PREDICTION OF PRODUCTION: REQUISITE OF AN INTEGRATED APPROACH

Hugo Challa
Department of Horticulture
Agricultural University Wageningen
P.O.Box 30, 6700 AA Wageningen
The Netherlands
Publication 548

ABSTRACT

In modern greenhouse industry the grower besides being a good grower also has to be a good manager. In fact the annual cost of labor, energy and capital investments is such that proper decision making is of primary importance. It is in this context that the problem of energy saving should be considered. The complexity and the range of many of these decisions make it highly desirable to provide the grower with suitable tools for making optimal choices.

Depending on the time scale three levels can be distinguished where decisions are made:

- strategical decisions: one - many years
- tactical decisions: months - year
- operational decisions: $\left\{\begin{array}{l}\text{days - weeks}\\ \text{minutes - 24 h}\end{array}\right.$

At each of these levels prediction of production may play an important role. Crop growth models therefore are a tool that may assist the grower in decision making. The present state of the art in crop growth models for horticultural applications will be discussed briefly. Depending on the decision-level and the type of decisions different models can be used. Examples of decisions and the involvement of models will be given.

Ultimately the grower aims at certain goals. It is the task of future decision support systems to take these goals into account at each decision level, but integrated within an overall decision structure. Speculations on how modern information technology may be involved in future greenhouse management will be made with an emphasis on the role of crop growth models.

Introduction

Energy saving can be considered as a problem at the level of the individual nurseries, at the level of a whole country or even at world scale. Related to this the problem changes from a primarily economical problem for the individual grower to a political and ethical problem at the level of countries and of the whole world. In this paper consideration will be given to the question of energy saving at the level of the individual grower.

In the Netherlands fuel consumption is an important but by no means predominating cost factor (situation 1986: Table 1; in 1987 due to the lower oil prices, the costs for "fuel" are even less, but in other countries they are often much higher). Depending on the kind of crop cultivated, heating costs range from about 10 to 25% of the annual value produced (Boers & van der Velden, 1986). Consequently for any decision aiming at a reduction of the consumption of fuel the associated effects on yield and on any of the other cost factors should be analyzed as well. Ultimately the grower needs an integrated approach, where optimization (maximization of the economic yield minus related costs) forms the basis of the decisions.

Table 1 - Annual cost of greenhouse operation, expressed as a percentage of the annual value produced (The Netherlands, 1986)

crop type % of annual value produced	vegetables %	potplants %
fuel	21	11
labor	33	28
capital investments	22	17
other costs	31	42

Basically the grower has the following ways to reduce fuel consumption per unit of product:

- improvement of the efficiency of the heating system
- insulation of the greenhouse
- use of alternative heating systems or energy resources
- cultivation at lower temperature
- use of less energy requiring crops or cultivars
- increase of yield

However, it is clear that with most of these measures reductions in fuel consumption will come together with increasing annual investment costs, and, worse, quite often with reduced yield. Thermal screens, for example, will not only require capital investments but due to the associated reduction in light transmittivity of the greenhouse cover, yield reduction has to be anticipated in general. Lowering of the temperature usually will give rise to delayed and or reduced harvests and may affect quality of the product as well. Use of alternative energy resources in stead of gas fired boilers, besides requiring extra investments in the installation also requires additional installations for CO_2 enrichment. Alternatively, it may well be that measures (higher temperature, artificial lighting) that result in higher energy consumption per unit greenhouse area ultimately will give rise to a lower energy requirement per unit of product. Decision making with respect to energy saving in greenhouses is therefore complex and usually requires an integrated approach, where all effects are taken into account.

The previous discussion makes clear that ultimately decisions of the grower with respect to energy saving have to be made by considering the economics of the nursery as a whole. To reduce the complexity of such decisions it is useful to distinguish, depending on the decision horizon, different types of decisions: strategical, tactical, and operational decisions (Fig. 1). Exact definitions will not be given here, and besides, a clear distinction cannot always be made. Generally speaking, strategical decisions are decisions related to long term investments like eg. building a new greenhouse, installation of movable benches, or thermal screens. Once such decisions have been made the next level of decisions (the tactical level) is concerned with problems of using the existing infra-structure in the best way: decisions on the cultivation plan, sowing/planting date, spacing, selection of the cultivar, etc. At the operational level decisions are taken that are concerned with the day to day actions, adjustments required to keep the actual situation in accordance to the tactical plans, and finally the minute to minute decisions aiming for optimal climate control.

