CONTROLS

Application Note

Irrigation System Design and Automation Considerations

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This paper is intended to help lead an experienced horticultural manager through the irrigation system design and automation process. It does not address specific crop requirements or irrigation equipment selection, but rather focuses on how you can integrate your preferred equipment selections into an automated irrigation control system that best serves the needs of your crops and production systems. It also provides some insight into how crop measurement and modeling systems work, to help you select the best control strategy to automate your production system.

Irrigation equipment or control system vendors are the best sources for specific product information. Once you select your suppliers, work closely with them to ensure your final automated irrigation system fits your needs and budget, and isn't just a poorly integrated aggregation of components that they sell.

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Part I: Irrigation System Design and Operation

Automated irrigation systems can greatly reduce labor, water, and fertilizer costs while at the same time reducing waste, runoff, and generally improving crop quality. So why don't more growers use fully automated systems?

Most greenhouse irrigation system problems we encounter relate to poor system design. Many design problems are unavoidable - they are the cumulative result of the inevitable changes that occur as you expand and modify your system or change your crop production objectives. Eventually you have to go back and re-evaluate the complete system and make modifications or improvements to bring things back in line. This process can be so difficult (and expensive) that many growers end up living with very poor systems that are costing them a lot of money because they just can't see a reasonable way out.

So, how can we get you "unstuck" and on your way to a properly engineered system? We will look at the major design and operating issues growers must evaluate in order to achieve an efficient, accurate, flexible, and reliable irrigation system design. Once the correct system is in place, a world of automation possibilities is just a few keystrokes away.

Let's look at automated irrigation system design considerations to explore this issue further. Automated irrigation systems can be broken down into several parts:

1. **Application systems** to apply water to the crop: sprinkler, drip, and flood systems. Selection considerations include: irrigation uniformity, reliability, greenhouse accessibility, zoning, disease, efficiency, runoff, and last but not least, cost.
2. **Distribution systems** to deliver the correct nutrients, water volume and water pressure to the application system. Design considerations include pipe sizing and routing, filters, pressure regulators, valves and pumps.
3. **Nutrient injection systems** to produce the correct nutritional balance for the crop. Considerations include differing crop feed requirements, residual volumes left in shared distribution lines, accuracy, and safety.
4. **Automated** irrigation decisions based on:
    a. Predetermined intervals
    b. Crop models
    c. Direct sensor measurements.

Each of these parts requires that the steps above it work properly. You can't automate a watering wand; and your sprinklers won't water your crop properly if the delivered water volume, feed type or pressure is too low.

Water and nutrient management provide some of the most powerful (and potentially dangerous) tools you can wield to influence crop quality, timing, yield, and robustness. In short, "The man with the hose grows the rose."

Let's start with the crop. Answer the following questions for each crop you produce:

- What does it need, when and where does it need it? How do you know this?
- What sort of application uniformity is required for optimum crop growth and management?
- Timeliness – how long can the crop reasonably wait between the time you decide to water it and the time it actually gets watered?
- Cycle time – what is the shortest watering interval for each crop?
- What constraints are you forced to work with (disease spread, limited water sources, water quality, preferred water delivery methods)?

For example: You may have a 'plug' crop that needs highly uniform, short, frequent overhead irrigations. Furthermore, you need to provide a balanced nutrient formula with every watering. Under high light conditions you may need to complete crop watering within thirty minutes of first deciding to water, or risk crop stress and damage. This crop example presents a very different profile than that presented by a small shrub in a five-gallon container, which may only need water every few days. Obviously, you have many more irrigation system options available in the latter case, and you don't have to be nearly as 'timely' in your irrigation response. You can install a much simpler and less expensive irrigation system without compromising your crop.

Now that you have defined your individual crop requirements you can combine them to determine how you might manage a complete irrigation system. You must serve two masters here. You want to simplify the irrigation system design as much as possible to reduce initial cost and simplify daily management and system maintenance, but you must always remember to properly meet the needs of the plant. So, how do you do this? Lets look at some considerations:

First, let's simplify our irrigation system requirements:

Reduce the number of irrigation zones (valves) to as few as you reasonably can, without running into conflict with the crop requirements identified previously. You certainly don't want to pay your control system provider or irrigation equipment supplier any more money than you have to, and supplying, installing, and controlling individual irrigation valves costs money! Try to plan your crop layouts to allow you to irrigate large blocks of similar or identical material at the same time, while minimizing the chance of irrigating empty sections.

