COMPUTER CONTROL OF GREENHOUSE CLIMATES

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Abstract

A general opinion will be outlined on potential computer applications. A description based on system theory of greenhouse culture and related factors is the fundament of this discussion. A system is described consisting of three levels: (i) the instantaneous greenhouse climate, (ii) short term plant growth and (iii) long term crop development. This system is also controlled on three levels.
Relatively simple mathematical models form the backbone of the control on the three levels. On the first level progress can be made by application of sophisticated control methods, where the use of a computer is essential. On the second level short term plant growth models can be applied in three approaches: (i) the use of plant growth measurements (the "speaking" plant approach), (ii) the avoidance of extreme climate conditions using the "fuzzy set" technique and (iii) the use of a model that is tuned by the grower on a medium long (1 week) basis.
Crop growth and development models can be used on the third level, where cost-return predictions seem attractive although ultimate desisions have to be made by the grower himself.

1. Introduction

In the Netherlands, the climate computer has been introduced in the control of greenhouse climates, thereby replacing the analogue control equipment. The computer facilitates the use of sophisticated control strategies and can offer a significant improvement in performance over presently used control equipment. This paper will outline some opportunities, using a description based on system theory of the relation between greenhouse climate and crop development. A system is described consisting of three levels: (i) the greenhouse climate which influences the plant, (ii) short term plant growth factors and (iii) long term crop development. This system is also controlled on three levels: the realisation of desired climate factors, the determination of the desired values of these climate factors and the strategy for an optimal yield.

In this paper (see also Bot et al. 1978), in section 2 the historical development of greenhouse climate control is described and the attention is focused on the present situation. In section 3 the system description is presented. Then, the control of the climate (on level one) is discussed and after that the conception of the "speaking plant" (level two). Crop growth models (level three) are discussed followed by a discussion on the potential benefits.

2. Present situation

In a discussion on the potential impact of the computer in horticulture it may be clarifying to realize that -at least in the Netherlands- the computer fits well in the development of automation in greenhouse climate control.

Automation made a hesitatingly start in the late fifties (Businger, 1963) by the introduction of thermostats for heating control. Later, electronic (or analogue) controllers were introduced.
At first elementary, but with growing capabilities such as automation of the ventilation windows and the (energy saving) light-dependent temperature control (Strijbosch 1966, 1973).
The computer fits well into this development. All control functions that are performed by analogue equipment can be programmed easily in a computer, with the additional advantage that the functions have become far more flexible since they are no longer physically related to electronic circuits.
Added to that, the vendor has the opportunity to extend the programs of his computer by new control functions which can be made operational without the disadvantage of considerable expenses of the grower for additional equipment.
When it is taken into account that for several greenhouse compartments the investment cost for a climate computer is on the same level as comparable electronic equipment, the rapid increase of greenhouse climate computer installations can be understood.
When we look upon the way controllers are used at present, there are three aspects that attract our attention.
The first aspect is that knowledge of the dynamic behaviour of a greenhouse is very limited. This means that even advanced controls, as programmed in commercial greenhouse climate computers are mainly based on rough, stationary relations and on experience. Given this situation, many problems that did occur in the control were solved in an ad hoc fashion. (For example the maximum heating pipe temperature.) This has the drawback that these ad hoc solutions, which interrelate with each other, lead to an unpredictable behaviour of the controller in unforeseen circumstances. It is only because the greenhouse climate changes relatively slow, that manual control can adequately override the controller.
The second (and related) aspect is that usually the grower is blamed for failing operation. Also when evidently an ill-functioning controller causes problems, the grower is expected to correct the controller by clever tuning of one of the many control functions that are available.
This may sound somewhat unfriendly, but it can be understood from a third striking aspect: there is an obvious mixing in the controller between what is good for the control of the meteorological climate factors (temperature and humidity) and what is good for the regulation of plant growth. The authors will not make the point that there is no relation at all - the practice of growing proves the opposite - but they feel that when a control method is advocated because it improves plant growth, in most cases in fact a typical control problem is straightened out.