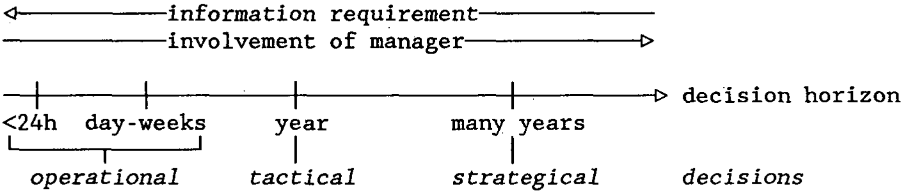

Figure 1 - Decision levels in relation to the decision horizon.

At each decision level there is a strong need for quantitative information on crop response to possible actions considered. However, it is clear that the further the decision horizon, the less accurate such predictions are (and have to be), and the greater the role of the grower as a manager will be (Fig. 1). In fact, besides production also other matters play a role such as a feeling for the market, risk analysis and factors specific for the nursery in question. Nevertheless prediction of production should form an important basis at all decision levels and consequently the potentials of crop models for decision making will be considered more closely.

Models

A quantitative model may be defined as a quantitative relation between input and output. The simplest quantitative models are the rules of thumb, like for example the often quoted "1%-rule" (1% reduction in light results in 1% reduction in yield). More detailed information is provided by tables, relating yield to different levels of, usually, one input factor, like eg. cultivar, planting/sowing date, etc.. At present strategical and tactical decisions frequently are supported by these two categories of models (eg. BEA in the Netherlands; Vermeulen et al.)

Another category of models are the statistical or regression models (Liebig & Lederle, 1985). These models are more flexible and able to deal with combined effects (multivariate optimization) as compared with the first category mentioned. Though regression models are largely of empirical nature (there is no relation between the internal structure and the real world) they have great practical advantages. The time to develop models for different purposes and for individual crops is far less compared to simulation models and besides the critical number of scientists required for their development is less (Penning de Vries, 1983). Besides all effects are taken into account, also side effects that are not known. A disadvantage, however, is that extrapolation outside the range of conditions considered is not allowed (no new strategies may be expected) and that with every crop and even with every new factor introduced the work has to be repeated fully: there is not much progress in the scientific knowledge which could enable a faster approach with new questions in the future. There is no doubt, however, that at present regression models provide the best solution for many practical questions at the strategical and tactical level.

Simulation, or mechanistic models are models that are based on quantitative knowledge of processes that are causally related to the phenomena considered. Because this knowledge is a prerequisite for the development of simulation models for crop growth, the threshold to introduce models in research programmes is high. Besides it should be noticed that the development of simulation models is team-work. Looking at the strategical significance of simulation models in the agricultural sciences, however, it is obvious that simulation models are of utmost importance:

- simulation models provide a bridge between the basic sciences (physics, plant physiology) and the applied sciences enabling a rapid and steady transfer of new plant physiological knowledge into the agricultural sciences, particularly for quantitative purposes
- because in many cases the basic physiological processes can be modeled in a generic way, models provide a way to share knowledge among agricultural specialists working on different crops
- use of models enables the study and analysis of very complex systems like that of the crop/greenhouse-system that are quite difficult to handle in other ways
- cooperation among scientists from different disciplines is stimulated because the systems approach enables the identification of subsystems that may be modeled by specialists in one field and joined with submodels provided by other specialists in a way to deal with more complex systems
- agricultural science is greatly stimulated as the modular structure of simulation models enables a rapid and versatile approach to a multitude of horticultural problems of varying abstraction levels and a wide range of crops, using a common scientific basis (formalized as a set of modules) that will grow with time

In spite of the fact that crop simulation models at present still suffer from weak points (eg. assimilate distribution, morphogenesis, quality) and that still a long way has to be gone until their full potentials can be used, their significance is such that stimulation of model research in horticulture is urgently needed.