Irrigation also has a big impact on climate temperature, humidity, and general plant stress, so you really want to try to closely align your crop types and irrigation zoning with your climate zoning.

Irrigation systems that use fewer irrigation valves tend to be less expensive to install, manage, and maintain. Obviously, at some point you have to break up large irrigation zones into several smaller irrigation valves if the flow and pressure requirements of a single large irrigation valve exceed the total delivery capacity of your irrigation system. Sometimes you trade off the cost of supplying and managing additional valves against the cost of a larger capacity irrigation system.

Next, let's look at irrigation system flow and pressure requirements:

Water pressure and flow rate requirements are usually defined for the specific application devices you are using: dripper, sprinkler or spray head, flood bench filler, etc. Work these requirements back to the zone level by multiplying the single delivery device ratings by the number of devices you wish to include in one irrigation 'valve' zone. Make allowance for pressure losses in the distribution lines within each zone, through the control valve, and through any pressure regulating valves or filters installed at the zone level. This will give you the required flow rate and pressure at the zone level.

Now that you have determined the size, location, and total number of valves, how do you calculate the total flow requirements for your irrigation system?

Given sufficient time, an irrigation system can easily supply the water needed by one irrigation zone, but if the system is supplying many zones, it might take too long to service all zones before it needs to return to the first zone for the next watering. If this happens, the irrigation system will gradually fall behind during peak water demand times and your crops may experience water stress. To see if this is a problem for your system design, divide the total water requirement for one water cycle (gallons or liters required to provide one irrigation for each of the valves on the system) by the maximum allowable completion time for one irrigation cycle. The result is the *minimum* continuous system flow rate required.

a) If this calculated minimum system flow rate is *less* than the flow rate required by the largest capacity valve on the system, simply design the distribution supply system to meet the largest valve capacity requirements and it will have more than enough capacity to service the other, smaller valves.
b) If the calculated minimum system flow rate is *more* than the flow rate of the individual valves, you will have to do one of three things:
   i) Divide this system into several smaller, independent systems, each servicing fewer valves so they can keep up to the delivery requirements, or
   ii) Design the system to supply two or more valves at one time, or
   iii) Go back and reevaluate the valve zone engineering and increase the water delivery rate for the individual valves so we can shorten the time required to complete each watering and thus complete a watering cycle within the maximum time allowed.

The water cycle time should be sufficiently short so that we can reasonably service any irrigation valve within a safe time (after it 'requests' water). To be really safe, you might think about worst-case scenarios like how quickly do you need to be able to get around to your irrigation zones if they *all* decide they need water when the sun comes out? Or, you might want to consider: what happens if I have a pump failure that takes a few hours to repair. How quickly can I catch up? As a general rule, it is wise to design your system to deliver a minimum of 10% - 20% more water than calculated to allow for changes to irrigation management objectives, small design calculation errors or degradation of system performance as it ages and accumulates dirt. Pumps operating at partial loads do not consume as much electricity as when at full load; so modest over sizing does not have a negative impact on operating costs. Your pump vendor should be able to help you select the most efficient pump for your application once you tell him your operating pressure and flow range requirements.

Now that we know our water delivery flow rates, we can calculate the distribution system pressure drops *at these flow rates* so we can properly specify and size the supply pump and piping. *You must meet these flow and pressure requirements.* Under-supply will result in poor water distribution and uneven watering – a disaster for many crops.

Work the valve zone requirements back through supply piping branches to main lines and finally to the main irrigation supply points. Calculate the pressure drop across each of these irrigation system components. Your irrigation component suppliers should be able to help you with these calculations. The main irrigation supply must be able to deliver the required volume at the total pressure calculated by summing all component pressure drops at the required flow rate.

At each step of the way, you must make sure that the irrigation system components you select meet the minimum requirements of all downstream components, under all operating conditions. If your system is designed to service more than one valve at a time, your calculations must be based on the combined flow.

Undersized piping will result in significantly higher-pressure losses across your system, requiring higher-pressure supply pumps and piping with higher capital and operating costs. *Seriously consider increasing your irrigation system distribution line sizes to keep system pressures low.*

Whenever you insert additional or special components into your irrigation distribution system, you must recalculate the supply pressure requirements by including these components in your evaluation. Examples include filters, strainers, elbows, and pressure regulating valves. You must use realistic estimates for pressure drop, including worst-case filter loading. Service intervals and filter condition warnings should be considered as part of this evaluation. Invariably these components are added to improve the uniformity and reliability of the complete system. Sure, you can save on some pump pressure if you don't use filters, but if you are constantly plugging up the final delivery devices (drippers for example) you have once again failed to meet the needs of your crop. Your crop does not care what your problems are, it only cares about its immediate conditions.

