INTEGRATION OF EXPLANATORY AND EMPIRICAL CROP MODELS FOR GREENHOUSE MANAGEMENT SUPPORT

Hugo Challa
Farm Technology Group
Wageningen University
Bomenweg 4
6703 HD Wageningen
The Netherlands
Hugo.Challa@Users.AenF.wau.nl

Keywords: DSS, cultivation schedule, management, horticulture, pot plant, *Ficus*

Abstract

In the management of greenhouse nurseries the grower has to deal with complex dynamic optimisation problems. In many of these problems the behaviour of crops is an important issue. Crop models, that formalise our knowledge about the crop, could thus be an important element of management tools in horticultural practice, but their role has been quite limited up till now. Yet, it is likely that such tools will become more important and that their implementation in future management tools will become more feasible than before.

An important role for such model based support systems will be in the design, evaluation and adaptation of cultivation schedules (blueprints). Models that are able to deal with such complex problems are built of many sub-models, because they have to cover the full problem domain, to provide useful answers. Relevant sub-models could be arranged in a parallel structure, where they sub run basically independent of each other, using the same inputs. Alternatively, output of (photosynthesis based) sub-models could provide input to other sub-models. For many applications it is in fact irrelevant what the source of information provided to a decision maker or an automated control system is, as long as the information is sufficient, correctness and reliability of the information are convincing, and basic functions of good DSS are provided.

1. Introduction

Crop growth models have been developed since the sixties. Now, thirty years later, they have developed to a powerful instrument in the hands of specialised scientists and in this way they certainly have influenced the development of crop science in general. Yet the promise of a wide use of models in agricultural practice in general and in greenhouse horticulture in particular, still has to be fulfilled. This is partly due to limitations in present crop growth models (Challa and Heuvelink, 1996), but it is also related to a more general problem of incorporating scientific knowledge into commercial software within a relatively small and fragmented domain, such as greenhouse horticulture. Within the framework of the present contribution the question is addressed how the knowledge represented in present crop growth models could be translated into practical applications, while keeping an open eye for the market and the software industry in this type of applications. The present contribution will in particular focus on pot plant nurseries, because they are characterised by a high information requirement, a complex organisation and a large number of species and varieties. The views expressed in this paper were strongly formed and influenced by the experiences in a European ESPRIT project where a team with members from the software and the greenhouse industry, together with scientists and members of a growers organisation have been working for a period of 2

Proc. Models-Plant Growth / Control Shoot-Root
Environments in Greenhouses
Eds. B. Bar-Yosef, I Seginer
Acta Hort. 507, ISHS 1999.

years on a management tool (HOrticultural PLanning and Integrated Cost Control Systems - HOPLICCS) for the greenhouse industry (Callewaert and Lippert, 1999).

When discussing possible applications of crop growth models in greenhouse horticulture, the first question to be answered is, whether there is, in fact, a need for such tools, now and in the near future. The need for such applications arises from developments that take place within the horticultural sector as a whole, but has also to do with the changing structure and size of nurseries.

Within the horticultural sector some major changes are taking place:

- transformation from a push (production oriented) to a pull (consumer oriented) market
- an increasing role of the organisation of the chain from producer till consumer
- increasing influence of the society with respect to agricultural production and production methods

At the same time, though not fully independent, there are important changes at the nurseries, that play a role:

- increasing scale of operation
- more complex organisation
- increasing competition
- more emphasis on organisation and management at nurseries
- better education of growers
- easier access to powerful computer systems
- easier access to powerful information resources

These external and internal changes force growers to become more aware of the way they manage their nurseries and of the tools they need. This need is not only observed by scientists (e.g. Harsh, 1998; Lentz, 1998), but also within the world of software developers and growers organisations (Callewaert and Lippert, 1999).

2. Crop growth models, management and other applications

It is common to distinguish different management levels in relation to time scale (Anthony, 1965): the strategic, the tactical, and the operational level. Looking at the previous description of the changes that are taking place in the greenhouse industry, each of these levels may be considered in terms of need for information and with respect to the role crop growth models could play.

