Crop Models for Greenhouse Production Systems

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Abstract

Although the physiological principles involved in the growth of greenhouse and field crops are not basically different, the development of models for greenhouse crops to some extent has followed its own way. This is mainly due to the specific characteristics of the crops and of the greenhouse production systems involved.
Many important greenhouse crops are multi-harvest crops, where the balance between vegetative and generative growth is an aspect of major concern to growers. Moreover, most products have a high water content and they are sold fresh. In food crops, taste is a valuable crop property. In ornamentals, shape and colour are important characteristics that put certain demands on the output of models. More generally, quality issues (e.g., shelf or vase life) often have to be approached in a different way than with field crops. Last but not least, the huge number of species is problematic for crop modellers in horticulture.

Modern greenhouse production systems provide the grower with a highly advanced, but expensive system for controlling the aerial and root environments of the crop. Through this control system growers are able to control the production process in great detail. The high added value obtained in greenhouses and the high quality requirements go together with a great deal of human interference in the production process: either directly, by pruning and training, or indirectly, by using various organisms for pest control and pollination. Crop management and the interaction of pests and diseases with the crop are both aspects that make special demands on crop models.

It is a major challenge for greenhouse growers to make the best possible use of the available options to achieve high productivity at the moment when products are required in the market. In addition, this must be accomplished while reducing the environmental impact by emissions of CO_2, nutrients, and biocides and at minimum cost. To optimise greenhouse production systems, crop models are needed. But, they also have to be integrated into more complex models of the nursery as a whole to address planning, scheduling, and logistics. For policy makers, there is a need for models at regional or national scale that help them to decide on measures related to environmental issues or economic development.

Models on product quality and integration of models from different disciplines to simulate nurseries and whole product chains are some of the important and challenging developments in greenhouse simulation over the last few years. Also, the implementation of models into practice is a hot issue generating many new and complex research questions.

INTRODUCTION

The facilities to grow crops in an enclosure, including the technology to control the environment, may be designated as greenhouse production systems. Greenhouse production systems are presently among the most sophisticated crop production systems (Challa et al., 1994). The methods used for heating, cooling, watering, lighting, screening, and fertilizing the crop in the most advanced production systems enable the grower to influence the environment of the crop in great detail. In this way, crop growth and development can be regulated with greater control than with field crops.

The intensive involvement of the grower in the daily production process and the refined control possibilities give rise to a major knowledge requirement in terms of the number of processes and the time-scale of the controls (Challa, 1997). Further complications arise from the increasing role of alternative objectives in addition to the primary production objectives that are considered in traditional agriculture. These include the role of the production chain, the importance of energy saving, and other environmental issues. These developments all lead to an increasing need for effective and comprehensive information.

Part of the information requirement of growers could be satisfied by crop growth models. Such models could provide detailed evaluations of alternatives, support decisions, and improve the performance of control systems by providing on-line estimations of relevant processes. Furthermore, they enable the grower to answer questions regarding complex phenomena that involve many inputs and outputs and conflicting objectives (Challa et al., 1994).

Greenhouse crop models can be used as such, but they are particularly helpful when they are integrated into models of greenhouse production systems where economic and environmental processes are also integrated. Greenhouse crop models could also play an important role at a regional or national scale, where policy makers are dealing with problems of, for example, emissions of nutrients and biocides, economic and social development of a country, and other problems at a high level of aggregation (Challa and Pluimers, 1997).

In the present overview, greenhouse crop models are discussed against the background of the particular situation of greenhouse horticulture as opposed to models developed for agriculture in open, uncontrolled environments.

GREENHOUSE HORTICULTURE

Modern, intensive greenhouse horticulture is characterised by high inputs and high outputs per m^2. Total investment requirements may amount up to about € 100 per m^2, depending on the type of crop and cultivation system. Investments are particularly high with potted plants where movable benches, sub-irrigation facilities, movable sun screens, supplementary lighting, and intensive mechanisation and automation are common.

Modern, intensive greenhouse horticulture is, in fact, a high-tech, semi-industrial, purely economic activity. Unlike agriculture, there is no other justification, such as landscape or natural values, for greenhouse horticulture. The production process is closely controlled since the product specifications and delivery times are determined by the market.

Greenhouse horticulture is taking place within an essentially closed environment. This closed environment isolates the crop from influences from the outside world. It reduces the influence of the outside weather and diminishes the pressure from pests, diseases, and weeds and allows effective forms of biological control.

Compared to field agriculture, horticulture is characterised by a large diversity in crops and varieties. With ornamentals, there is a fast turn-over of species and varieties grown in greenhouses. This diversity is a major handicap in the advance of horticultural science because a huge database of crop specific knowledge has to be built and maintained. But, the worldwide research capacity is much smaller than in agriculture.

Intensive greenhouse production of horticultural crops is a year-round activity with a constant supply to the market, efficient utilisation of expensive production facilities, and a continuous labour requirement. The continuous production, however, also gives rise to knowledge requirements with respect to production and quality control in highly variable environmental conditions. For example, extremely poor radiation conditions prevail in mid-winter at high latitudes and high radiation levels exist in the summer in the tropics and subtropics.

