillations. Acta Hort. 718:43-50.
Wubs, A.M. 2010. Towards Stochastic Simulation of Crop Yield: a Case Study of Fruit Set in Sweet Pepper. PhD Thesis. Wageningen University, The Netherlands.

Figures

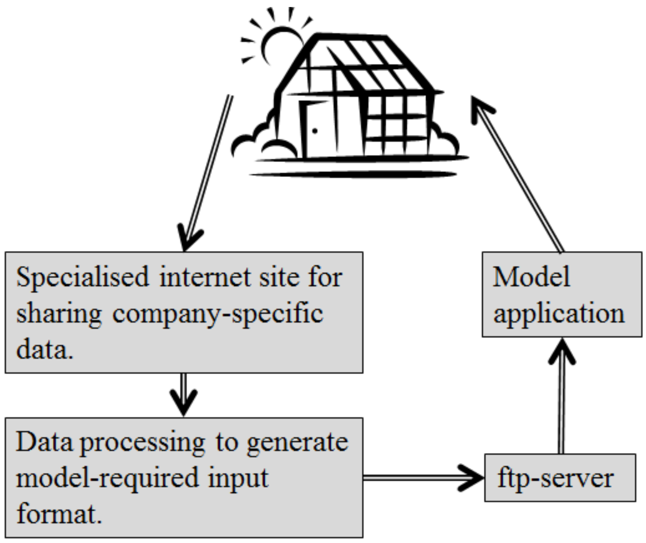


Fig. 1. Scheme depicting the flow of information.

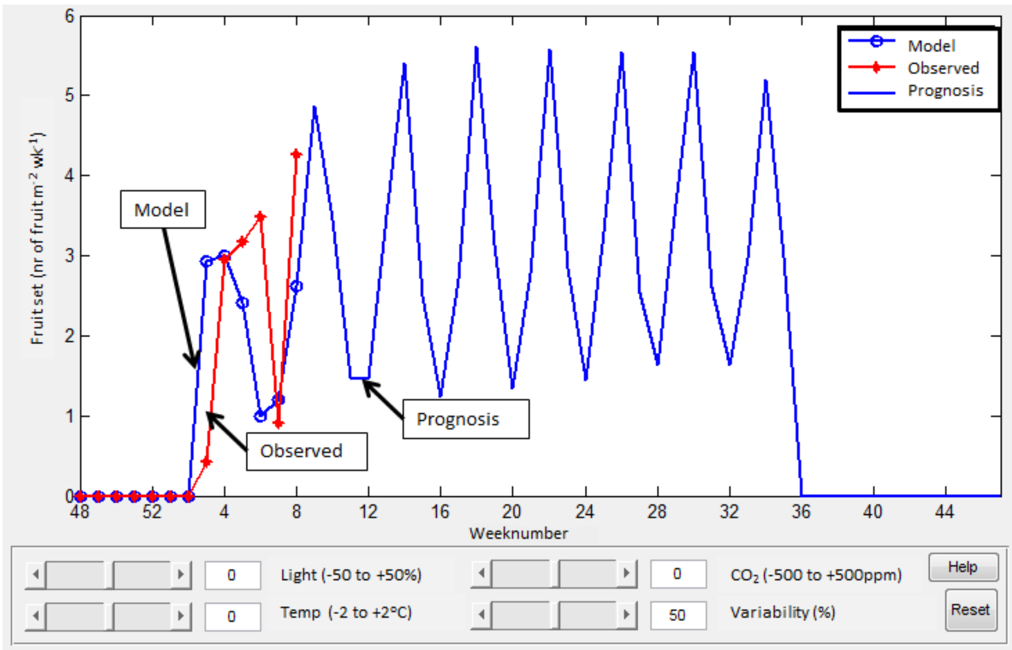
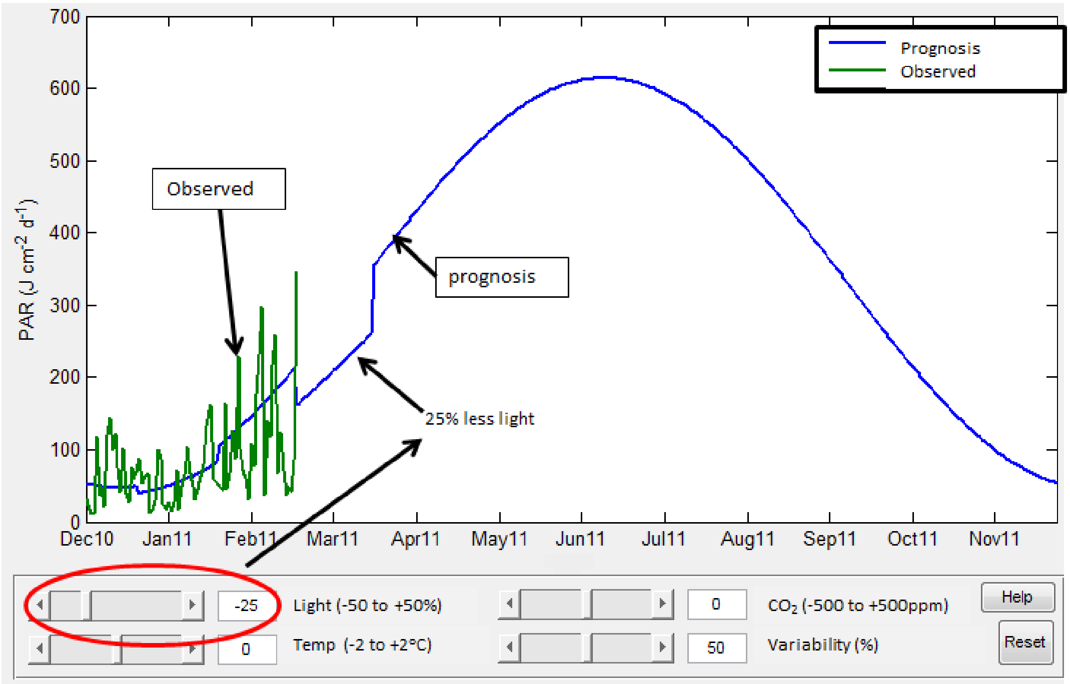