The strategic level deals with long-term (> one year) decisions, usually concerned with matters like capital investments and other decisions with a long-term impact. Many of these decisions have little to do with crop growth, but a number of investments will alter the crop environment, such as greenhouse design, systems for supplementary lighting and for CO_2 enrichment. Tactical decisions typically consider periods in the order of one year (growing season), including one, or several cultivation cycles and their interactions. The production plan, including plans for allocation of resources to different batches, as well as the choice of the pertinent cultivation schedules (if there are alternative schedules that could be considered) belong to this category. Operational decisions deal with the day-to-day management of nurseries and are characterised by a strong influence of all kind of uncontrollable factors ("disturbances"), such as the weather, occurrence of pests and diseases and fluctuations in the market, availability of labour, etc.

This framework for dealing with nursery management may now be considered with regard to information requirement and the role of crop models (Fig. 1).

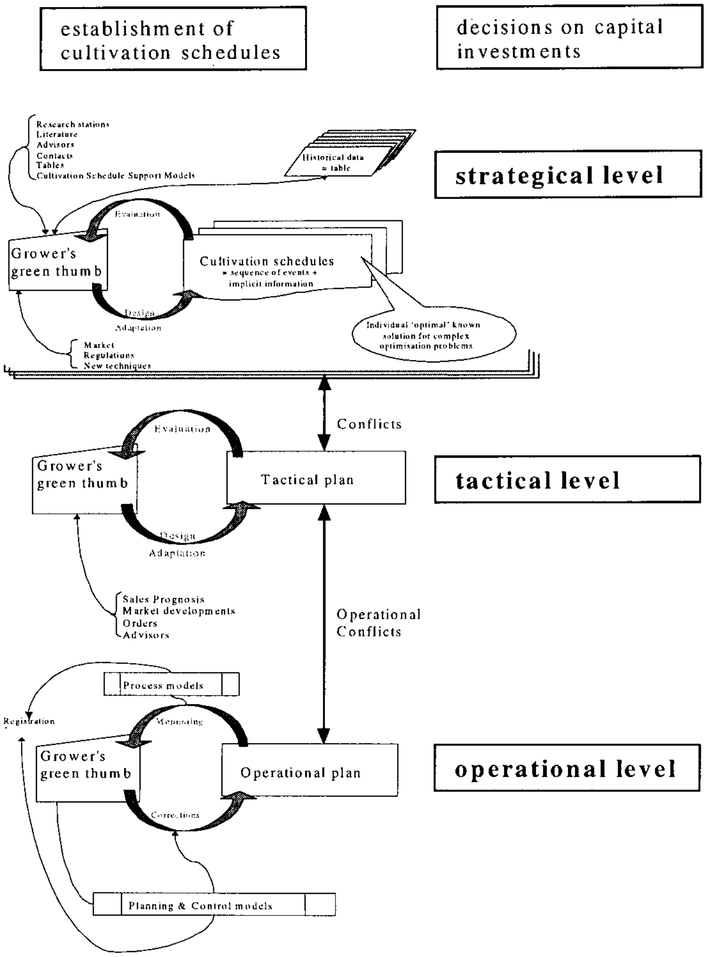

Figure 1. The possible role of crop growth models at different levels of management.

Cultivation schedules play a central role in the planning of nurseries. A cultivation schedule is a full description of the cultivation process, in terms of actions, timing and crop status over time, including the crop attributes at harvest, in terms of quantity and quality. The cultivation schedule, in other words, defines the start and end of the production process of a given product, including the requirements in terms of materials, space and labour.

Normally cultivation schedules are developed on the basis of blueprints provided by research stations and extension services, and further adapted on the basis of experience and personal appreciation of the grower. A cultivation schedule may be considered as an "individual 'optimal' known solution of a complex optimisation problem" (Fig. 1, top), which, in other words, is specific for a grower and his individual circumstances. Examples of these individual circumstances are, first of all the personal appreciation and judgement of the grower of the conflicting requirements that form the basis of the cultivation schedule. In addition, the market segment that the grower is aiming for, the particular product combination, the technical infrastructure and labour provision at the nursery will influence what is considered an optimal schedule. The establishment of (standard) cultivation schedules is a strategic decision, because these schedules form the basis for tactical and operational production planning and in that quality they are not modified frequently (during implementation at tactical and operational level, cultivation schemes may be modified, but not the cultivation schedule they are based upon).

Although these schedules may be considered as optimum for an individual batch, their application may give rise to conflicts in production planning of the nursery as a whole at the tactical level and in that (multi-batch) case the schedules may need adjustment to accommodate them better to that particular conflict situation. At operational level, during the implementation of the tactical plan, the grower may have to adapt cultivation schedules, because of deviations of the state of the crop, changes in the sales prognoses, or space constraints (Leutscher *et al.*, 1999).

