Steering crops in high-tech controlled environment agriculture:

actionable strategies to achieve predictable, high-quality results with stone wool

Steerable



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Steerability is the keyword when it comes to precision growing. But how can growers leverage stone wool growing media and real-time data to gain unparalleled control over plant development? And which metrics are most important to monitor? In this second whitepaper in our series, Grodan's Jos Beerens (Senior Crop Technical Specialist) and Marielle Taft (Head of Crop Advice North America) dive deeper into measuring and steering based on WC%, EC and nutrient supply when using stone wool.

Crop steering based on WC% and EC values

Based on extensive scientific research and practical field trials, Grodan has developed crop-specific phase models providing growers with basic steering guidelines for their particular crop. For each crop type, the model outlines which impulses (vegetative or generative) the grower should send to the plants in order to get the best results in each phase of development: from rooting-in to flowering, fruit development and ripening.

In the root zone, the key steering parameters are the water content percentage (WC%) in the substrate – which can be influenced by the irrigation flow rate, volume, timing, frequency and overnight decrease in WC% – and the electrical conductivity (EC), which is influenced by the fertiliser concentration. Moreover, changes in slab temperature can have an influence on root development and activity (see Table 1).

Table 1. Crop steering irrigation strategy. Timing and EC differences.

Irrigation Start and Stop Times		
Start	0-1 hr after sunrise/lights-on	Vegetative
Start	1-2 hr after sunrise/lights-on	Neutral
Start	2-4 hr after sunrise/lights-on	Generative
Stop	0-2 hr before sunset/lights-off	Vegetative
Stop	2-3 hr before sunset/lights-off	Neutral
Stop	3-4 hr before sunset/lights-off	Generative
	Vegetative	Generative
EC	Lower	Higher
Water Content	Higher	Lower
Overnight decrease in WC	Smaller	Larger

General rule of thumb for crop steering in the root zone:

- For **vegetative steering:** smaller irrigation volumes at a higher frequency ➔ increase the WC% day level and/or decrease the EC in the substrate
- For **generative steering:** larger irrigation volumes at a lower frequency ➔ decrease the WC% day level and/or increase the EC in the substrate

The most important influences are the overnight decrease in WC%, and the frequency and volume of shots given in conjunction with the sustained substrate EC. "This is the case regardless of the crop phase. What differs per phase is what kind of energy allocation the grower tells the plant to favor and which root zone and climate scenarios need to be carefully avoided," states Marielle Taft. "The grower also needs to take into account the impact of the outside climate and seasonal patterns, and adapt their irrigation strategy to avoid creating unnecessary stress."

Using crop-differentiated phase models, growers can ensure they are on track to achieve the desired crop steering goals (i.e. vegetative or generative development) in the relevant growth phase by monitoring a number of key performance indicators (KPIs). If the data shows deviations from the desired situation stipulated in the Grodan phase models, the grower can then take corrective action quickly by adjusting the irrigation strategy.

"Higher-frequency irrigation with smaller overnight decrease in WC% generally has a vegetative effect. Therefore, the stop time at the end of the day is a major factor affecting crop production. If a grower stops too late, there will be insufficient overnight decrease in WC%, leading to a high WC% which fosters vegetativeness rather than generativity – and this will be undesirable in the flowering/fruiting stage," says Jos Beerens. "Insufficient overnight decrease in WC% also makes the roots more vulnerable to diseases, potentially weakening the plant and damaging the crop performance."

"The EC level is an important parameter to monitor because it impacts crop function on so many levels," comments Taft. "When steering generatively, for example, a large overnight decrease in WC% alone will not automatically lead to healthy, balanced generative growth if the EC is out of control. EC levels have to be looked at closely in conjunction with WC% due to the interdependence of pore water salinity and the plant's ability to take up water. A lot of growers focus heavily on overnight decrease in WC%, without considering EC refreshment and the risks of osmotic stress. So WC% and EC really work in tandem in terms of their ability to steer a crop vegetatively or generatively."



