Crop Modeling and Automated Control Systems

An Argus Discussion Paper

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Introduction

This discussion paper explores the relationship between crop modeling systems for greenhouse cropping, and automated greenhouse control systems.

What Is Crop Modeling?

In developing a crop management strategy there are two distinct problems to be resolved:

1. What are the objectives?
2. How can we achieve the objectives?

Crop growth and production modeling systems are suited to accomplishing the first problem, while climate control systems are specifically designed to address the second.

Though they have evolved separately, with different purposes in mind, there are some potential advantages to combining the capabilities of control systems and crop modeling systems for both research and commercial purposes.

Crop modeling systems are designed to assist in analyzing the growth and development of crops and the environmental variables to which they are exposed. This information is then used to try to predict how changes in the factors of production will affect growth and yield. Crop models attempt to create mathematical expressions of the components of growth and their interrelations. These may include:

- Growth determining factors
- Growth limiting factors
- Growth reducing factors

Automated climate control systems are used to operate the equipment that is used in crop production environments to maintain the target values for the controlled factors of production such as:

- Temperature
- Humidity
- Light
- CO2
- Water
- Nutrients

Background

The ultimate expression of a plant, the way it grows, looks, and reproduces, is a combination of nature and nurture. Nature, or the genetic makeup of the plant, determines the range of possibilities for its size, habit, flowering, and fruiting. Nurture determines where a plant will fall within this range of possibilities. For example, a tomato plant will never produce pineapples, regardless of how or where it is grown: it is genetically limited to producing tomatoes. However, depending on the environmental circumstances in which it is grown, it may produce many large tomato fruit, or just a few small fruit, or no fruit at all. Under identical circumstances, another tomato plant with different genes may perform altogether differently (although still no pineapples).

For many decades scientists have been trying to systematically quantify and understand the factors that govern how the genetic potential of an organism is expressed. As they gathered more data it was useful to try to put this information into mathematical models that could predict the relative influence of each variable such as temperature, light, water, and available nutrients. Although many models have been created, most have been experimental, and designed to support the basic research efforts in plant physiology and genetics. Today there is increasing interest in crop models that can provide management support for commercial production. The idea is, that if the effects of changing and cumulative environmental conditions can be accurately predicted, corrective management steps can be taken to keep a crop on track. Other potential benefits include avoiding disease, and maximizing beneficial growth while minimizing input costs.

During this same period, companies that provide computerized greenhouse control systems were emerging. As they evolved, many companies developed increasingly sophisticated systems to automate the process of creating and maintaining plant growth environments. For many years now, it has been possible to 'dial-in' a particular climate and nutrient regime and, provided that the greenhouse is sufficiently equipped with the machinery to deliver the desired effects, you can automatically achieve and maintain almost any climate suited to the target crop.

Some companies, including Argus, also provided capabilities for automatically adjusting climate targets based on changing conditions. Examples include:

- Target temperatures that can be varied according to changing light levels
- Irrigation and nutrient applications that can be modified according to changing temperature, light, and other local conditions.

On newer Argus systems it is possible to vary almost any target according to changes in other measured variables or combinations of variables. However, we should be clear that this type of automated target modification is based on relationships that are relatively simple to define logically and mathematically. While much can be accomplished with these tools, they do not contain the kind of crop-specific intelligence or baseline crop data that you might think of when you hear the terms 'Expert System', 'Decision Support System', or 'Crop Model'.

Defining the Targets

Traditionally, climate targets have been established through experience, and evidence-based research. Greenhouse environmental management targets have been established for most commercial crops and their growth phases. These targets are often general, and may not be specific to your geographic location or the cultivars you are using. You often need local experimentation and experience to further refine the guidelines.

Growers Make the Best Crop Modelers

As a grower, whenever you enter climate setpoints into a computerized climate control system you are establishing the climate target values, which, based on your best information and experience, will result in optimum production of the crop during a particular growth phase. Periodically, you need to revisit these setpoints in response to the observed performance of the crop. You analyze the current crop performance in relation to the conditions, and you then make a prediction as to where this is going, and decide what, if any changes are needed to keep the crop on track.