A cultivation schedule, therefore, may be no longer optimal, when the conditions are different, or new knowledge is gained. In those cases, usually outside the field of experience of the grower, the relations are too complex to evaluate on the basis of only experience, and there may be a need to have other tools. Crop growth models, here, could complement the grower's experience and help to develop better cultivation schedules. Sometimes cultivation schedules cannot be implemented as such, because conflicts arise with the planning of other batches at the tactical planning level (Fig. 1, middle), and sometimes there is a need to modify the cultivation planning, because disturbances (market, weather conditions) play a role (Fig. 1, bottom). In those cases, there exists a strong need for adequate tools to support the required decisions for adaptation. Later we will consider in some detail the kind of information needed. Crop growth models, in fact, are a tool that would enable the manager to make better choices, by offering a tool to evaluate the decision. Except for experience, there is hardly an alternative for such sources of information.

It should be remarked here that crop growth models could also play a more important role in applied research than is presently the case. They may be useful to:

1. direct research
2. compare experimental results
3. analyse experimental results
4. generalise results
5. develop applications as mentioned before

Ad 1 direct research: in some cases it is possible to carry out a sensitivity analysis to investigate the relative importance of a measure, to determine the order of magnitude of the expected effects and to decide next on the set-up of suitable experiments to confirm the expectations. Knowing the relative importance of the effect of a measure may help to decide upon the relevance of a certain research line.

Ad 2 compare experimental results: sometimes it is rather hard to compare experiments with each other, because more than a single factor is different in comparative experiments, as is often the case with experiments that are carried out at different periods, or in climate experiments, where there is usually a strong interaction among the climate factors.

Ad 3 analyse experimental results: in many cases a treatment of a crop gives rise to immediate and delayed effects. Without a suitable model it is often not possible to understand the mechanisms that cause the observed effects. When an experiment is simulated with the observed environmental conditions and perhaps some crop parameters it is likely that the experiment can be interpreted much better.

Ad 4 generalise results: better understanding and better insight in the results obtained in experimental work provides the best basis for generalisation. Generalisation means reuse of the same knowledge and hence a gain in efficiency of the research process.

Ad 5 develop applications as mentioned before: there is already much valuable knowledge represented in the form of crop growth models, but even a very powerful model is not sufficient as a tool for growers. A great deal of work is required to develop an application for growers on the basis of a model. This requires close co-operation among applied and fundamental research, to avoid frustrations and failures.

A model that could be brought into practice relatively easily, is a model predicting potential production (Challa and Bakker, 1999). The concept of potential production in greenhouses differs somewhat from that in a field situation, because there is no clear definition of the growing season and, moreover, the CO_2 concentration may deviate strongly from the average outside value, due to CO_2 enrichment, but also depletion, due to crop photosynthesis at low ventilation rates. Nevertheless, it is feasible to describe a reference crop with a LAI of 3 and a low (340) or high (1000 ppm) CO_2 concentration, that may represent an average situation prevailing in many greenhouses for substantial periods of the year. For these reference conditions it is possible to establish the annual course of potential production, which, in turn, can be used as a basis for comparison with actual production, and for evaluating of photosynthesis mediated effects of alterations in greenhouse conditions.

The previous examples have shown that one may expect an increasing demand for models in practice, provided that they are adequately incorporated in user oriented tools. It may thus be worthwhile to have a closer look at the kind of information needed and the way this information could be represented in crop growth models.

3. Model integration

When we consider the most sophisticated, mechanistic models they are characterised by a large number of processes that are described in considerable detail. Examples are photosynthesis models that describe the dry weight accumulation and distribution over time, or plant water models that deal with flow of water through the plant. For a grower many details that are described in those models are rather useless, whereas other quite relevant information is not represented at all. Of practical value are primarily those parameters that are related to timing of the harvest, and amount and quality of the produce. Although timing of harvest and productivity are not easy to model, major difficulties are encountered when modelling product quality (Van Meeteren, 1999). To model quality, a large number of, often widely diverging, crop properties should be quantified and related to relevant (most often poorly defined) quality determinants. Common determinants are e.g. height/size, shape, scent and colour of the product, number and size of flowers, post-harvest behaviour, etc. Unfortunately there are no models dealing adequately with all these attributes. Some specialised models deal only with single aspects, while ignoring others altogether. Examples are:

- plant architecture / height (e.g. De Reffye *et al.*, 1998)
- flowering / harvesting time (e.g. Fisher *et al.*, 1996)
- water relations (e.g. Van Ieperen, 1996)
- ion uptake (e.g. Le Bot *et al.*, 1998)
- pest / disease dynamics (e.g. Shipp and Van Roermund, 1998)

One may, therefore, wonder if it would be feasible to build a crop model, that would incorporate all these different aspects and that would cover the information requirements of growers, including quality aspects. In order to discuss this option we will first consider the structure of photosynthesis driven models (Gijzen *et al.*, 1998) as a possible basis for more elaborate models (Table 1).