Critical root zone KPIs include:

- Start/stop irrigation time
- Average daytime WC% / peak daytime WC%
- Stabilised substrate EC during the day after drain
- Overnight decrease in WC%
- Inter-irrigation overnight decrease in WC% in the P2 phase (the overnight decrease in WC% between events)
- Moment of first drain
- Slab temperature

These KPIs can be influenced by irrigation timing, frequency and volume, and the nutrient profile.

Discover how **GroSens Suite** supports data-driven crop steering.

Why is it important to monitor and visualise this data?

Accurate root zone data allows growers to adapt their irrigation strategy to steer the crop in the desired direction. Information about changes in WC% and EC can also indicate the need to adjust the climate setpoints. "For example, an insufficient overnight decrease in the WC% may indicate that the nighttime humidity is too high for the plant to take up the water. These two parameters are therefore key values for both irrigation-driven and climate-driven steering," explains Beerens.

Besides being important for crop steering, root zone data also helps growers to monitor plant health and resilience. "If the root zone conditions are not managed proactively, growers not only risk tactical issues with plant development and fruit quality, but also suboptimal conditions in the substrate – such as low oxygen availability or high salinity – that make plants more susceptible to pathogens," says Taft.

"Another valuable aspect of gathering this data is to build up a record of what happened throughout the entire crop cycle. That way, if any issues such as fruit cracking or necrosis occur, it's easier to pinpoint the causes of those issues in order to avoid them in the future," she continues.

Pushing the boundaries of irrigation-based steering

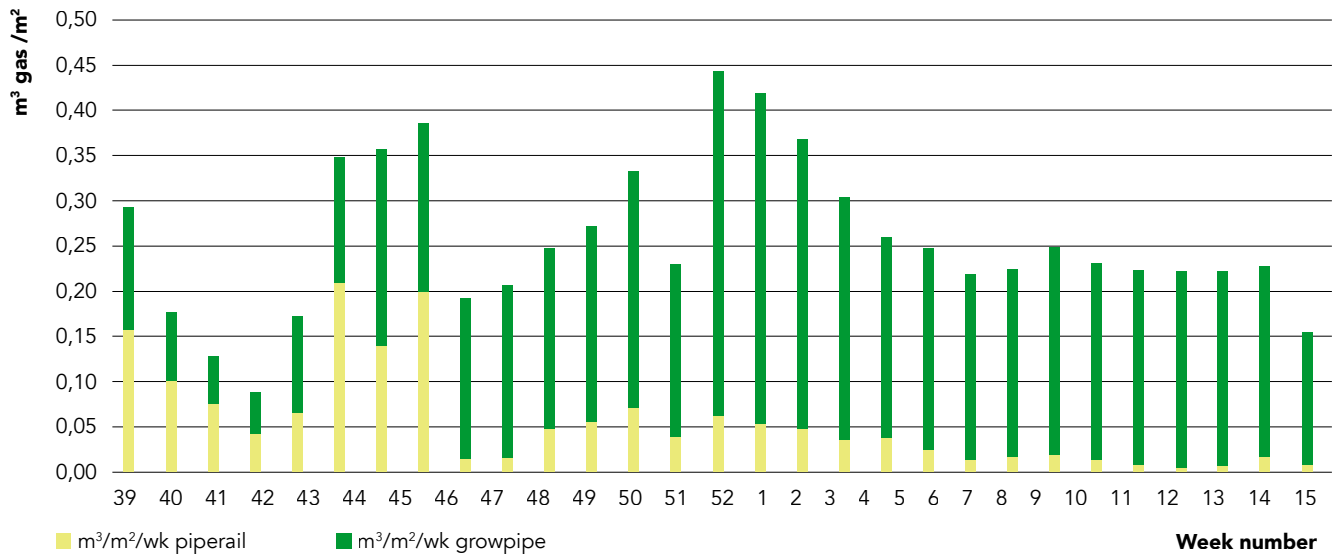
Besides publishing crop-specific guidelines, Grodan conducts scientific research trials to push the boundaries of irrigation-based steering in practice. One example is the low-energy tomato trial at Botany Research Centre. "As many growers are switching to LED lighting, which produce less heat than HPS lamps, managing humidity without increasing the heating costs has become a bigger challenge. Together with Signify and Botany, we explored how irrigation can provide a solution," explains Taft.