In the situation as it is, the application of the greenhouse climate computer in its own right will not lead to significant improvement, if the computer programs are based on the present knowledge. In research on climate control it is therefore of much importance to follow a different approach.

3. A system approach

For a proper understanding it is necessary to define the problem more precisely (Bot et al. 1977). In other disciplines system analysis has proved to be a powerful tool (Karnopp et al. 1975). The problem is divided here into well organized sub-problems and the relations between them are

established.
Often a hierarchical process description turns out to give satisfactory results. Here the problem is sub-divided into levels, of which the higher levels include the lower ones in increasing complexity. The control of this process can also be hierarchical.
The problem at hand is the regulation of plant growth and development in order to obtain a maximal yield at minimal costs. This is attempted to effectuate by a specified climate regime in the greenhouse. Other factors, like pest management, use of fertilizers are not of interest in this problem formulation. In this problem description essentially three different levels can be distinguished.

The first level describes the *micro-climate* in the greenhouse.
We try to influence this by the control of the overall greenhouse climate where meteorological climate factors (Seemann 1974) like air temperature, humidity and carbondioxe are of primarily importance. These meteorological climate factors are all measurable so that control can be realized. The term control is here used in the sense that a control takes actions based on measured values of the relevant climate factors. Other factors, which are more difficult to measure, also determine the micro-climate, like air movement in the plant canopy and rate of air exchange.

On the second level the short term plant growth -characterized by the plant processes *transpiration, respiration, photosynthesis* and CO_2 assimilation- is of interest. To implement a control, plant growth should be measured, which is not (yet) feasible. The point can be stressed that the grower operates as an observer on this level. Generally not the actual plant growth is of interest, but what one from experience expects the plant to do under given circumstances. A number of cultivation methods, as they are incorporated in present controllers, can be thought on this level - such as the light-dependent temperature control. In the hierarchical process, the control on the second level sets the desired values of the climate factors on the first level. The first level will try to realize the desired values.

The third level is the long term crop growth and development. Here we are mainly interested in aspects like *quality, yield, time of harvesting* and the directly related economic value. The aim of this being maximal profit for minimal costs. A cybernetic mechanism that controls this level on the basis of measurements cannot be established. Decisive here is the expected yield, based on "blue prints" of cultivation methods in addition to the grower's experience, intuition and spirit of enterprising.
The expectations of the yield lead to actions on the second (and the first) level.

A schematic diagram of the described system is found in fig. 1. In the following the application of climate computers on the three levels will be discussed, and the progress that can be expected in the future.

4. Control of the climate factors

On the first level progress can be made in the development of new control methods which are based on dynamical models of the greenhouse climate.
Depending on the purpose of these models, the complexity can vary. For example, very simple models can be used in order to obtain a deeper

understanding of the heating system (Udink ten Cate and van de Vooren 1977a).
Models that are more related with reality - for example models that are used in simulation of ventilation in greenhouses - can be of a more complex nature. In this respect it is remarkable that there is hardly understanding in the way the various factors determine the instantaneous greenhouse climate in the respective mutual relationships. On this point the knowledge of physical phenomena appears to have blind spots, although this knowledge is essential.
The new control methods will be based on improved knowledge of the physical phenomena and on advanced control theory (the so-called "modern" control theory). The authors are working along these lines and it is expected that progress can be made depending on available funds and manpower.
An example of "modern" control is the adaptive (= self tuning) control of the heating system in the climate glasshouse of the Naaldwijk Experimental Station (Udink ten Cate and van de Vooren 1977a, b).

Models of the greenhouse climate can be used for predictions, where also the influence of the crop can be considered. One may think here of a model for prediction of the period that condensation occurs on fruit when during the warming-up of the greenhouse in the morning a certain temperature trajectory is followed. (Although the prediction of the period that condensation occurs on leaves in the open field appears to be difficult, Goudriaan 1977).
Another aspect of more refined models of the physical phenomena is that in simulation the performance of new control strategies can be studied in advance, thereby avoiding cumbersome experiments. Also the significance of the measurement of other factors than the usual ones - such as the temperature of the glasscover (Hoenink 1978) - can be examined before a decision on the development of new measurement devices is made.