Table 1. Structure of photosynthesis driven models. List of symbols: LAI = leaf area index, PAR = photosynthetic active radiation (400-700 nm), CO_2 = CO_2 concentration of the air, T = crop temperature, R_S = stomatal resistance, DWi = dry weight of organ i, FWi = fresh weight of organ i.

step	**input**
generate outside diurnal radiation (direct and diffuse)	latitude, day of year, daily global radiation
diurnal radiation climate	
transmission through greenhouse cover	greenhouse orientation, specifications
radiation climate inside greenhouse above crop	
radiation interception within canopy	LAI, crop geometry, scattering coefficient, % PAR
light distribution within the canopy	
leaf and crop photosynthesis	photosynthesis characteristics, CO_2, T, R_S etc.
maintenance respiration	crop dry weight, T, maintenance coefficient
daily net carbohydrate formation	
daily growth rate, growth respiration	conversion efficiency, carbon production value
DM distribution function	developmental stage
DWi organ i = 0 - n, FWi organ i = 0 - n	dry matter-content

It should be noticed that this category of models represents a way of looking at a crop, which is not necessarily consistent with the theoretical framework of other models. Such discrepancies, however, may form a serious problem in the integration of different models. They are avoided when different models are run in parallel (Fig. 2).

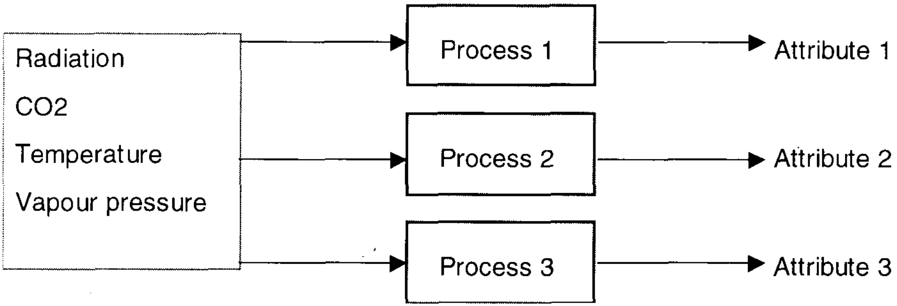

Figure 2. Parallel arrangement of independent (sub-) models.

Another option would be to consider the overlap among models in terms of processes and state variables, where models could benefit from exchange of information (Fig. 3) and overlap in process description is avoided. To integrate models along these lines it would be interesting to speculate about ways to do this and to consider potential links between sub-models:

- internal states, or rates of photosynthesis driven models
- carbohydrate-, ion concentrations

- water status
- developmental stage

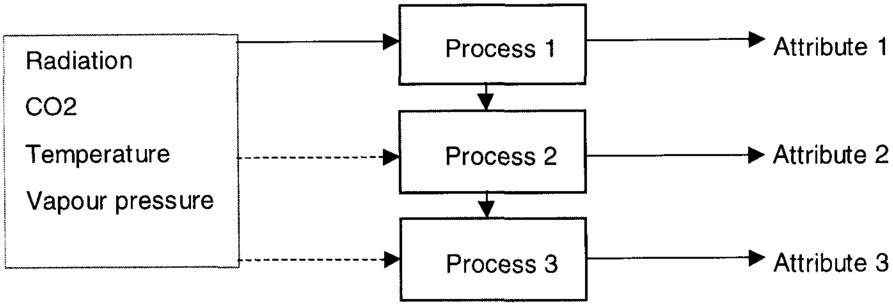

Figure 3. Integrated arrangement of interacting sub-models. Dashed lines indicate that only supplementary information is provided.