Engineering your water delivery systems is pretty straightforward once you know your individual zone and sustained delivery demands. You also need to trade off between system performance, flexibility, service, life, and cost. This is not so easy: Carefully evaluate available system components and make your selections based on cost, availability, quality, reliability and general suitability for your application. There are many different ways to achieve the same final result.

Laws to consider:

1 Pressure drop climbs to the second power of flow rate. Increasing the system pressure to 'squeeze' more water out of an undersized pipe is a fool's game. Doubling water flow rates in an existing system increases pressure drop by four times!

2 Irrigation system operating, maintenance, and construction problems increase to the second power of pressure. Double the system pressure and your problems may increase four-fold (wear, water hammer, broken joints etc).

3 Energy costs go up linearly with pressure. Double the system pressure and you double pumping costs.

So, do yourself a favor: *Be generous with your irrigation pipe sizing*. Minimize pressure drops between the pump and the delivery device. A generously sized system comes with the added bonus that you have the option of squeezing a *little* more volume out of the system through modest pressure increases, should you decide on some unplanned expansion in the future.

Other Design Considerations:

Design your irrigation distribution system to include provisions for easy system expansion in future. Do this by determining where a future main line connection could be made from a much larger supply to allow this system to run as a branch of a much larger system. If you have a good idea what future expansion might require, it is sometimes cheaper to size some of the more critical or hard to change components to satisfy the projected future needs:

1. A pipe running under a road could be oversized so that you don't need to dig the road up later.
2. An irrigation pump could be sized with a larger volute and motor, suitable for the projected future flow, but perhaps installed with a smaller impellor and/or operated at the lower end of it's volume range to match current needs. A simple impellor upgrade would extend capacity if it is needed in the future.
3. A system could be laid out as an end-feed system now, and site expansion could involve nothing more than mirroring the layout in one direction to double the size and perhaps mirroring it again to double system size again, by adding a relatively small length of larger diameter central connecting manifold.

Avoid complex designs that have multiple connections to irrigation water supplies or multiple paths between the water supply and the zones. These systems become almost impossible to design or manage efficiently because of the difficulty determining pressure drops and delivery volumes. These systems are even harder to modify later, and make central nutrient feed management and other advanced control functions practically impossible.

Irrigation system retrofits can be completed much as heart bypass surgery is done – you don't throw out the whole vascular system, you just replace or bypass the most restrictive components. Use the process described above to determine what you really need (zone and sustained system flow rates and pressures) then test each of your existing irrigation system components to see if they are capable of satisfying this requirement. If not, identify them as limiting components and either replace them with upgraded components that meet the requirement or go back, re-evaluate, and possibly redefine some of your original conditions to reduce loads below the existing capacity restrictions.

So, we are pretty proud of ourselves. We have designed or upgraded a complete irrigation system that fully meets the specified irrigation needs of the crop. Not so fast, we are not done yet! Let's look at nutrient feed issues.

Part II: Nutrient injection

Most greenhouse crops require liquid feed programs. You will have to match an injection or feed system to the engineered irrigation system requirements (pressure and flow rates). The injection system must be able to handle the full range of flow rates required by the irrigation system. Most greenhouse growers keep it simple and use ratio-metric injectors, feeding a fixed formula and solution strength to all crops on the irrigation system. This works fine for some short-term crops but is not usually sufficient for longer-term crops that require better management of the total nutritional balance. The fertilizer injection system can become quite complex if multiple stock solutions and acid or base addition is required to serve these crop needs.

Feed Multiplexing Issues – Line Volumes and Purging

At the top end of the complexity scale, you can use computerized feed management that selects both the composition and concentration of feeds for each crop serviced by the irrigation system. This might seem like a great idea (and it is!), but you must be very careful about irrigation system piping layouts, because the residual volume of old feed in the shared irrigation supply lines between the fertilizer injector and the crop irrigation valves can be considerable, effectively delaying the delivery of new feed by many minutes after the change is made at the fertilizer injector. In some cases, this delay can be greater than the length of a zone watering, meaning that the zone may only receive the 'old' feed and never the new feed intended for it!