Because it can be expected that the control of the meteorological climate factors can be improved - which means that the setpoints will be followed more closely- it appears to be possible to introduce in research the distinction between climate factors and plant growth. As mentioned earlier, in the commercial equipment functions related to climate control and short term plant development are mixed, and much research is implicity based on similar presumptions.
An example. It will become possible to define air movement and subsequently the boundary layer resistance of the leaf in relation to factors like wind velocity, position of ventilation windows and outside air temperature. Research can be undertaken on the relation between air movement and plant growth, and not on the relation between minimum aperture of the ventilation windows and plant growth or between minimum heating pipe temperature and plant growth, as it is presently done. When plant growth is explicity discussed, however, the second level is approached.

5. The speaking plant

On the second level the short term plant growth has to be regulated. There are several control strategies which can serve this purpose:
- the measurement of plant processes and their use in the control (via a mathematical model);
- the application of a linguistic model of plant growth in order to avoid extreme situations;

-the use of a model that is adjusted by the grower on a medium long time scale.

Direct measurement of plant processes which give an indication for plant growth strikes one's imagination. Therefore, we like to call this the "speaking plant" approach. One could think here of direct type measurements like leaf-thickness, water transport in the stem, evaporation measurements with fast responding lysimeters. The drawback of these measurements is that they are to be performed on living matter which is - to put it mildly - rather problematic, especially for routine measurements. Indirect measurements like CO_2 absorption for photosynthesis are more easily made on a routine basis, but are subject to strong and systematic disturbances. Added to this the growth is not determined by a single factor. The results of the experiments of Takakura (1971) with respect to maximisation of photosynthesis, for example, fit into this picture. In fact, this area is rather unexplored and not much can be said of possible future applications.

Another strategy is to avoid extreme situations. From practical experience much is already known of situations where plant growth is damaged. In the practice of nursing the grower appears to follow this strategy when he alters the climate control setpoints. In the present analogue controllers this strategy is implemented in control actions that follow from plant behaviour. It does not appear easy to incorporate such a strategy in a controller. A solution might be found in the application of methods which are based on linguistic relations, the "fuzzy set" theory introduced by Zadeh (1973). This kind of solution is subject of a present study by the authors.

When the routine measurement of plant factors is considered too cumbersome and unreliable, and when the avoidance of extremes is considered too rough, another approach can be followed. If sufficient knowledge of short term plant behaviour is available, an approximate model can be constructed which roughly predicts the plant growth. Since the model is not correct, if only because in the plant development several discontinuities can be distinguished, the model needs occasional adjustment. On medium long term (one week) the grower may act as an observer and could carry out adjustments. It is obvious that it is not at all easy to make these kinds of observations in the right manner and to use them as data for a computer model.

6. Crop growth models

As is explained before, on the third level one cannot speak of control in the strict sense, because the economical profit is only established once at the end of the growth period. What can be used are the expectations of the yield, quality and the time of harvesting.
This is what happens in the practice of growing, where the expectations are based on the grower's experience and on horticultural knowledge, for example of the best temperature regime for a crop. In this field very much research has been done. This has resulted in the "blueprints" for the growing of various crops.
New developments that are partly based on short term plant growth, see Challa (1977) are applied in the cucumber experiment of 1977 in the climate glasshouse of the Naaldwijk Experimental Station.
A trend can be observed to the accumulation of knowledge that facilitates to carry out cost-return analysis beforehand, such as how much is paid

for earliness in terms of increased fuel consumption and which price can be expected by marketing the yield.
This kind of applications have an intuitive appeal, but there is also a danger that the computer will directly replace the grower.
It can be doubted if this is really possible, if only because it is hard to weigh subtle risk factors in an explicit way and to put them into a computer which will perform some calculations. Also, it is the grower who has to feed data into the computer in the decision procedure.
If there have been failures in the field of automation, it has been on this subject.