Within the context described here, knowledge plays a key-role: the advanced control possibilities in greenhouses, the wide range of conditions and crops under consideration and the high costs and production value per m^2 all lead to a high added value of knowledge.

GREENHOUSE PRODUCTION SYSTEMS

Greenhouse production systems differ a great deal, depending on the crop produced and the region in the world. The description given here is representative of the situation in northwest Europe (Bakker et al., 1995). However, the same principles apply to advanced production systems in North America, for example.

The most essential property of greenhouse production systems is the enclosure by a cover of glass (plastic) that enables the grower to modify and control the climate inside the greenhouse (Von Zabeltitz, 1999). The greenhouse is provided with facilities for natural or forced ventilation to control air temperature and to remove water vapour from crop transpiration from the greenhouse (Day and Bailey, 1999). A heating system is available to heat the greenhouse air and sometimes also the root system. Due to the enclosure and the activity of the crop, the CO_2 concentration in the greenhouse air will deviate from ambient levels when the rate of ventilation is low. Under these conditions, CO_2 enrichment is common using flue gases from the combustion of suitable fuel, such as natural gas, or using pure CO_2 stored in tanks (Nederhoff, 1995).

With the cultivation of ornamentals, the use of various types of screens is common. Depending on the type, screens are used for day length control of flowering (darkening screens), diminishing the radiation load on the crop (sun screens), or for energy saving (energy screens) (Bakker and Van Holsteijn, 1995). Supplementary lighting is very common in the year-round cultivation of day length sensitive ornamentals. Although day length can be controlled with low level radiation since the flowering response is a low intensity light response, the use of supplementary light to increase photosynthesis is rapidly expanding. Enhanced photosynthesis is especially important in winter at high latitudes (Moe, 1997) not only to increase production in winter, but also to improve product quality and to guarantee a continuous supply to the market.

In many cases, crops are not grown in soil, but in various types of substrate (Dasberg, 1999). In this way, cultivation has become less dependent on the local soil. Moreover, cultivation problems due to soil borne diseases can be overcome and, in general, it enables better control of the root environment. This is especially true when used in combination with systems for irrigation and fertigation, which is the simultaneous supply of water and nutrients to the crop.

Characteristic of greenhouse crops is the time-scale needed in the operation of the controls. With field crops, a time-scale of weeks to days is common. In contrast, control in greenhouse cultivation typically deals with intervals of hours or minutes (Challa and van Straten, 1993). As a consequence of these detailed control requirements, in combination also with the number of control possibilities, the knowledge necessary for optimal use of these powerful, but expensive options to control greenhouse production systems are very high, compared to the situation with field crops.

KNOWLEDGE REQUIREMENTS

Based on the characterisation of the greenhouse production system, it is now possible to consider knowledge requirements for greenhouse cultivation into more detail against the background of different applications.

Climate Control

Climate control is a complex problem because it deals with highly variable objectives at equally variable time scales in a system where the effects of the actuators are strongly interacting and where influences of the outside weather play an important role (Challa and Van Straten, 1993). Moreover, many uncertainties, such as fluctuating prices, future weather conditions, and the occurrence of pests and diseases, have to be considered in decisions regarding climate control.

The objectives with regard to climate control can be summarised (Van Straten and Challa, 1995):

- productivity
- product quality
- timing of production
- maintain productivity of the crop
- control risk with regard to pests and diseases
- respect environmental requirements
- labour environment

This combination of objectives that are often mutually conflicting and, depending on the situation with different weights, leads to complex optimisation problems with different time horizons and information from different disciplines (Seginer, 1999).

Control of the Root Environment

In the root environment, several objectives play a role. Oxygen, nutrient, and water availability are often conflicting requirements and, moreover, environmental regulations with respect to emissions have to be taken into account. Therefore, the amount and timing of irrigation, as well as the nutritional composition of the solution provided to the crop needs to be quite balanced. In the search for optimum conditions for crop growth, the need to provide sufficient water and nutrients in the right proportion and to prevent salination is often conflicting with the requirements for minimum emissions of nutrients into the environment (De Willigen et al., 1998; Otten, et al., 1999).

Crop Management and Planning

Many important greenhouse crops, such as fruits, vegetables, and roses, are indeterminately growing, continuously harvested crops. In these types of crops, it is important to maintain a proper balance between vegetative and generative growth. Growers try to control this balance by nutrition, climate control and crop management. There is a great deal of scientific knowledge about dry matter partitioning in crops (e.g., Marcelis and De Koning, 1995). But, the practical implementation of this knowledge is still difficult because it is not easy to translate these principles to simple rules. In fact, the whole sink-source situation in a crop needs to be taken into account to forecast the effects of certain measures.