Other than the obvious recommendation that you must minimize shared supply line volume, resolving these issues is beyond the scope of this document. Consult with your control system contractor to develop effective solutions for your specific problems. *For most growers, simple, single feed systems will suffice.*

Finally! We have a complete properly engineered system that can supply the correct liquid feed at the correct times, correct flow rate, and correct pressure for each irrigation valve on the irrigation system.

Now let's see if we can control it!

Part III: Automated Irrigation Decisions

What are we trying to do? Most growers would respond with: "Replace evapo-transpiration water losses in my crop", but this is by no means the only consideration. Good management of evapo-transpiration water replacement can also accomplish the following:

1. Deliver feed to the plant
2. Regulate crop growth through 'drought stress'
3. Leach salts from the growing media
4. Reduce water runoff.

But it will not address the following:

1. Deliver pesticides or fungicides
2. Wet things down (high temperature; frost protection)
3. Prepare plants for shipping – moist but not wet.

A grower can manually manage all these requirements and many more. Not only will a good grower evaluate the water needs of the crop, but they will also check root health, look for insect and disease problems, evaluate crop progress and quality, monitor and manage crop labor, while they're doing the rounds through the crop production areas. These other requirements will not go away if we automate the irrigation decision process, but it would be nice if we can free up more time for the grower to manage these other needs. Besides, growers are human, and often not able to make watering decisions when they need to be made because of competing demands for their time.

So, lets look at automating the decision process with the twin objectives of decreased labor and increased watering efficiency and accuracy. Before we do this, we need to consider the effect that variability has on our system. There is little point in closely managing water application if crop production system variability is large. We need to minimize production variations, and then ensure the automated watering decisions are sufficiently accurate to support the production system. There is little point in creating the perfect watering model, accurate to +/- 5% if you have +/- 30% variability in your crop production system. You will simply be wasting your time, since you must grossly over water most of your crop to satisfy the needs of the driest plants.

Production System Variations:

Variation is the enemy of automation. Most economical automated systems require highly uniform conditions to perform well, if at all. In greenhouse production, we have three major contributors to variation and each must be well controlled to keep the overall system sufficiently uniform for irrigation automation. Luckily, crop uniformity is also a marketing objective, so a frequent side benefit of automated production systems is improved marketability.

- **Crop -** The crop must be uniform in type, size, and development so that all plants in an irrigation zone each consume roughly the same amount of water. Variations of +/- 10% are typical for highly uniform crops.
- **Environment -** Water loss is, in large, partly a function of the immediate plant environment. Shade spots, cool corners or ends, localized drying caused by HAF fans, heaters or edges of benches, uneven pot spacing, uneven pot soil fill or uneven soil mix – all have large impacts on water needs. Growers must go to great lengths to minimize these effects. Total variations of +/- 20% are typical for highly uniform production systems.
- **Irrigation delivery -** Each plant must receive the same amount of water as all the others. Variations in dripper delivery or sprinkler pattern unevenness can easily account for +/-10% or more in variation.

These uncertainties interact with each other, one often mitigating another, so that total production variability may be only 20% in a good production system (although, on an unlucky day it could be the total of all variations!). For example, a naturally larger plant may find itself more water stressed than its smaller neighbors, naturally slowing its growth down while they catch up. If we achieve good production uniformity, we can manage our crops a little closer to the 'edge' to reduce water and nutrient waste.

Sub-irrigation can eliminate application delivery errors, so it is, in theory, the most accurate and least wasteful irrigation water delivery system, but high initial cost, diseases, salt buildup, and nutrient imbalances make sub-irrigation impractical for many crops.

Now that we have reduced production system variability to reasonable minimums, let's automate the irrigation decision process.

Replacing Evapo-Transpiration Losses:

We have three approaches to irrigation decisions:

1 Manual decisions

2 Ask the plant

3 Create a plant model

Manual Decisions

It may seem strange to go to all the work of developing a properly engineered irrigation and feed delivery system, only to run it manually when you have finished, but remember the saying "it's the plant, stupid!" There are many reasons for watering a crop that are not easily defined in crop models or measured by sensors. The grower is still the best arbiter in these situations. At least the properly engineered irrigation system automatically and accurately services your irrigation decisions – a great labor saving as compared to manual water delivery (hose) or manual irrigation valve operation.