7. Why automation?

To this point the goals of automation are only discussed in general terms as improved control, higher quality and so on. Which benefits can be expected from the research and how can they be formulated?
Where the improved control of the climate (on level one) is mentioned, more accurate realisation of the desired climate setpoints is intended. In practice this means that problems like large overshoots and unnecessary ventilation of heated air can be prevented. Nursing methods like the exchange of moist air by opening the ventilation windows can be performed more accurately. On this level one can think in terms of less waste of energy.
The savings on energy will not be impressive here, but interesting when they accumulate. Especially more economic ventilation can lead to savings, and at the same time maintain a good crop quality.
It is an obvious advantage that the grower will not have to invest in new equipment because the results of the research can be translated in new computer programs for the greenhouse climate computer.
The programs themselves can - once developed - at little expenditure replace the existing ones.

On the second level it is more difficult to express an opinion.
The imitation of the grower by the computer in a strategy aimed at avoidance of extreme climate conditions will lead to a better climate because the computer - as opposite to the grower - watches the situation continuously.
The introduction of plant measurements (the "speaking plant") offers advantages, provided it turns out to be realizable to develop (1) an integrated model of plant growth and (2) use this model in an effective control strategy. The same holds for a model that is adjusted by the grower. Benefits here should be formulated in terms of quality related to energy saving climate conditions.
Also, progress on the third level is hard to formulate in terms of profits. When relations between long term yield and quality, and short term climate can be established, a cost-return analysis could be made. The decisions, however, should be made by the grower himself, since spirit of enterprising - which cannot be included in a computer program - plays an important role.

In the discussion, the present situation in horticultural practice is more or less taken as a starting point. Changes in the construction of greenhouses are not treated and are in first instance not relevant to computer control problems. It is not unrealistic, however, to think that improved control added to a better knowledge of the greenhouse climate will facilitate new constructions. An example hereof is the well-known thermal screen which - in contrast to what is expected - does not lead to economic savings because of decreased yield at the lower energy consumption. Would better knowledge and control of the greenhouse climate serve the desired - and obvious - purpose in a more efficient way?

9. Conclusions

Conclusions that are drawn from the above discussion will necessarily bear a speculative character. Comments should be given on the likely increase in knowledge, the opportunities to use this knowledge in climate control strategies and the expected efficiency of new control methods.
As far as the authors are concerned positive opinions can be given on the improved control of the meteorological factors of the greenhouse climate (level one) and the introduction of control strategies in order to avoid extreme climate conditons. From the theoretical point of view it is also feasible to incorporate explicit models of plant growth and crop growth in the control but it is difficult for the authors to comment on the realizability of the models.
The formulation of the problem in this article is in fact postulated on the idea that there is a fundamental difference between scientific knowledge, knowledge that can be transferred into control methods and the efficiency of these control methods. In our opinion it is believed too often that the introduction of the greenhouse climate computer in itself will generate a transformation from already available knowledge into knowledge that can be applied for control purposes. From our discussion it is obvious that this will not be the case. It might be the merit of the system approach that at least on this issue a definite statement can be made.

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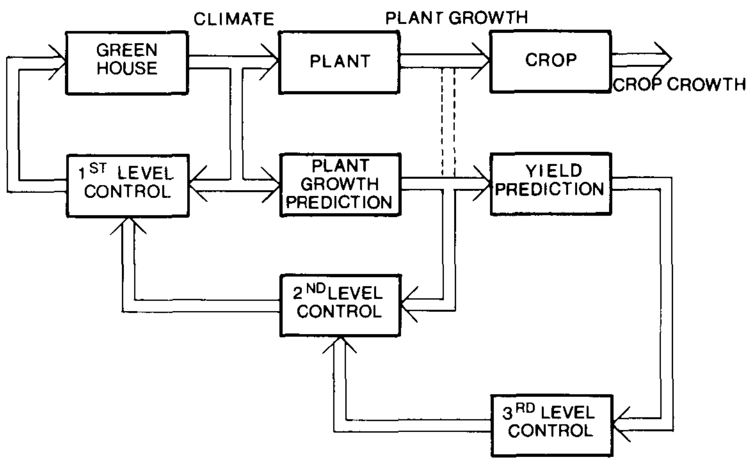

Fig. 1. Greenhouse climate control as a hierarchial system