Crop production modeling systems are an attempt to replicate portions of this human process. Of course, computers don't really think like people; they can't make intuitive leaps, nor can they see, hear, and smell. They need to use mathematical rules and precise measurements to try to sort out what is going and what to do about it.

Counting Easter Lilly leaf buds and using graphical tracking of plant heights to make better decisions about climate temperatures are examples of simple, measurement based decision-support systems that do not require the use of computers. However, as the models become more complex and attempts to integrate several measured variables are made, it generally takes a computer to process all of the information.

Using Computers to Predict Crop Growth and Yield

Imagine the perfect computerized crop modeling system. You would simply enter the crop you intend to grow, along with your yield and quality expectations, and it would plot a course to get you there. Even if you get a little blown off track by unexpected weather or other circumstances, the model would adjust to provide new targets for getting your crop to the finish line. This is the promise of crop models. However, no such models yet exist for commercial greenhouse horticulture.

There are many climatic, genetic, nutritional, and management factors that affect the way a crop will respond. Determining an appropriate crop management strategy that can cope with these uncertainties has been a source of much research investigation and effort. Computer simulation models of root-zone, crop, and atmosphere relationships are making valuable contributions to our understanding of the processes that determine crop response and our ability to predict crop performance under different circumstances.

Plant simulation models attempt to predict the response of a target crop to environmental variables. Some look at only one variable such as water availability, while others may try to address the combined effects of multiple variables. This is not easy. Most variables, such as temperature, affect a range of growth responses and other plant processes. When two or more variables such as light and temperature are varied at the same time, the interactions can be very complex. For the commercial greenhouse industry, this is a particular challenge due to the diversity of species and cultivars grown. A great deal of time and money needs to be invested to design models that are specific to each crop, and often to each cultivar. Models tend to work best in situations where there is a high degree of uniformity of control and repeatability. Therefore, if you are changing species and varieties with each season, or mixing cultivars and species in the same environment, predictive models may be of limited value.

Achieving the Targets

It's difficult enough to decide what the right targets should be - achieving them is no small task either. For the most part, a greenhouse control system does not particularly care what the targets are – it is focused on achieving them within the defined limitations of the controlled equipment and the tolerances of the crop.

The primary function of a greenhouse control system is to automatically operate the connected greenhouse equipment to maintain climate parameters such as temperature, humidity, light, CO_2, root zone moisture, and nutrient levels within the target thresholds. In doing so, the system must respect a number of rules including proper and safe equipment operation, the specific needs and tolerances of the crop, and economic considerations such as total energy use. For example, roof vents are operated to deliver air exchange for maintaining temperature humidity, and CO_2 targets. However, they cannot always be operated in lockstep with these objectives alone:

- External factors such as rain, snow, and wind limit the range of conditions over which most roof vents can be safely and effectively operated.
- Under rapidly changing conditions such as intermittent clouds, it may be necessary to slow down or dampen the responsiveness of the control system to avoid excessive vent movements (thereby reducing energy use and equipment wear).
- Sudden temperature changes may adversely affect crop health, so the control system may need to apply the vents in a gradual manner to provide sufficient ramping from one setpoint to another.
- To avoid excessive energy use, it is often necessary to limit the amount that ventilation that can be used for problems such as dehumidification, particularly when heating is being applied at the same time.

This is what greenhouse control systems do best. Whether the targets are entered as fixed operator setpoints, or modified by other measured parameters, or passed in from an external decision support system, the job of the control system is to operate the greenhouse equipment to meet the targets while respecting any limitations that may be imposed.

What a Modeling System May Not Know

Externally caused upsets such as insects, disease, or extreme outdoor temperatures may take the crop beyond the boundaries of any automated crop model. When this happens, there is a potential for the model to fail dangerously. For example, excess watering often causes root disease. The symptom, however, is a wilting plant that seems to need more water. If the model incorrectly interprets the reason for plant stress as insufficient watering it will only make the problem worse. Ideally, models will be developed to recognize some of these situations by using appropriate combinations of sensing technologies. In the above example, if the leaf temperature, air temperature, light levels, relative humidity, and the soil moisture were monitored simultaneously, the model might not necessarily be able to diagnose root disease (it could be fungus gnats) but it could conclude that conditions had gone sufficiently "out of bounds" to signal the need for a human to intervene and sort things out.