"Our aim was to avoid creating humidity – because ventilating the excessive humidity in the winter actually costs much more in terms of energy loss than providing additional heating," says Beerens. "So we only irrigated the crop with what it needed based on the climate conditions, rather than oversupplying water and then having to remove the excess." To avoid ventilation, the team installed an active air dehumidification unit. The results show a 56% saving on gas compared to the traditional approach (see Graph 1).

"This trial illustrates that precision growing on stone wool makes it possible to utilise the irrigation strategy as a way of minimising unnecessary transpiration and therefore reducing the energy consumption in a greenhouse. It has also sharpened the focus on drain and provided the basis for further discussion about when the first drain moment should occur – or whether it's even necessary at all on some days," states Beerens.



Graph 1. Heat consumption in m^3 gas /m^2/week from pipe rail and grow pipe*



*Low energy tomato trial 2024-2025 (Grodan & Philips Horticulture LED Solutions)

Tips for implementing irrigation-based steering in practice

Know your system

Consider the volume of the substrate in the context of the existing irrigation system. Different substrate configurations require different dripper capacities (e.g. 1.2-4 litres per hour), different dripper quantities and thoughtful dripper positioning throughout the slab. In some substrate types, for instance, it will be more difficult to refresh the entire substrate if drippers are spaced too far apart.

The irrigation volume is calculated as a percentage of the substrate volume per dripper.

Definitions of irrigation volumes

- **Small** = 2% of the substrate volume per dripper. Focus: maximum re-saturation of WC% until drain and/or decreasing drain percentage in the afternoon
- **Standard** = 3% of the substrate volume. Focus: stable and uniform growth and root zone conditions.
- **Large** = 4-6% of the substrate volume. Focus: minimum re-saturation of WC% until drain and/or refreshment, decrease of slab EC.

Have a goal-based plan, but stay flexible about the timing

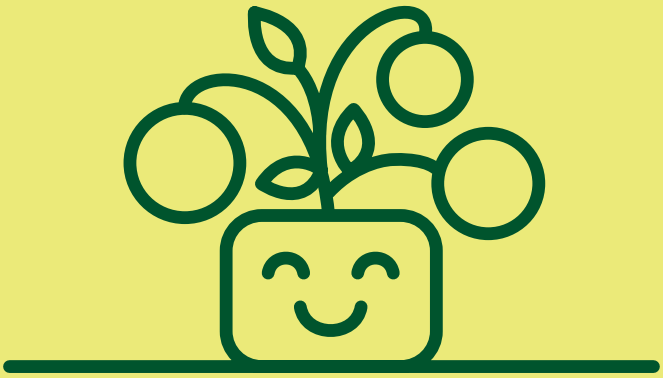
A daily plan such as Grodan's Day Dynamic provides an essential guideline for the general direction of steering. But to optimally support the development of both the plant and its root zone, it is also important to think critically and adjust the irrigation strategy according to external influences.

> "This may require growers to adopt vegetative-generative steering to avoid extremes"

If it's a cloudy or damp day outside, for example, it may make sense to delay the first watering and/or to stop irrigating sooner. Similarly, on a warm sunny day, the plant will require more water for longer due to a higher rate of activity and transpiration. The gift EC should also be taken into account, depending on actual climate and plant activity.

Avoid sending mixed messages to the plant

Even after implementing irrigation-based steering, the greenhouse climate remains a beneficial steering tool. However, growers should take care that the two steering strategies support one another rather than conflicting. "This means making use of the most effective and efficient climate-related, plant-related and root zone-related parameters at each moment to keep the crop in balance. This may require growers to adopt vegetative-generative steering to avoid extremes," says Taft.



