Agricultural Systems 139 (2015) 144–152

Contents lists available at ScienceDirect

Agricultural Systems

journal homepage: www.elsevier.com/locate/agsy

Support system for decision making in the management of the greenhouse environmental based on growth model for sweet pepper

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ARTICLE INFO

Article history:
Received 8 March 2015
Received in revised form 20 June 2015
Accepted 29 June 2015
Available online xxxx

Keywords:
Temperature
CO_2
Radiation
Control
C++

ABSTRACT

Over recent years, intensive Mediterranean agriculture has been gradually changing from very low-technology greenhouses to those incorporating intermediate and, in some cases, advanced technology. The Decision Support System (DSS) can help growers, engineers and students learn about and manage the system dynamic and its influence on production. This work shows the calibration and validation of a pepper growth model based on physiological principles and on the works of several authors. The model gives good results on dry matter production estimation as well as partitioning between different plant organs. The promising results obtained in the model validation (tested with real data from the southeast of Spain) allowed us to design and implement the Graphical User Interface (GUI). This software tool, which predicts pepper crop growth using models based on climatic variables, permits the development of an optimum control system. The DSS final version is user-friendly and easily managed by growers.

1. Introduction

Crop growth models can be used to better understand the physiological processes that determine yield and allow strategies to be tested. Many of these processes have their limits genetically determined, but microclimate plays an important role (Rodríguez et al., 2015; Sánchez-Molina et al., 2014a). In this line, a greenhouse is an ideal setting for farming because climate variables can be manipulated to achieve optimal plant growth and development (Ramirez-Arias et al., 2012; Sanchez et al., 2012).

In this work, automation of the management of crop growth is carried out by the hierarchical approach comprising subsystems, processes and variables in relation to the crop (Fig. 1): the inputs are variables that can be acted on (windows, irrigation valves, heating, etc.), the disturbances are variables that cannot be manipulated (Berenguel et al., 2006), but can be measured so their effect on the system is taken into account (e.g., weather, pests and diseases) and the outputs are the variables to be controlled (interior temperature, relative humidity, water, nutrients and so forth). Integration of the greenhouse subsystem is an important challenge because of the need to know not only the interactions, but also the possibility of controlling them (Rodriguez et al., 2008). In this architecture, supervision and control are carried out by the grower (Wolf et al., 2002; Ewert et al., 2002). The information necessary for decision-making comes from a diversity of sources, such as common knowledge, books and specialized publications, and the experience of the persons who work in the specific field. The availability of this information would help optimize crop growth (production), lower costs and assist in decision-making at the right time (Rodríguez et al., 2015).

Consequently, control system requirements must be determined based on the desired crop performance and accordingly have a crop growth model is therefore important (Marcelis et al., 1998; Heuvelink, 1999). Nonetheless, these models are quite complicated to use and they require considerable knowledge of the crop. Therefore, having a software tool capable of implementing such a model would greatly assist growers and researchers in the decision-making process (Jame and Cutforth, 1996; Hoch and Agabriel, 2004). Decision Support Systems (DSS) and Expert Systems fill this role, they are computer-based systems that assist decision-makers by allowing them to access and use data and growth models (Aubert et al., 2012; Castelán-Ortega et al., 2003; Chevalier et al., 2012). These systems are interactive, utilizing models with internal and external databases. The main characteristics of DSS are flexibility, effectiveness, and adaptability. These characteristics have guided much of the DSS research; however, the potential benefits they offer greenhouse climate control have not as yet been exploited.

This work describes a DSS based on a crop growth model for pepper with the aim of optimizing crop growth conditions. These crop growth models are based on climatic variables and are a good support tool for decision-making systems in production management. The model presented in this paper is focused on the models developed by Marcelis

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http://dx.doi.org/10.1016/j.agsy.2015.06.009

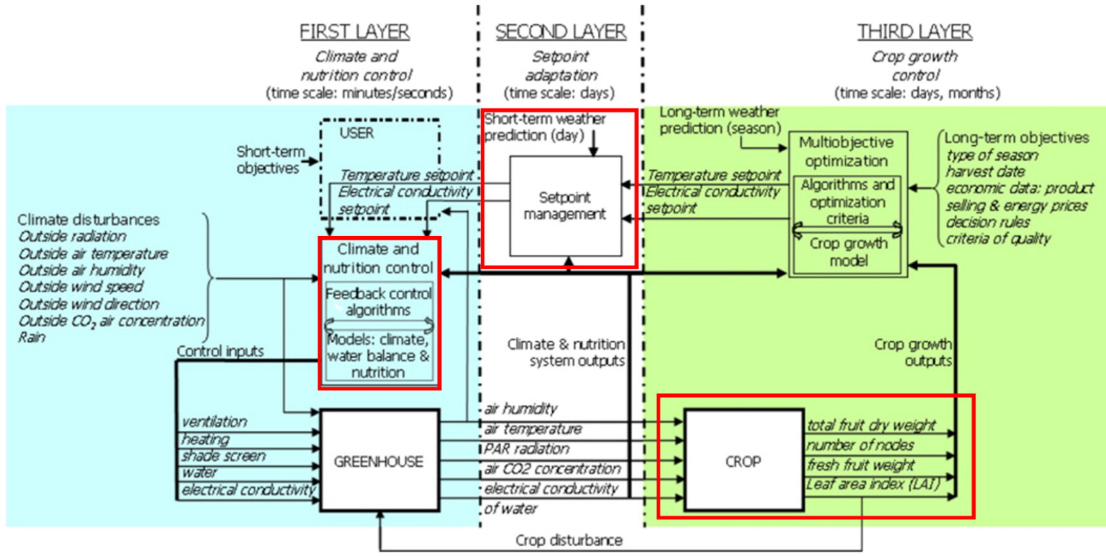

Fig. 1. Hierarchical architecture (Ramirez-Arias et al., 2012).