Crop growth simulation models

To calculate growth and production of horticultural crops in greenhouses the following processes are considered:

- light transmission through the greenhouse cover
- light distribution in the crop canopy
- leaf photosynthesis
- conversion efficiency of assimilates to structural dry weight
- dry matter distribution

- leaf area formation (light interception by the crop)

Depending on the situation, or the problem, or in case a new hypothesis about underlying mechanisms arises, certain modules may be modified, simplified, or extended and modules may be added to taylor the model in the way desired. SUCROS, a summary model commonly used for calculations on the growth of field crops (Spitters et al., 1988) for example can be easily modified to enable the calculation of potential production of greenhouse crops in dependence on season and CO_2, provided that a module be added that deals with light transmission of the greenhouse cover (Fig. 2). Exactly the same model, however, by just changing the input data concerning the properties of the cover, may be utilized to evaluate the effects of a reduction in transmittance on yield (Fig. 3). Likewise by making small modifications in the module that generates the diurnal course of outside radiation, predictions can be made on the effects of various artificial lighting strategies with virtually the same model.

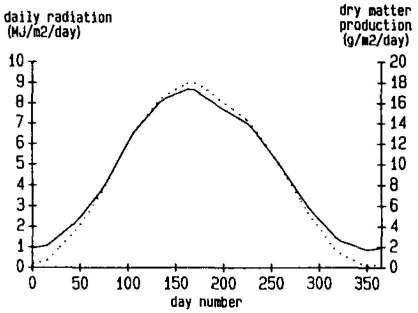

Figure 2 - Daily dry matter production of a hypothetical greenhouse crop with fixed leaf area index (LAI=3) and fixed crop dry weight (165 g/m^2) throughout the year, and average light conditions in the Netherlands. Temperature = 20 °C; greenhouse N-S orientated; transmittance of greenhouse cover for diffuse light = 73%; [CO_2]: 340 ppm.

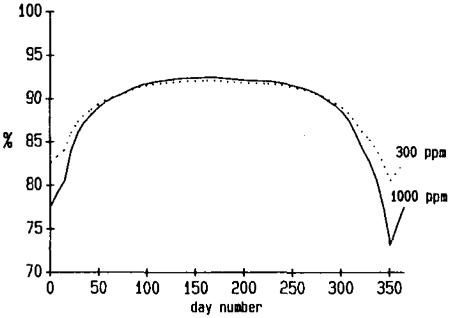

Figure 3 - Relative reduction in dry matter production throughout the year as a result of a reduction of transmittance of the greenhouse cover of 10%, at CO_2-concentration of 300 and of 1000 ppm. Otherwise the same conditions apply as in Fig. 2.

Another important feature is the possibility to extend or to limit the borders of the system in consideration (Fig. 4). If the system is confined to a single leaf (Fig. 4a), CO_2-concentration near the leaf, radiation absorbed by the leaf and temperature of the leaf are input variables. If, however, the whole crop is considered as the system (Fig. 4b), *radiation*, CO_2 *and air temperature inside the greenhouse* are input variables and the model calculates the required input variables at the level of individual leaves. An even more aggregated model arises when the combination of the greenhouse **with** the crop forms the system (Fig. 4c), where ventilator opening, pipe temperature, rate of CO_2 supply and outside weather are the inputs, whereas now inside temperature, CO_2 concentration and radiation at the top of the canopy are generated by the model.

Decision support systems

In the near future models of various degree of sophistication will become available to support the grower in making optimal decisions in his management and control (Fig. 5). Strategical decisions will be based on predictions of average crop performance under average climate conditions. Alternative decisions will be evaluated for their economical impact (costs and yield) and associated risks (sensitivity analysis), and optimization may be pursued using modern mathematical techniques. Models may be adjusted to the individual grower's situation according to the average crop performance on the own holding. Future computer networks (linking auctions and the grower's computers) will facilitate automatic registration of relevant information.

To make optimal use of the infra-structure resulting from strategical decisions, the decisions at tactical level require models that predict in more detail the performance of specific crops and cultivars under the specific circumstances of the grower in question, in relation to factors like temperature regime, planting system, etc., with the expected prices of crops, labor, fuel and other supplies of that moment. This will result in an optimal cultivation plan (blue print) for **that** year, and **that** nursery.