Depending on the complexity of the production modeling system, it may not know or need to know the requirements of the controlled equipment or the growing structures. Remember, its primary function is to think about what the crop needs. However, the requirements of the crop are just one of the things that an automated control system has to consider. For example, if it is snowing outside and the air temperature needs to be raised to prevent the roof from collapsing, the control system must be configured to override or ignore any temperature targets set by the operator (or the modeling system) in the interests of preserving the structure. A good model will, however, take this undesired event under consideration and possibly modify future targets to compensate accordingly.

This illustrates that, in most cases, the automated control system must have the final say about what the actual controlled climate variables will be, since it has more to think about than the instantaneous needs of the crop. A suitably intelligent modeling system will compensate for these upsets and plot a new course for the crop once the situation causing the control override has passed.

Garbage in …

Crop and equipment safety are prime considerations for any good environmental control system. When accepting control instructions from external systems it is vital to have safety features in place to avoid dangerous mistakes or omissions.

Like an obedient soldier, your automated control system ‘just follows orders’. It does not particularly care what the orders are or who issued them, provided the source is authorized to make changes. Therefore, if you are in a position of authority over the control system, and you issue orders that will destroy your equipment and kill your crop, the control system will make sure that this happens as quickly and efficiently as possible.

To the control system, a linked production modeling system is the same as a human operator. It can make any changes for which it is authorized. The control system has no way of determining whether the instructions it is receiving are brilliant or completely insane. Therefore, before an automated control system can safely accept non-human control instructions, each incoming control instruction should be protected with several operator-definable safety features such as:

- Methods for detecting communications failures
- Default values in case of communications failure
- A limited range of acceptable (safe) values
- Maximum rates of change
- Any other rules that should be enforced to protect the crop, the equipment, and the growing structures from damage.

Putting it all Together

Many greenhouse control systems already provide a substantial amount of decision support information in the form of live measurements, recorded data, and pre-programmed alarms. Human operators use this information for daily management. It can also be passed to external programs for use in external crop models and simulations. Likewise, it is possible for setpoints that are normally adjusted by human operators to be manipulated by designated crop modeling software configured for this purpose.

In the future, some control system vendors may attempt to incorporate crop-specific modeling intelligence into their systems. In effect, they will be moving towards selling crop models or production knowledge rather than control systems. To the extent they succeed, this may be of interest to growers whose methods of production and crop selections best fit their models. However, this ‘closed systems’ approach to crop expert systems will also mean that growers using these systems will be limited to the range of offerings provided by their automated controls vendor.