The current rate of photosynthesis is determining the potential for growth of a crop and it would be logical to expect a relation with morphogenesis, in terms of growth of organs and developmental processes. There is much evidence that organ growth responds relatively fast to variations in environmental conditions, including those that primarily affect photosynthesis. An example of a possible link between a dry matter (potential) production model (a mechanistic model based upon plant physiological and physical principles) and a plant height growth model (an empirical table relating week number to weekly growth in length) is given for *Ficus benjamina* (Fig. 4.), where both attributes shows a remarkably strong relationship. Although thorough testing under a wider range of conditions is required, this promising result suggests that there may be a possibility to link sub-models using output of the crop growth model as an input for the plant height module. The graph also shows that when dry matter production is high (at higher radiation levels), there is no further increase in length growth rate. It is not known if this phenomenon is a result of prevailing unfavourable conditions, or rather related to cultural practices like the use of screens or whitewash.

In other cases, there could be a link between the sink-source ratio and certain phenomena, such as flowering, branching, rooting, growth cessation and abortion. Sink-source ratio could be simulated in crop growth models (Marcelis, 1994), on the basis of calculated source (crop photosynthesis) and sink activity (potential growth rate of all organs). Obviously, such an approach offers new perspectives, compared to attempts to link environmental factors directly to the phenomena mentioned.

Also in the case of another quality problem, blossom end rot (BER) in tomato, there may be perspective for use of models to predict the chance that BER would occur (Schotman, 1999). The phenomenon is so complicated that it is hard to solve without some analytical tool. The occurrence of BER is in essence related to the growth rate of the fruit and to the calcium distribution towards the fruit, because it is a calcium deficiency disorder (Marcelis and Ho, 1999). Growth rate of an individual fruit depends on its developmental stage and the ratio between supply and demand of assimilates in the whole plant. Calcium supply to a fruit depends in essence on the transpiration stream to an individual fruit in relation to that to all other organs. The calcium, as well as the assimilate supply of fruits could be approached with quantitative models.

It would be worthwhile to extend these examples with other cases, where crop photosynthesis based models could provide relevant information to other sub-models and to create hybrid models for a number of problem areas that are difficult to approach with models of either category alone. In particular it would be interesting to investigate whether this approach would lead to a more generic description of the relations between environment and crop performance with respect to morphogenesis and product quality. It is likely that the potential for extrapolation with black-box models would be enhanced by linkage with explanatory models. For example, CO_2 effects to some extent could be comparable with effects of radiation and in that case there is no need to establish a completely new relationship for this factor since it could already be described by the crop photosynthesis module.

Besides the traditional black-box models based on regression analysis, neural nets could describe in a more flexible way some of the less well understood parts of the system, while output from explanatory models could facilitate this process (J. Meuleman, pers. comm.).

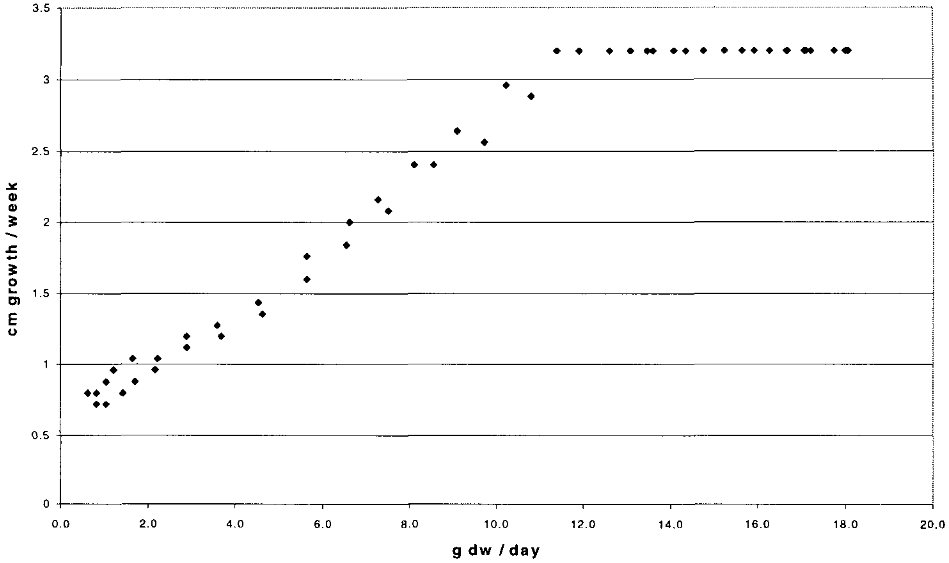

Figure 4. Average weekly growth in plant height (y-axis), plotted as a function of average daily dry matter production rate, for *Ficus benjamina* (growth data from Floreac B.V., Belgium) in different periods of the year.