At the operational level deviations from the cultivation plan due to weather, pests, prices, etc. will be dealt with, using short-term predictions of crop performance, based on actual crop status, market situation, labor situation, etc. This may also result in adjustments with respect to the average climate that should be pursued. Finally optimal set-points are calculated from moment to moment by means of optimization algorithms that use crop growth- and greenhouse models (Challa, 1985).

The grower in this view will take the decisions at the strategical and tactical level, supported by information from his management system. At the operational level, however, the grower's role will become less direct: aims, observations and judgments of the grower will form the basis for the optimization procedures at this level, but set-points will be calculated by the system, without interference of the grower, but, of course, within the limits allowed by the grower.

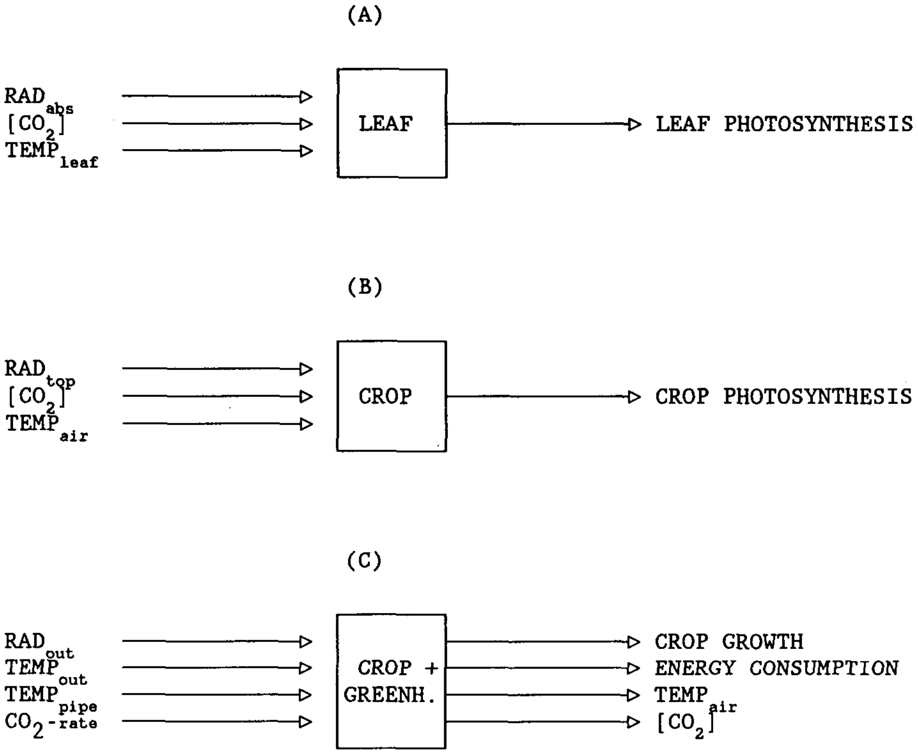

Figure 4 - An example of the possibility to extend the borders of the system from a single leaf (A) to a whole crop (B), or to the system crop + greenhouse (C). RAD_{abs}=radiation absorbed by the leaf; $[CO_2]$=CO_2-concentration in the greenhouse air; $TEMP_{leaf}$=leaf temperature; RAD_{top}= radiation at the top of the crop; $TEMP_{air}$=temperature of the greenhouse air; RAD_{out}=radiation outside the greenhouse; $TEMP_{out}$=temperature outside the greenhouse; $TEMP_{pipe}$=temperature of the heating pipes; CO_2-rate=rate of CO_2-supply.