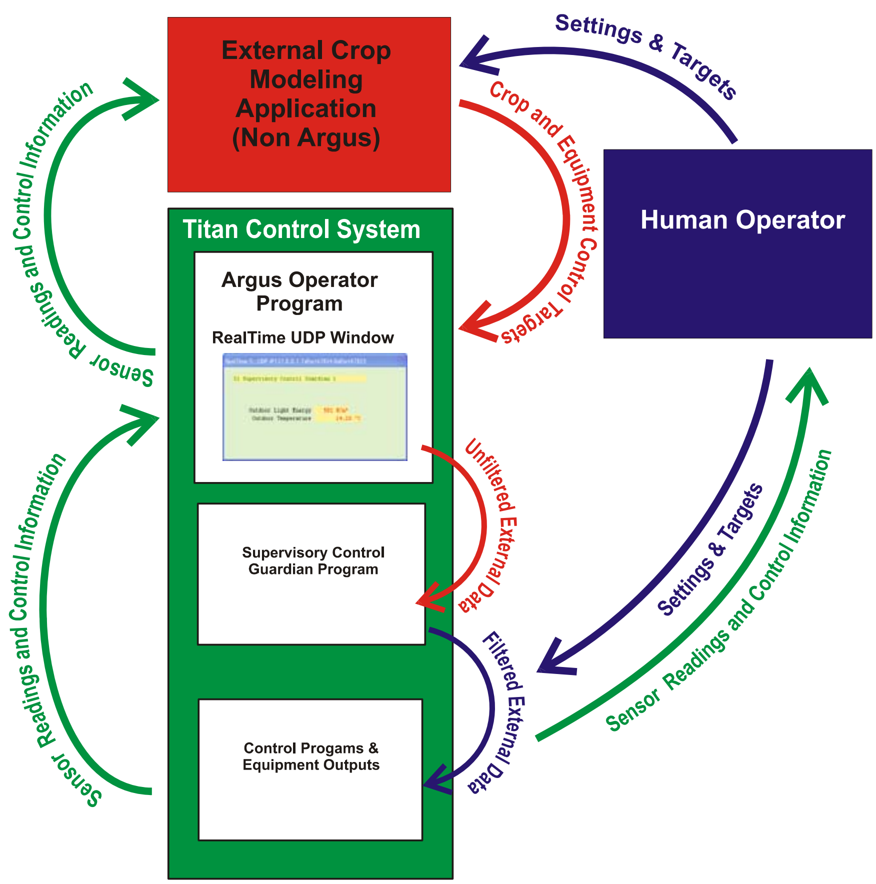
Argus has always supported a flexible approach to environmental control programming. Our customer base is perhaps the most varied in the industry, so we have been reluctant to write control software that is weighted towards any particular branch of greenhouse horticulture. We have continually refined our programs to encompass a full spectrum of control options that can be configured at runtime by our service personnel or system operators. This intentional approach means that we have not developed specific control modules aimed at rose production or tomatoes, nor have we geared them towards specific equipment brands. Rather, we have provided the flexibility to adapt our control programs to the needs of each crop and to each customer's controlled equipment and preferences.

Likewise, our approach to crop modeling and decision support systems is to accommodate as wide a spectrum of applications as possible. Rather than embed expert system software into our control systems, we have developed methods for working and communicating with external applications. By adopting this 'open systems' approach, our customers are free to take advantage of a full range of emerging decision support products. Researchers will also benefit from this interconnectivity since they can use the control system to provide the input measurements and the equipment control outputs for testing their models. This frees them to focus on plant growth and physiology, without needing to worry about the complexities of equipment control.

The Supervisory Control Guardian Program

For Titan systems, Argus has developed the Supervisory Control Guardian as a safe means of receiving information and control instructions from outside sources into the Argus system. For example, if you wish to use an external crop modeling program to set targets for climate temperatures and other parameters, this program will safely import the results of your model into the Titan system. It enables an external program to automatically direct or influence the activities of the Titan system. The program is called the Supervisory Control Guardian because it watches over the incoming data to make sure that it is safely within the tolerances and the limits that you define. It also requires the incoming data to be refreshed at regular intervals to make sure that the communications link is sound. If any problems occur, there are configurable failure mode contingencies and alarms to alert you.

Typical Program Linkages for Supervisory Control Applications



Two-way communications are made possible with the use of the UDP RealTime window that acts as a host for inter system communications (see the above diagram). In this way the Titan system can also provide feedback information to the external model such as sensor readings and equipment states.

Summary

You may begin to see production modeling systems increasingly promoted over the next few years, some by greenhouse controls companies, and some by others. Their effectiveness depends entirely upon how well they can speak for *your* crop, *your* location, and *your* conditions. They may also offer increased productivity, and the opportunity to save energy through more precise estimation of the growth processes and growth potential for any given climate regime.

A greenhouse control system is similar to autopilot. It is programmed to keep the greenhouse ‘flying’ on a defined course until the pilot (operator) intervenes. Enabling direct supervisory control without any operator intervention is like flying in a plane with no pilot. It may be technically possible, but who wants to be the first to ride in it?

With this in mind, the safest way to begin using these new tools will be in an advisory capacity, or as a ‘decision support’ system. Rather than just hooking them up to the control system and heading off on vacation, it will be much more prudent to consider the answers they provide as suggestions. Evaluate how well the conclusions match with your own skills and judgment. Only when you are satisfied that the model is doing at least as good a job as you can do should you consider allowing it fully automated access to the control setpoints on your environmental control system.

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