Document and benchmark the plant response

Steerability not only opens up short-term opportunities for data-driven decision-making, but also forms **the basis for continuous improvement**. It is essential to capture the crop steering strategies that have been implemented and document the plant response, especially if multiple cultivars are simultaneously involved. A detailed record of physical measurements (crop registration data) and general observations of the plant – in conjunction with all the metrics from GroSens and other greenhouse systems – creates an initial baseline. This supports benchmarking to measure progress cycle-by-cycle and year-by-year. **Armed with these insights, growers can fine-tune the steering strategy and also identify the cause of any problems to avoid making the same mistakes twice.**

Make changes gradually

To see whether the strategy is taking effect, don't change too many variables at once. For instance, when implementing irrigation-based steering for the first time, keep the fertiliser recipe the same as before. If the real-time data indicates any potential problems, resist the temptation to over-correct them. Instead, make small, incremental adjustments to advance towards the goal. This not only gives you a clearer overall picture, but also minimises unnecessary stress for the plant.



The future of steerability

Given the ongoing advancements in sensor technology and integration with artificial intelligence (AI), growers can expect to see new opportunities for more automated steerability. One example is precision fertigation. "We are moving ever-closer to automated nutrient recipes that give the plant the perfect balance of every individual element it needs, when it needs it – down to the micromole level. This could make the need to achieve drain truly a thing of the past," explains Taft.

Sensors combined with AI could also enable automated irrigation strategies in the not-too-distant future, Beerens hopes. "Rather than having to keep monitoring the computer data and manually adapting their irrigation approach, growers could one day let the system determine the start/stop times, volumes and frequencies, as well as the EC and fertiliser composition, depending on the crop phase and conditions. With our stone wool growing media and data solutions, crop-specific knowledge and existing phase models, we can provide valuable input for such technological developments."

Other high-tech possibilities linked to steerability include things like predictive yield and plant stress models, supported by readings from the GroSens sensors. "Based on monitoring and analysis of how particular actions will impact plant development, we could generate extremely accurate and precise yield predictions, making it easier and more efficient for growers to plan their labour requirements, harvesting, cold storage and sales activities, and reach better agreements with customers," comments Beerens.

"I am particularly excited about future advancements in digital twins for greenhouse environments, using sensors, vision cameras and predictive models to map the climate," says Taft. "They could give growers considerably more foresight into pockets of variation within the greenhouse that could require extra attention from an irrigation perspective, whether due to more or less heat, sunlight, ventilation or pest pressure."

"Although Grodan is a stone wool specialist, the root zone is such an essential part of crop success that we're always thinking about our products and solutions within the greater context of agronomic innovation. So even if an advancement doesn't seem directly related to the substrate, we make it a priority to understand how it relates to us. That holistic approach is the basis of Grodan's continued imperative to develop and disseminate new and relevant knowledge direct to growers. We're here to help them take advantage of future advancements in CEA. We started over 50 years ago and plan to continue long into the future" concludes Taft.

Learn more

Read the first whitepaper to learn what steerability means exactly, and how stone wool supports improved yield, quality, resource efficiency and sustainability. Every crop steering strategy depends on timely, reliable insight. **Connect with Grodan** to explore how GroSens Suite can help you monitor, interpret, and act on root zone data.

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Designed to grow

Grodan is the global leader in supplying soilless rootzone management solutions for Controlled Environment Agriculture. These solutions are applied to the cultivation of vegetables, medicinal crops and flowers such as tomatoes, cucumbers, sweet peppers, eggplants, roses and gerberas.

At Grodan, we aim to help feed and treat the world's growing population by innovating solutions from our stone wool growing media to enable 'more-with-less' growing. Through the method known as out-of-soil, our stone wool substrates, sensor systems, software and expertise support the reliable, informed growing of healthy, fresh, high quality produce. Our material is 100% recyclable, and supports growing methods that use up to 50% less water, 20% less chemical plant protection products and 75% less land. Sustainability plays a prominent role within Grodan, from manufacturing stone wool substrates to recycling solutions and services.

Grodan has more than 50 years of cultivation experience. We pioneered the development of hydroponic growing methods in the 1960s, and today, our soilless rootzone management solutions are used in large-scale commercial greenhouses and indoor facilities in over 70 countries across the globe. The head office is located in Roermond, the Netherlands.

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