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Research Paper

A methodology for model-based greenhouse design: Part 3, sensitivity analysis of a combined greenhouse climate-crop yield model

B.H.E. Vanthoor [a,b], E.J. van Henten [a,b,*], C. Stanghellini [a], P.H.B. de Visser [a]

[a] Wageningen UR Greenhouse Horticulture, P.O. Box 644, NL-6700 AP Wageningen, The Netherlands
[b] Farm Technology Group, Wageningen University, P.O. Box 17, NL-6700 AA Wageningen, The Netherlands

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Greenhouse design is an optimisation problem that might be solved by a model-based greenhouse design method. A sensitivity analysis of a combined greenhouse climate-crop yield model of tomato was done to identify the parameters, i.e. greenhouse design parameters, outdoor climate and climate set-points, that most strongly influence greenhouse performance. The analysis was performed for a low-tech greenhouse in Almeria, Spain, and a high-tech greenhouse in Texas, USA. A single-variate sensitivity analysis showed that outdoor climate has the strongest impact on the performance of the greenhouse system, followed by greenhouse design parameters and greenhouse climate set-points. The high impact of the outdoor conditions stresses the need to select a proper location for the greenhouse. Concerning the design parameters, the analysis revealed different results for the two locations and greenhouses studied. This emphasises that a 'custom made' approach to greenhouse design should be followed exploiting local conditions. In both cases, structures with a higher PAR transmission and a NIR-selective whitewash should be used. Seasonal patterns in the model sensitivity of for instance PAR, NIR and FIR emission coefficients of the cover indicate that a greenhouse with adjustable cover parameters will be advantageous over a design with fixed greenhouse cover parameters, as is usually implemented. A multi-variate sensitivity analysis revealed strong joint effects of parameters on crop yield. A joint increase of the PAR transmission and temperature set-point for ventilation favoured the crop yield for both greenhouses, stressing a simultaneous approach to both design and control of greenhouse systems.

1. Introduction

Optimal design of protected cultivation systems for the wide variety of conditions that exist around the world can be addressed as a multi-factorial optimisation problem (Van Henten et al. 2006). Such an optimisation problem relies on a quantitative trade-off between economic return of the crop and the costs associated with construction, maintenance and operation of the greenhouse facility. As suggested by Baille (1999) a systematic approach that integrates physical, biological and economical models is the most promising way for strategic decision-making of greenhouse configuration for

* *Corresponding author*. Wageningen UR Greenhouse Horticulture, P.O. Box 644, 6700 AP Wageningen, Netherlands. Tel.: +31 317 483328; fax: +31 317 423110.
E-mail addresses: bvanthoor@hortimax.com (B.H.E. Vanthoor), eldert.vanhenten@wur.nl (E.J. van Henten).
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world-wide climate conditions. To solve this optimisation problem, we developed a model-based greenhouse design method. This method is able to design greenhouses for a broad range of climatic and economic conditions. The key components of the method are a greenhouse climate model, a tomato yield model, an economic model and an optimisation algorithm as presented in Fig. 1. As a first step, this method focuses on the optimisation of the selection of alternatives to fulfil the following eight design elements: the type of greenhouse structure, the cover type, the outdoor shade screen, the whitewash, the thermal screen, the heating system, the cooling system and the CO_2 enrichment system.

As the number of factors involved in this optimisation problem is very large, it is beneficial to identify those parameters that most strongly influence the economic trade-off and consequently the greenhouse design. A model sensitivity analysis (SA) is an appropriate technique for that purpose.

In horticultural science, several researchers applied a sensitivity analysis to greenhouse climate models and crop yield models (Nijskens, De Halleux, and Deltour (1991), Chalabi and Bailey (1991), Nava et al. (1998), Cooman and Schrevens (2007), Van Henten and Van Straten (1994), Van Henten (2003)). However, none of them analysed a combined greenhouse climate and crop yield model and none of them performed the analysis specifically with a view to greenhouse design. Therefore, the goal of this study was to address both these topics in an integrated fashion using sensitivity analysis techniques.