The vast bulk of plant watering decisions can be fully automated. Many growers have successfully used these strategies for decades. Even (or especially) delicate watering decisions like mist propagation of soft cuttings can easily be modeled to produce results much superior to the best manual or time clock based control systems. Let's look at some of these strategies:

Ask the Plant

Ask the plant how much water it is using. This may seem kind of obvious, but you can ask the plant and it will tell you the precise answer to your question. The trick is to ask the right plant(s) the right questions; and make sure the result is something you can rely on. This is the strategy you use when you walk through your crop, lifting pots to assess weight, looking for wilted plants or knocking plants out of pots to assess soil column moisture levels as part of the information gathering you do before you make your watering decisions manually. The plant is always calculating the amount of water it needs and actively drawing this water from its environment. All we need are some sensors to measure the result of this water uptake and we are in business.

How do we ask the plant about its water needs? There are a few simple practical measurement systems that produce good reproducible results suitable for irrigation system control. There are many other moisture measurement techniques that may be more accurate, but they are best left to the research people for reasons of cost or sensor reliability.

1) Soil moisture measurements:

a) **Soil Conductivity.** There is a good correlation between soil conductivity and soil moisture content in most greenhouse crops. Salt buildup will affect the absolute conductivity reading, but the relative reading changes greatly between wet and dry, giving lots of range over which to set water trigger thresholds. Sensors can be relatively inexpensive and do not require routine maintenance.

b) **Soil Capacitance.** Similar to soil conductivity.

c) **Soil Tensiometer.** Measures the water 'tension' in the soil directly. This method of measurement gives a good approximation of the water extraction difficulty experienced by the plant and can be used as a threshold for watering. Tensiometers are not directly affected by salt content, providing constant readings over a range of salt contents. Tensiometers require some routine maintenance.

d) Other sensors:

(a) **Weight**. You can weigh one plant or an entire bench. Short-term weight changes are almost entirely due to changes in soil moisture (unless you sell the plant or harvest the tomatoes!). Longer term, the weight of the crop will change with plant growth, but this weight change is usually small and can be compensated when you routinely adjust your watering thresholds for other reasons.

(b) **Leach volume.** Crops can be watered until sufficient leach or drain volume is produced to ensure good irrigation management. This strategy does not tell you when to water, but it does tell you how much to water. You may have to use the leach volume from the previous watering to manage the current watering because of the time delay between water application and final drain down.

The Problem with Asking the Plant

Devising a measurement system is relatively easy, but we must also ensure the selected plant(s) are representative of the whole crop, and we must make sure the measurement system is reliable. To be safe, we should sample several different plants, each with its own sensors. This strategy will reduce measurement or sampling errors, however it will increase monitoring cost and complexity, since each irrigation decision group will require several sensors. If it is impractical to measure several plants, you might still use just one plant, but keep the measurement system under careful human supervision to ensure it is working properly. This supervision does not have to be as skilled, because they are just monitoring the measurement system for obvious, easily identified failures, rather than the nuances that must be considered in the actual decision-making process.

Model the Plant

In an attempt to improve decision reliability and reduce cost, many growers resort to crop models. Even though the model is almost always going to produce an inferior result as compared to a well-instrumented plant, the result may be more than good enough for real world growing conditions because production system variability is usually worse than the results from a good crop model. Most commercial growers value simplicity and reliability in their automation systems and will make small adjustments to correct for model errors as a part of their routine crop management – something they must do anyway, regardless of the automation strategy.

Models can be extended to predict water requirements over the life of a crop. For example, misting programs can automatically and continuously adjust misting response as cuttings callous and root. The grower need only adjust the 'alignment' between actual crop development and the model stage. For many crops, this alignment is either unnecessary ('close enough is good enough'), or only needs to be done every few days.

Major model factors that affect water usage:

a) Radiation energy (drives everything)
a) Temperature
b) Humidity
c) Wind (boundary layer; air exchange)
d) Plant size (leaf area index)
e) Plant shape (sun vs. shade leaves)
f) Plant spacing.

Light-Sum Based Models

Radiation energy (solar, lamps) can often account for 80% or more of crop water usage. This accuracy is entirely adequate for most crops and production systems where internal production variability is usually greater.

Plants use only a very small portion of the total radiant energy they receive for growth, while the large majority of unused energy must be rejected to keep the plant cool. Some radiant energy is reflected before it enters the plant, but this reflection ratio will remain fairly constant for most light conditions. Healthy plant leaves are usually within a couple of degrees of ambient air temperatures, leaving little driving force for radiant or convective heat loss, so the bulk of cooling is produced by the evaporation of water (transpiration). This correlation between radiation and water transpiration is the basis for all 'light-sum' watering models. More advanced light-sum models have many options for fine-tuning response during very dark weather or at night when radiation is a poor predictor of water usage. Some models allow the grower to change irrigation response based on the time of day to compensate for increased afternoon plant stress or to increase osmotic pressure in the early evening to reduce plant stretch or guttation overnight, to cite two examples.