In greenhouse horticulture in Europe, the production chain is a concept that is of increasing importance within a market characterised by heavy competition and over-production. In the production chain, a link is created between the demand and the possibilities of the nurseries to meet this demand in terms of quantity, quality, and timing. For this approach, it is important for the grower and the market to balance supply and demand. This requires a detailed knowledge about the state of the crop and its expected performance in the future (Harsh, 1998).

Environment and Policy Development

As a result of the public concern with regard to the environment, there is more and more legislation and increasing awareness among growers to protect the environment. Important developments in the Netherlands are agreements between the national government and the greenhouse industry to reduce the environmental impact of individual nurseries. This is encouraged by the creation of special labels for products produced in an environmentally friendly manner (Pluimers et al., 2000). A quite relevant aspect of these agreements or labels is the possibility to quantify the environmental impact of various activities at the nursery. In addition to registration of these activities by the grower, there is a need to know the environmental impact, or at least the environmental pressure, of these activities to obtain an overall environmental score for a nursery.

Not only at the level of individual nurseries, but also at a national or regional level, there is an increasing need for information and insight in the effectiveness of environmental policies. Governmental, as well as grower's, organizations are aware of the need to assess the ability of policies to achieve certain targets knowing that is not the policy maker, but the grower, who makes the decisions at the nursery.

MODELS AND OTHER SOURCES OF INFORMATION

In the previous section, we have seen how important the role of information is in greenhouse horticulture. Traditionally, the most important sources of information are experience and observation. The grower with green thumbs and long experience is able to "read" the plant and to know what measures should be taken to achieve his goals. Because of increasing international competition, environmental concern, and chain-oriented production strategies, decisions of growers are influenced more by other factors than plant performance alone. Moreover, due to rapid changes in cultivation techniques and more flexible climate control strategies, growers are even more dependent on scientific principles and new information resources.

An important line of research is provided by the development of sensors. The so called "speaking plant" concept enables the grower to use on-line information from the crop and to follow accurately some of the relevant production processes (Hashimoto et al., 1985). A second line of research focuses on the development of crop growth models. These models integrate knowledge from different disciplines and provide tools for more flexible, effective, and efficient management of a nursery or production chain or for policy development (Gary et al., 1998). It is this second line of research that will be elaborated further here.

Greenhouse Crop Models

The first crop growth models were built for field crops and the development of greenhouse crop models followed several decennia later. Basically, there is little difference between field and greenhouse crop growth models. The main adaptations that were necessary include: modified radiation conditions due to the greenhouse cover (Critten, 1993), the use of supplementary lighting and screens (and the associated rapid changes in radiation), extreme climate conditions in winter and summer, a more elaborate description of temperature effects on crop performance, CO_2 concentration effects, and the very important role of maintenance respiration in winter cultivation (Challa and Heuvelink, 1996).

Crop Quality Models

In greenhouse cultivation, a quite distinct development has taken place with regard to modelling of crop quality (Van Meeteren, 1998). Quality in greenhouse production covers a wide range of properties, often less common in agriculture.

The first crop quality models dealt with external plant quality. Plant height, for example, is an important quality attribute in ornamental plants (e.g., Karlsson and Heins, 1994). More recently, quite advanced models for plant architecture have been developed (De Reffye et al., 1998; Prusinkiewicz, 1998).

Models describing the internal quality of greenhouse products are still rare. Seginer, et al. (1999) presented a model on NO_3 in lettuce and Verkerke et al. (1998) indicated how the taste of tomato fruits could be modelled. Vase life of cut flowers is difficult to model with present knowledge. Recently, however, the water relations of cut chrysanthemum have been investigated in great detail. This has given rise to a detailed model that could be used for research on the quality of cut flowers (Nijsse et al., 2001).

Model Applications

As in open field agriculture, models still play a minor role in greenhouse cultivation (Lentz, 1998) in spite of their great potential (Leutscher et al., 1996). Most widespread is the use of models for timing and quality control in ornamentals (e.g. Fisher et al., 1996). Here, the benefit/cost ratio is such that there are rewards to a grower who invests time and money. Other applications are introduced step-by-step in software of e.g., climate control systems and decision support and management information systems (e.g., Dijkshoorn-Dekker and Meuleman, 2000; internet site: www.letsgrow.com).

At the level of regions or countries, models are becoming available that deal with economics and environmental issues regarding greenhouse horticulture. They have the potential to cover the need for information of governmental and grower's organisations involved with environmental legislation and agreements, economic policy, and environmental planning, for example. In fact, there is no alternative to models at this level and it may be expected that they will play an increasing role in the development of policies and in the negotiations between different interest groups.

CONCLUDING REMARKS

Greenhouse horticulture represents an almost perfect environment for the implementation of scientific knowledge in agricultural science. The advanced control possibilities and the specific demands on the production process all trigger the formulation of a wide range of intriguing, scientific questions. The type of research needed to deal with these questions may create a great deal of spin-off to other fields of agriculture. There is, however, an urgent need for research focusing on implementation of models in applications that are accepted by the market. If this does not happen and the promises of crop modelling research do not materialize, the future of this difficult but essential type of research will not be very prosperous.

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