4. Towards wider application of models

Until here model application in practice has been considered mainly from the point of view of information provision, but it is clear that models are not even the main bottleneck for further progress. Apart from the general problems of introducing DSS in horticultural practice (Lentz, 1998), a major problem for software developers is to create crop, or even cultivar specific software. In this paper linkage of generic processes with specific problems has been considered and it may well form a philosophy for dealing with diversity in horticulture: link crop specific phenomena as much as possible to well known and generic phenomena with relatively simple crop specific modules, that are easy to build and maintain. Parameterisation of such simple sub-models would be easier than more complex stand-alone models, because much variation in data could be described by the generic model linked with it. Ideally, historical nursery data collected by the grower, or by an automated system, as described by Dijkshoorn-Dekker and Meuleman (1999), could be used for parameter estimation.

I have indicated some trends that have not yet reached the moment of realisation. I expect that the processes that lead in this direction still need time until growers and software suppliers feel that there is indeed an advantage to invest in this type of developments. The joint effort of modellers and applied researchers is needed to prepare the way for effective model support in greenhouse horticulture.

References

Anthony, L.N., 1965. Planning and control systems; a framework for analysis. Boston, Harvard University.

Callewaert, L. and Lippert, T., 1999. HOPLICCS : HOrticultural PLanning and Integrated Cost Control Systems. Acta Horticulturae, in press.

Challa, H., and Heuvelink, E., 1996. Photosynthesis driven crop growth models for greenhouse cultivation: advances and bottle-necks. Acta Horticulturae 417: 9-22.

Challa, H. and Bakker, M., 1999. Potential production within the greenhouse environment. Ch 15 in: Ecosystems in the world, Vol. 20 Greenhouse Ecosystems. Eds. G. Stanhill and H.Z. Enoch, Elsevier, Amsterdam, Lausanne, New York, Oxford, Shannon, Singapore, Tokyo. Pp. 333-348

De Reffye Ph., Houllier, F. and Blaise, F., 1998. Modelling plant growth and architecture. Some recent advances and applications to agronomy and forestry. Acta Horticulturae 456: 105-116.

Dijkshoorn-Dekker, M.W.C. and Meuleman, J., 1999. Information-management-system for growth control of *Ficus benjamina.* Acta Horticulturae, in press.

Fisher, P.R., Lieth, J.H. and Heins, R.D., 1996. Modeling flower bud elongation in Easter lily (Lilium longiflorum Thunb.) in response to temperature. HortScience 31 (3): 349-352.

Gijzen, H., Heuvelink, E., Marcelis, L.F.M., Dayan, E., Cohen, S. and Fuchs, M., 1998. HORTISIM: a model for greenhouse crops and greenhouse climate. Acta Horticulturae 456: 441-450.

Harsh, S.B., 1998. Information systems for management in protected cultivation. Acta Horticulturae 456: 469-475.

Le Bot, J., Adamowicz, S., Robin, P., Gary, C. and Andriolo, J.C., 1998. Modelling nitrate uptake by greenhouse tomato crops at the short and long time scales. Acta Horticulturae 456: 237-245.

Leutscher, K.J., Renkema, J.A. and Challa, H., 1999. Modelling operational adaptations of tactical production plans on pot plant nurseries: a simulation approach. Agricultural Systems, 59: 67-78.

Lentz, W., 1998. Model applications in horticulture: a review. Scientia Horticulturae 74: 151-174.

Marcelis, L.F.M., 1994. A simulation model for dry matter partitioning in cucumber. Annals of Botany 74: 43-52.

Marcelis, L.F.M., and Ho, L.C., 1999. Blossom-end-rot in relation to growth rate and calcium content in fruits of sweet pepper (*Capsicum annuum* L.). Journal of Experimental Botany 50: 357-363.

Shipp, J.L. and Van Roermund, H.J.W., 1998. Pest and disease modeling and its role in integrated farm management. Acta Horticulturae 456: 419-429.

Van Ieperen, W., 1996. Consequences of diurnal variation in salinity on water relations and yield of tomato. Thesis Wageningen Agricultural University. Pp. 176.

Van Meeteren, U., 1998. Quality models in horticulture need product quality: a rare but challenging field of exploration. Acta Horticulturae 456: 175-187.

Schotman, P., 1999. Improving support for greenhouse climate management. PhD thesis, Wageningen University.