Light sensors are very reliable, and it is quite easy to confirm proper sensor operation. Most importantly, *a single light sensor can be used as the basis for many simultaneous crop models*, since local differences in light transmission or shading tend to remain consistent. Compare this to the cost of placing one or more soil sensors in each separately managed watering zone! Since a grower setting must be entered into the model to indicate the desired watering point, local shading effects (differences between the global light sensor and the local light level in the crop) can be corrected with this single setting, along with the effects of plant size, spacing, and type. It is hard to screw up your model when you only have one setting to play with!

VPD Based Models

Most of the other environmental factors can be pulled into a more complex model such as Vapor Pressure Deficit (VPD), which in effect estimates crop water loss based on the moisture content and the temperature of the air at the leaf surfaces. This model relies on expensive and less reliable humidity sensors, and really needs a separate sensor at each separately managed irrigation zone for best results. Some of the model variables (wind speed) are assumed to be constant, and just like with the radiation model, a setting made by the grower adjusts the model for the effects of plant size, spacing, and type. Many plants contain a mixture of shade and sun leaves; old and new leaves and may also vary in the total leaf area or spacing. A true VPD model will produce a different result for each leaf due to microclimate differences, and different leaves will respond differently to the local VPD. In practice, it is not possible to create or manage true VPD models for most crops. Simple, whole plant VPD models are best suited to specialty crops like propagation where all leaves are similar in type and exposure.

The Problem with Models

1. All models are incomplete. To the extent they are incomplete, the model results will deviate from actual water usage. More complete (and accurate) models can be developed, but they rapidly become unusable in commercial situations because they become impossible to tune correctly. If your model is not producing the desired results and you have 5 variables to play with in the model, which one(s) should you change, and by how much? Change the wrong variable, and your model becomes even less accurate, not more.
2. All models rely on sensor information. Failures or errors in sensor inputs will produce bad model results. Garbage in: Garbage out.
3. A model failure will result in improperly watered plants, just like any other failure. While complex models make small improvements to the theoretical accuracy, they greatly increase the risk of catastrophic failure and incorrect watering. Is it worth the risk?
4. A robust but less accurate model may be better since you need to evaluate your crop every few days (at the least) and might as well apply corrections to your simple model as a part of your overall crop evaluation

process. You usually need to make setting changes anyway to direct crop development, so you might as well incorporate corrections (more, less) into the same process.

Automation Conclusions:

1. Crop models can be reliable, inexpensive, and flexible, but they cannot respond directly to the crop. VPD and other environment models are not always a very good predictor of actual crop water usage.
2. Direct or indirect moisture sensors respond directly to the crop or crop environment, but only see the plant they are looking at, not all the other plants in your crop. Selecting and maintaining the representative "talking plant" is critical.
3. Manual decisions are still the most accurate, if you can only chain an attentive grower to the greenhouse! You should still consider manual decisions at critical cropping times or for special objectives not easily served by water use measurement or model systems.

In our opinion, the most robust strategy for automated irrigation decision-making is a combination of plant measurement and crop modeling. Here is how it works:

1. Set up a good, simple, crop model and get it adjusted to your crop. Run your irrigation based on the results of this model.
2. Set up a single plant monitoring sensor and use the information it collects to:
   a) Trigger management alarms
   b) Feed into historical records for future reference
   c) Possibly generate 'emergency' waterings if measured results are extreme (along with high priority alarms, of course!).
3. Use the information collected by this sensor to improve your understanding of what is happening in your crop. Apply your improved understanding when you make adjustments to the primary control model. At least some of this understanding can be applied to many other independently operating crop models, as long as they are for related or similar crops. Obviously, information collected from a water lily may not be much use to the cactus growing in the next greenhouse!

The worst thing about automation is that it tends to breed complacency! Just because you have automated your watering schedules doesn't mean you can ignore the crop! Pumps can fail, pipes can break, wrong settings can be entered, and sensors can become dislodged. Computers are very faithful, and they never forget. This means that they will faithfully kill your crop with too much or too little water if they are set improperly. You may not be carrying around a hose all day, but you still have to be out there to make sure the job is getting done properly.

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