HUMIDITY CONTROL ALGORITHM IN THE GREENHOUSE

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Probably the last big challenge in the greenhouse automated environment control scene is that involving the control of atmospheric water vapour. Variously termed relative humidity, aerial moisture, vapor pressure or vapor pressure deficit, this variable in the environment of today's highly technical and computer-automated greenhouse plant production system has, until very recently, escaped the close scrutiny afforded temperature and light.

This apparent indifference to a rather important environmental influence on plant production and quality was largely the result of inadequate technology in controlling humidity in the greenhouse. I suppose one could make the case for a somewhat circular "Catch 22" argument wherein the low demand for technical developments in humidity control was caused by our relative ignorance of the effects of humidity on plants. And in the absence of humidity control technology, how could basic research pursue the questions of plant-environment interaction, which lead us to exercise the appropriate control strategies.

That was before. Now we have the latest generations of high-pressure fog systems and the vastly improved reliability of several classes of solid state sensors. Now we have a precision in humidity control for greenhouses that used to be reserved for small growth chambers and sealed systems. And we rushed to implement our new power over the greenhouse environment it suddenly dawned on us that we didn't know the set point should be. Our experience in studying plant-environment interactions over the years has taught us that environmental variables have optimum levels in their effects and that different plants respond differently, even varieties of the same species. It was time to take stock of a few of these issues as they related to the development of humidity control strategies.

Our recent research at the University of Guelph has been dedicated to evaluating the application of humidity control in the greenhouse, its effect on the greenhouse environment and its effect on the productivity and quality of plant commodities. The most extensively studied commodity has been greenhouse roses, largely as a result of the generous financial support of the individual rose growers and Roses Inc. The techniques and practices are now incorporated into a wider scope of greenhouse environment investigations under the auspices of grant support from the Cecil Delworth Foundation, Agriculture Canada, the Natural Sciences and Engineering Research Council of Canada and the Ontario Ministry of Agriculture and Food. Research funding has also been provided by Lander Control Systems Inc. (Guelph, Ont.) In direct support of investigations aimed at evaluating humidity control algorithms or "recipes" for management. This program of research aimed at investigating aspects of plant-environment interaction was established and has grown as a collaborative university-industry-government program involving all of the above agencies and industries.

Economical and practical humidity control strategies have been the focus of our research efforts. I will attempt to put our objectives and findings in a general context in an effort not to limit the scope of applications and technology transfer. Bear in mind that the management recipe or algorithm I will define has evolved in greenhouses in the southern Ontario climate. Nevertheless, the basic ideas and principles are generally applicable with appropriate modifications to account for environmental variables such as light, temperature and ambient humidity. The economic issue is another, which is rarely far from our consideration, and factors which affect this will be explained.

Our mission was to define an optimum control strategy for humidity. It would consider the physiological responses of the plants in question such as transpiration, water status and growth as well as post harvest issues of shelf life and quality. There were also interactions with other hardware components of the greenhouse to account for such as duty cycles on pumps (since that influenced maintenance costs) and temperature effects, which would influence operation of fans and heaters.

In considering the technology applied to humidity control, fog systems (not to be confused with mist systems) are an elegantly simple means of generating and maintaining control over atmospheric moisture. They produce a cloud of tiny water droplets which, when distributed properly, will not condense on foliage or structural elements of the greenhouse. Instead this cloud quickly evaporates to establish desired humidity levels and contribute to cooling. As heat is taken from the air around the fog line installations, this cooler (and therefore denser) air falls into the greenhouse canopy displacing warmer air and contributing to the natural vertical convection patterns of ventilation in the greenhouse. Aiding distribution and evaporation of the fog with horizontal air flow (HAF) is recommended since this also reduces the chance of temperature gradients which could foster condensation.

There are a wide variety of high-pressure fog systems from which to choose on the North American market but the basic principle is essentially the same. Some points to consider are ease of installation, non-drip nozzles and a nice, quiet pump. The single most important issue has nothing to do with the hardware but is, in fact, your water quality. Most (but not all) municipal supplies are adequate if filtered. Private water supplies such as wells and ponds, which may be high in mineral and particulate content, create a maintenance nightmare with nozzles. A deionizing filter or reverse osmosis system may be required to get the most efficient use of the fog system. (Bear in mind that deionizing treatments make water very demanding on copper and brass plumbing; stick with high pressure synthetic or stainless steel piping and valves).

The greenhouse experiments around which we evolved our humidity control strategies used a MicroCool high pressure fog system (Environmental Engineering Concepts Inc., Palm Springs, California, USA) supplied with reverse osmosis treated water (Culligan Ltd., Mississauga, Ontario) and operated by the greenhouse environment control measurement of humidity using solid state humidity sensors. This array of technology was operated in the research greenhouse complex of the Department of Horticultural Science at the University of Guelph.

Before I continue with a description of some of our experiments, it seems appropriate to add a brief discussion of the terminology associated with the study of humidity. To a certain degree, many of the misconceptions and inaccuracies related to the interaction between humidity and plants have been fostered by the way we measure and talk about humidity. The average individual uses the term "relative humidity" with confidence and ease. Humans have a general "feel" for this assessment of atmospheric moisture that makes it relevant to their relationship and interaction with the aerial environment. It seems natural, therefore, to continue to apply this measure of humidity in research associated with greenhouse humidity control or in attempting to outline a management strategy of humidity control in the greenhouse.