Fig. 2. Graphical user interface with example base run of fruit set time series (week numbers are for growing season of 2010-2011). The line connecting the closed dots shows observations. The line connecting the open circles shows the model output for the points in the past (open circles) and prognosis in the future (line without symbols). The output in the screen could be toggled between Temperature, Light, CO_2, Fruit set (shown here), Plant load, Harvested number of fruits, Harvested fresh weight, Source/sink ratio and Average fruit weight.

3A



3B

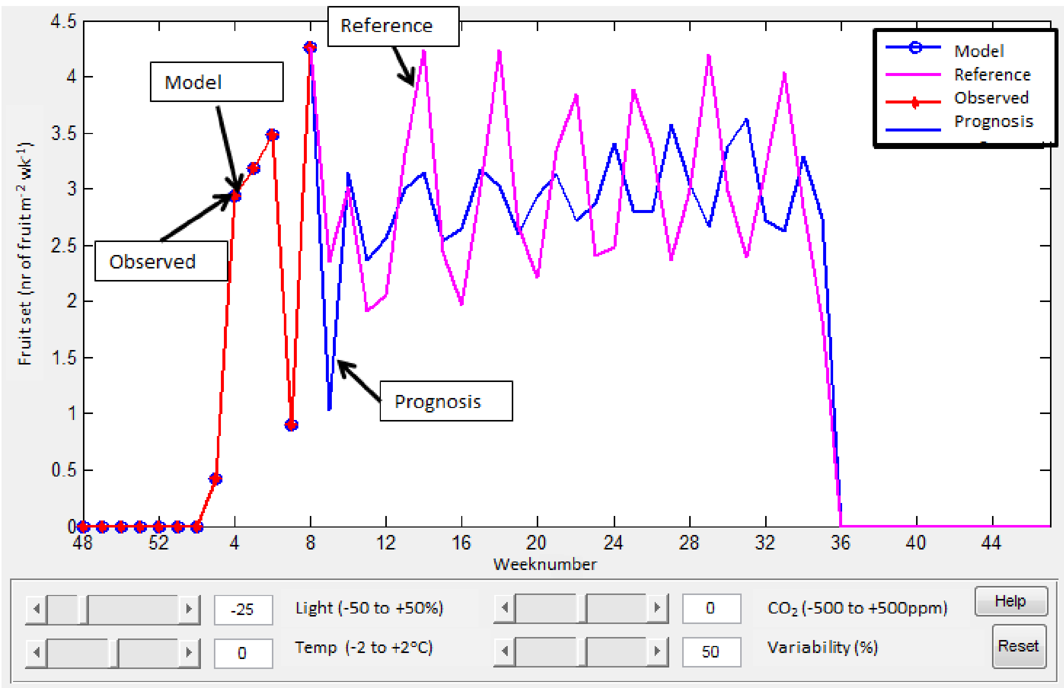


Fig. 3. Example scenario, assessing the effects of a period of 4 weeks with relatively low light intensity (25% below the standard climate, 3A) on the weekly fruit set (3B). Combined realized daily light level and sinusoid prognosis function in Figure 3A form the input to compute the prognosis line in Figure 3B. The same scenario without the dark period was used to calculate the reference line (3B).