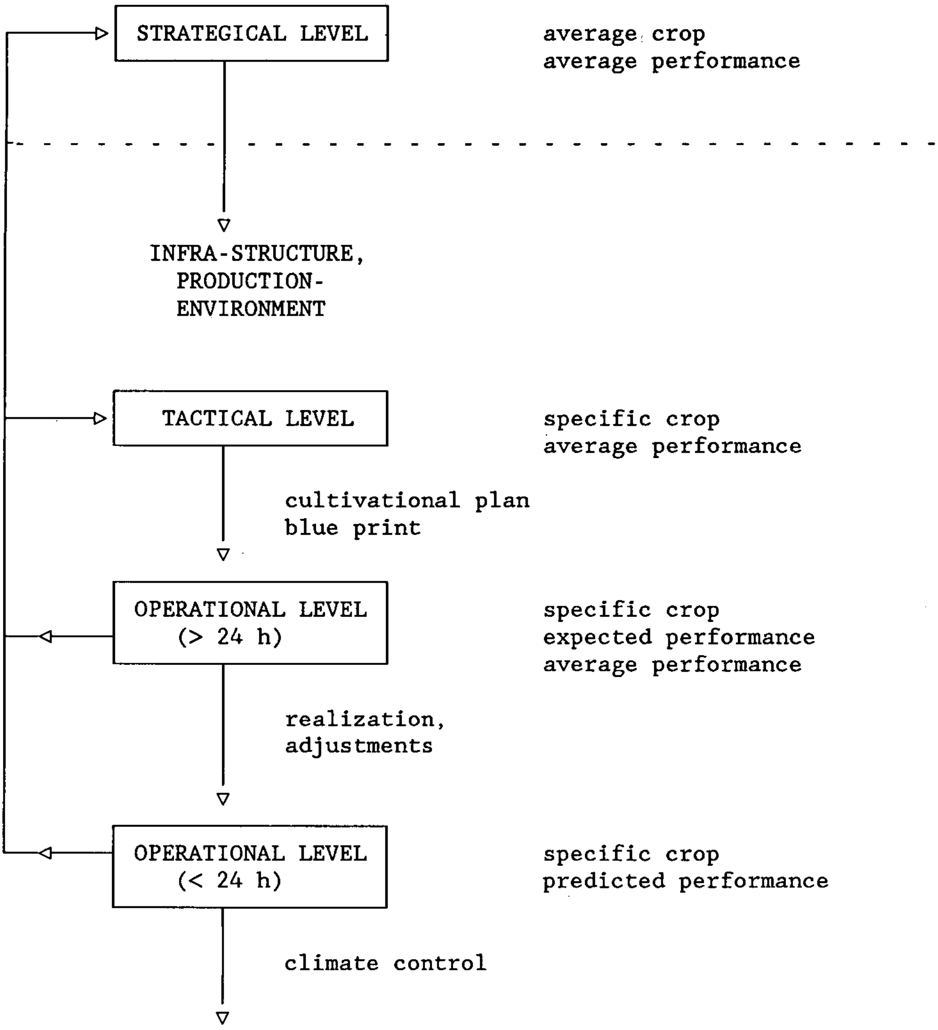

Figure 5 - Information flow between various decision levels, explanation see text

Bibliography

Boers, A. and Velden, N.J.A. van der, 1986. Raming van de bedrijfsuitkomsten in 1986 van de glastuinbouw- en champignonbedrijven. Periodieke Rapportage 24-86, LEI, Den Haag, The Netherlands, 17 pp.

Challa, H., 1985. Report of the working party "Crop growth models". Acta Horticulturae 174: 169-175.

Liebig, H.-P. and Lederle, E., 1985. Strategy for modelling plant growth. Acta Horticulturae 174: 177-192.

Penning de Vries, F.W.T., 1983. Modeling of growth and production. In: Encyclopedia of plant physiology, New series, Vol. 12D., Physiological plant ecology IV, (Eds. O.L. Lange, P.S. Nobel, C.B. Osmond, H. Ziegler), Springer Verlag, Berlin, Heidelberg, FRG, p. 118-135.

Spitters, C.J.T., Keulen, H. van, and Kraalingen, D.W.G. van, 1988. A simple and universal crop growth simulator: SUCROS87. In: Simulation and systems management in crop protection. (Eds. R. Rabbinge, S.A. Ward and H.H. van Laar), Simulation Monographs, Center for Agricultural Publishing and Documentation, Wageningen, The Netherlands.

Vermeulen, P.C.M., Ruijs, M.N.A., and Benninga, J., 1988. Farm management advisory systems for horticulture. Acta Horticulturae 223. In prep. (Proceedings of the X-th Symposium for Horticultural Economics, 1987, Warschaw, Poland)