Relative humidity, as we are all reasonably well aware, is a measure, in percent, of the amount of water vapor in the air compared to the total amount of water vapor that **could** be in the air at a given temperature. Of course, as the air temperature rises, its capacity to hold water vapor also increases and, conversely, as air temperature falls it will hold less and less water vapor. So, arriving at this common measurement of aerial moisture requires knowledge of the relationship between water vapor concentration (or partial pressure) and air temperature. This allows us to predict the absolute maximum quantity of moisture that the air will hold at a given temperature which we then divide into the actual quantity of moisture present at the time of our measurement and multiply by 100 to arrive at "percent relative humidity". Sadly, mental arithmetic is a lost art in this age of the computer so the trusty hand held calculator (or its equivalent in the circuitry of most solid state sensors) helps us to the final answer. Unfortunately, even the most sophisticated, genetically manipulated plant species has yet to master the simple calculator or even simpler mental arithmetic to achieve this evaluation of humidity.

Plants cannot respond to or detect moisture that is **present** in the air (until it condenses or falls on them) but instead respond to atmospheric **demand** for moisture, which is another way of defining the moisture that is **not present** in the air. That is the **vapor pressure deficit** and is the **difference** between the actual concentration or partial pressure of water vapor in the air and the maximum possible concentration at that temperature. It doesn't require that the plant have any knowledge of arithmetic or predictive relationships. The plant simply opens its stomatal pores as the sun rises and permits the evaporation of water from the leaves in response to the atmospheric demand established by prevailing ambient conditions. If the atmosphere becomes too demanding, plants exercise a variety of mechanisms to cope and still maintain physiological functions. Viewing humidity from the plant's perspective was the first step in approaching a rational strategy of humidity control.

Therefore, all of our measurements of humidity which were to be correlated with plant physiological and growth responses were evaluated as vapor pressure deficit (VPD) rather than relative humidity (RH). Our greenhouse environment control responded to VPD feedback and our set points were established in units of millibars (mb) which is a pressure unit. Concentration units (eg. g/m^3) are also common. To put the units in perspective, a VPD of 10 mb at a temperature of 20 C represents a relative humidity of about 56%, 10 mb at 30 C is closer to 76% RH. TO make the point about atmospheric demand more clearly, 80% RH at 20 C represents a VPD of about 4 mb. Raising the temperature to 30 C but maintaining the same 80 % RH results in a VPD of 8 mb. Thus, even though the relative humidity remained unchanged, the atmospheric demand for moisture felt by plants was doubled.

In our experiments the range of humidity treatments including 6 mb, 18 mb and uncontrolled ambient humidity which ranged from 5-50 mb VPD. Temperature was controlled at 18 C during the night and 22 C during the day. Of course daytime (and sometimes night) temperatures would often rise much higher than these set points during the summer months when the combination of vents, shades, evaporative coolers and fog usually kept the greenhouse air temperature below 30 C.

Greenhouse roses were the selected plant commodity for these experiments and measurements were made of plant water status, stem elongation rates of plants and total production in the various humidity treatments. Stem elongation is a particularly relevant variable to measure in greenhouse roses since this commodity is graded on that basis. It was measured by attaching on end of a length of Kevlar thread to the growing apex of a shoot while the other end was attached to the movable core of a linear displacement transducer. In this way, stem elongation measurements were made continuously on growing shoots with a resolution of 0.01 mm and the environmental influence of humidity on stem growth was determined.

The results of these experiments showed that roses, like most plants, undergo a daily cycle of water stress and recovery. The extent of the stress is determined both by the supply of water to the roots and the environmental demand for moisture represented by the VPD of the greenhouse atmosphere. Even under conditions of adequate supply, the plants in our experiments exhibited levels of mid-day water stress which limited stem elongation under conditions of high environmental demand. These conditions were most prevalent during the summer months but could also occur during bright days in other seasons. The use of humidity control significantly mitigated the mid-day water stress in plants under these conditions with the result that stem elongation and was enhanced relative to uncontrolled aerial moisture conditions. At night or during dull overcast days, the influence of humidity control at 6 mb VPD in terms of enhancing stem elongation and water status was diminished to the point of usually being not significantly different from plants in the drier treatments. These particular experiments during the spring and summer of 1992 showed only modest trend of increased production and quality of greenhouse roses with increased humidity. However, those seasons, relative to other years, were dominated by other environmental variables such as light and temperature, which tended to overpower the influence of humidity. Earlier experiments with humidity control in the greenhouse resulted in production increases from 5-30% (depending on the season with higher increases in summer) under conditions similar to those established for these experiments. There were also some indications that post harvest shelf life was extended in some cultivars grown under humidity control.

The general conclusion of our studies to date is that humidity controlled at appropriate levels will mitigate the onset and extent of mid-day water stress in plants and contribute to enhanced cell expansion and growth under otherwise stressful conditions. The specific recommendations from our work also incorporate a cost versus benefit analysis in order to optimize the management the management strategy. For example, humidity control during Canadian winter months will often require that the fog, which is evaporated into the greenhouse environment, is done so at the expense of heat generated by the burning of fossil fuels. This will certainly be the case during winter nights and during days when the solar radiation level is below the threshold of contributing much to the evaporation of water. From our experience that threshold is about 400 unmoles/m^2/s (which is roughly equivalent to 88 W/m^2, 22 Klux, 2000 FtCandles). This threshold also applies during most of the rest of the year except during the hottest part of the summer when a minimum humidity should be maintained in the greenhouse to reduce dehydration stresses. The most economical and practical range of VPD to maintain in the greenhouse is 8-10 mb (0.8-1.0 Kpa). At temperatures of 20-25 C that represents a range of relative humidity between about 55% and 75%. However, remember, those RH values are for **your** benefit, not the plants'.