et al. (2006), which was modified and improved with the works of Scaife and Jones (1976), Collatz et al. (1991), Rabbinge et al. (1991), Teh (2006), and Gonzalez-Real et al. (2008).

The paper has been organized as follows: Section 2 gives the background to the crop growth modeling process. Section 3 gives a general overview of the greenhouse and its main characteristics as well as the experimental data collected. The main results and discussion are summarized in Section 4. The decision-making software developed is shown in Section 5 including an example of its utilization. In Section 6, the main conclusions are drawn. Finally, an Appendix section has been added with information as well as parameter and variable values.

2. Pepper growth model

The model presented here is dynamic and deterministic and driven by: photosynthetically active radiation (PAR), temperature and CO_2 concentration inside the greenhouse (Fig. 2). In general, such models quantitatively describe the mechanisms and processes that cause crop growth. They are typically hierarchical models of at least two levels of depth with the highest level describing the production of dry matter (growth, W_T) and leaf area index (LAI), while the lower level describes leaf photosynthesis (P_{leaf}) and maintenance respiration (R_m).

The calibrated and validated model in this paper is based on the works of Marcelis et al. (2006), who presented a mechanistic dynamic model validated with six experiments in greenhouses in France and The Netherlands. It is built on the generalist model of Gijzen (1994), called INTKAM and is derived from the cucumber growth model developed by Marcelis (1994). Gross leaf photosynthesis is estimated using the model of Farquhar et al. (1980) and stomatal conductance from Nederhoff et al. (1992). Crop photosynthesis is calculated from these leaf photosynthesis calculations by using the Gaussian integration method (Goudriaan and Laar, 1994) and maintenance respiration from the works of Spitters et al. (1989). The model is also based on the assumption that dry matter distribution is regulated by force or a similar uptake ability of the different plant organs.

The developed model uses these substructures included in Marcelis et al. (2006) and further improved by the works of other authors. It consists of a set of five ordinary differential equations (ODE), algebraic equations, parameters and constants. The plant dry matter is estimated by the generation of carbohydrates from the photosynthesis process. The model shows the plant as a set of organs competing to access a common pool of assimilates. The remaining carbohydrates are available for plant growth and development. Each organ growth rate is given by the amount of available carbohydrate and organ growth factor (Gonzalez-Real et al., 2008). As a first step, the leaf photosynthesis is obtained (Collatz et al., 1991; Teh, 2006). Then, the gross photosynthesis is calculated, using the leaf area index (LAI), which is an indicator that represents the leaf surface available for taking up solar energy; it is estimated using the Gompertz function (Scaife and Jones, 1976). The organs dry weight model presented by Gonzalez-Real et al. (2008) was used to address the problem of synchronous production oscillations in the sweet pepper crop. These oscillations are caused by the crop physiology (fruit abortion in periods of heavy fruit load per plant), resulting in an over-supply at market. Pruning, harvesting, aborting fruit and climate control are introduced to modify this pattern in the model behavior. It is a discrete time model describing the crop development in time steps throughout a day.

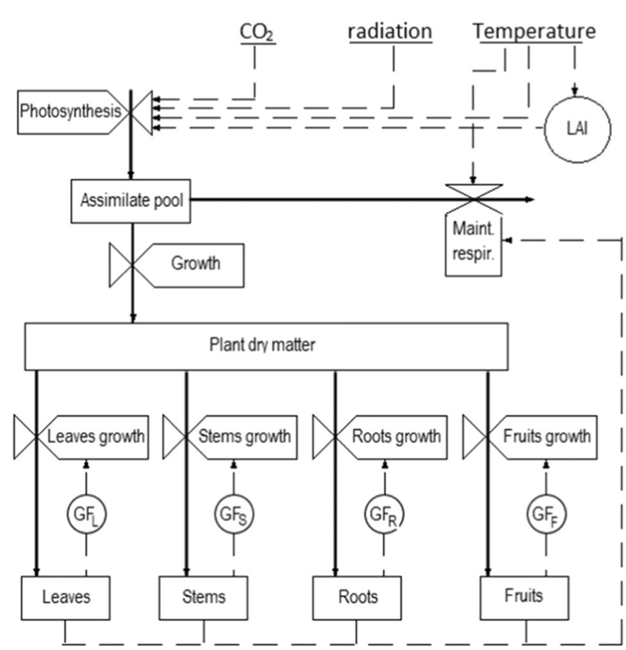

Fig. 2. Diagram of the proposed growth model.