Some preliminary studies already gave directions for investigation. Vanthoor, Stanghellini, Van Henten, and Gazquez Garrido (2008) revealed that the sensitivity of tomato yield to a single greenhouse design parameter depends on the absolute values of the other parameters. Additionally, it was found that the sensitivity of the crop yield with respect to the cover design parameters changed over time. In another paper Vanthoor, Stanghellini, Van Henten, and De Visser (2008) showed that the design and climate management are mutually dependent. Based on these preliminary findings, in this study it was decided to analyse the sensitivity of some key performance indicators to variations in the input parameters i.e. design parameters, the outdoor climate and the indoor climate set-points. Since the model-based method aims to design greenhouses for any location, we analysed the impact of the outdoor climate variables, although they cannot be controlled. Attention was paid to seasonal effects in the sensitivity as well. Additionally, further to a single-variate parameter sensitivity analysis as commonly implemented in various studies, in this study, a multi-variate analysis was also implemented to identify the impact of joint variations in input parameters.

The paper is organised as follows. First, the greenhouse climate-crop yield model to be used for greenhouse design is presented briefly and key performance indicators are identified. Secondly, two SA techniques are described: a single-variate analysis that determines local sensitivities to indicate relevant input parameters at an individual basis and a multi-variate analysis to reveal the combined effect of two input parameters. Thirdly, to show how the results of the SA depend on both greenhouse design and climate conditions, the SA was performed for two different greenhouse designs used under different climate conditions: a low-tech greenhouse in Almeria, Spain and a high-tech greenhouse in Texas, USA. Results of these two cases will be presented and discussed.

2. Materials and methods

2.1. Model description and analysed input parameters and model outputs

A model that describes tomato yield as a function of greenhouse climate (Vanthoor, De Visser, Stanghellini, Van Henten, 2011b) was embedded into a model that describes greenhouse

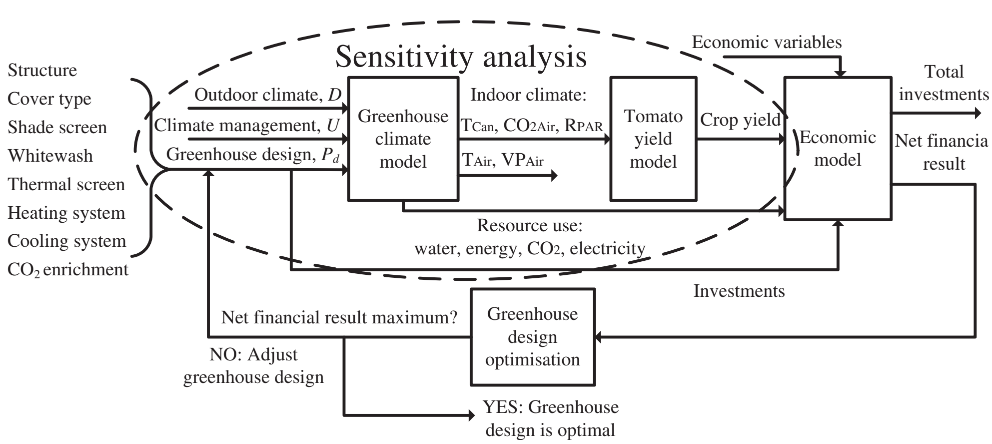

Fig. 1 – An overview of the model-based greenhouse design method. The method focuses on the optimisation of the following eight design elements: the type of greenhouse structure, the cover type, the outdoor shade screen, the whitewash, the thermal screen, the heating system, the cooling system and the CO_2 enrichment system. The key components of the method are a greenhouse climate model (Vanthoor et al., 2011a), a tomato yield model (Vanthoor et al., 2011b), an economic model and an optimisation algorithm. In this study, the sensitivity of the model outputs, i.e. indoor climate, resource consumption and yield to the input parameters i.e. outdoor climate, climate management and greenhouse design is determined.