Book of Abstracts

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From functional-structural tomato model to tomato digital twin

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Introduction

Digital twin is a concept used in many areas with applications in prototype design, production optimisation, monitoring, predictions, or virtual testing. It is also an emerging trend in greenhouse horticulture (Ariesen-Verschuur et al., 2022), which is increasingly data-driven, also due to rapid technology developments and the availability of sensors in the area of plant phenotyping. A digital twin is a virtual and dynamic representation of a real object that mirrors its states and behaviour (Ariesen-Verschuur et al., 2022). Although the exact definition seems to vary in different application areas, there are 3 important parts of a digital twin: a model, an evolving set of data relating to the object, and a means of dynamically updating the model based on the data (Wright and Davidson, 2020).

We designed a proof-of-concept digital twin of a tomato crop with the aim to help increase resource use efficiency of greenhouse tomato systems. At the core of this digital twin is a dynamic functional-structural plant (FSP) model. FSP models can simulate plant development and growth in 3D and can be used to predict crop response to environmental factors and management decisions. Dynamic changes in tomato shoot architecture in response to temperature treatments can be well captured by using an FSP model (Chen et al., 2014). In this study, we built on the concepts from their model and added functionality to be able to simulate growth and yield for different cultivars and explore strategies in tomato cultivation, e.g., in lighting and leaf pruning. To make the FSP model suitable for a digital twin application, further functionality was added to support model updating based on data collected from climate sensors and camera images (see van Daalen et al., Xin et al. in this Book of Abstracts).

Materials and Methods

The FSP model was developed in the GroIMP platform (gitlab.com/grogra/groimp), version 1.6. In order to simulate light distribution inside the greenhouse compartment, the model incorporates the tomato plants, planting pattern of the crop, and greenhouse construction. An interface was developed to link the FSP model to a greenhouse climate model Kaspro (de Zwart, 1996), which simulates indoor climate using outdoor climate data and greenhouse properties. To present the results of model simulations to the stakeholders, a new application in Unity was developed that enables interactive visualisation of different scenarios.

To collect data for model development, experiments were conducted in 2021 in the Netherlands Plant Eco-phenotyping Centre (www.npec.nl) facility with four tomato cultivars: 'Merlice', 'Brioso', 'Moneymaker', and 'Gardener's Delight'. A plant-to-sensor system was used to image all plants approximately every 3 days. To calibrate the model for different cultivars, additional manual measurements were performed on optical properties of leaves, photosynthesis light and CO_2 response curves, as well as biomass and size over time.

Results and Discussion

Our FSP model of tomato allows for the simulation of light distribution. It takes into account shading patterns caused by the greenhouse construction, the planting pattern, 3D plant architecture, and optical properties of leaves to quantify light capture by individual leaves. Leaf carbon assimilation is done using the light absorbed by the leaves, and assimilate allocation is calculated based on the concepts of source/sink balance. Organ production and sink duration are temperature driven. The environmental inputs used by the model (incoming light, temperature, CO_2) are calculated by the climate model.

Simulation results can be imported into a Unity application (Fig. 1). Currently, this application allows for the comparison of two scenarios, illustrated by a selection of climate variables and model outputs. Sliders can be used to interactively visualise the daily and seasonal change in sun position and to show the evolution of 3D plant architecture at daily intervals, also in reverse order.

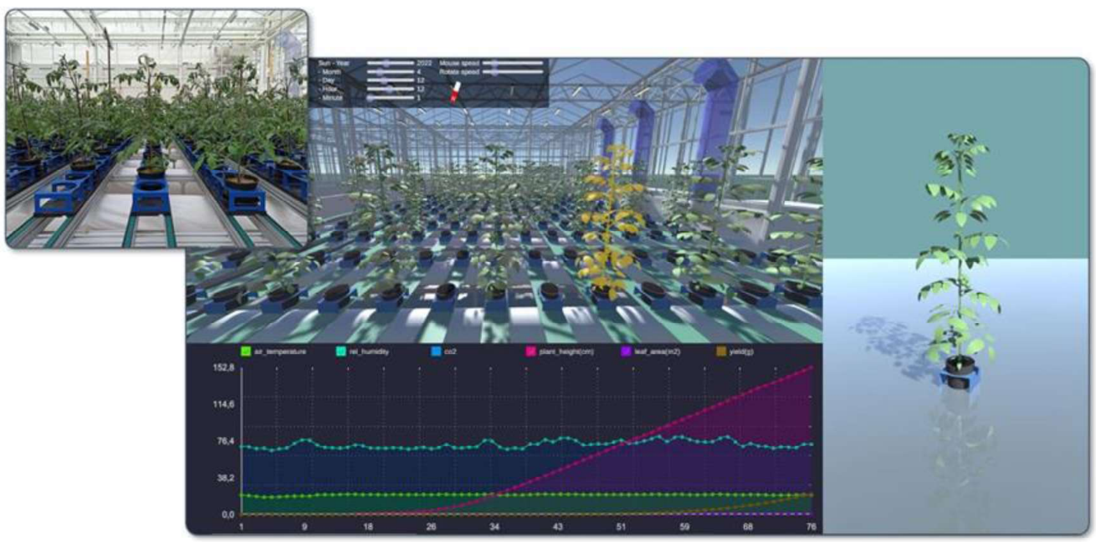

Figure 1: Digital twin application with virtual representation of a real crop inside a greenhouse.

Conclusion

The model can simulate feedback between light absorption by leaves and assimilate production, allowing to run scenarios for different cultivars and cultivation strategies. Our model is especially useful in a digital twin framework when the role of individual plant traits or the effects of manipulation of plant architecture (e.g., pruning) are relevant. A forthcoming analysis will show which model parameters, and thus which sensor data, are minimally required for a digital twin relevant for a greenhouse tomato cultivation.

References

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