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Innovative Trends in Irrigation Technology: Enhancing Efficiency in Container Nurseries

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Summary

This paper examines the shift from traditional timer-based irrigation to data-driven, precision irrigation systems that use real-time data such as evapotranspiration (ET) models and leaching fraction measurements to optimize water and resource use. Canopy www.CanopyGrow.Tech is a company focused on revolutionizing irrigation with advanced software and hardware solutions. Examples include Saunders Brothers Nursery's 43% reduction in water use and 33% decrease in fertilizer within their first year, as well as Holden Nursery's 50% water savings with improved plant health. These nursery irrigation practices - underscore how a focus on crop quality, paired with automation and real-time data integration, can enhance operational efficiency, reduce waste, and elevate crop outcomes—leading to more sustainable and profitable practices for nurseries.

INTRODUCTION

This paper includes innovative trends in irrigation technology and processes related to irrigation - and how one can leverage them to maintain perfectly watered plants, while making employees' jobs easier.

I grew up in the family nursery business at Saunders Brothers. After earning a mechanical engineering degree from Virginia Tech and returning to the farm, I assisted with implementing their current irrigation system. This experience ultimately led to my current project at Canopy, and I am excited to share these insights with you. Saunders Brothers' irrigation approach includes utilizing leaching fraction measurements (Owen et al., 2019), evapotranspiration-based irrigation, automation, and infrastructure investments

Why irrigation matters

To set the stage, consider the quote from Hunter et al. (2010) that "Without question, irrigation provides the life-blood of pot (container) plant production. Compared to in-ground culture the relatively small amount of available water in a pot quickly becomes a major limitiing factor to growth unless the water status is regularly reinstated. With the exception of sub-irrigation, all overhead application systems either apply too little or too much simply because no instrument can provide accurate needs-based information on total pot water deficit." (M. Hunter et al. 2010).

This captures the essence of why irrigation is critical, especially in container nurseries where precise water management can drastically impact plant health and resource efficiency. Additionally, it highlights the challenge that exists when it comes to precisely watering with overhead irrigation.

Moving toward smarter irrigation practices

This paper covers what to consider, how insights are improving efficiencies and adding value to nurseries today, and how it starts with a simple idea: smarter, not harder. Traditionally, nurseries have relied on fixed timers to control irrigation, but the "set and forget" method is outdated. Today, real-time data allows systems to make decisions based on weather and plant needs, making nurseries far more efficient.

My goal is to provide insights you can start implementing in your nursery. Let's discuss the kind of data needed and how to make informed irrigation decisions because, imagine trying to bake a cake without knowing the oven temperature. It is complete guesswork. Without the right information, you cannot make the right decisions on how much to water. From a show of hands at the 2024 IPPS Southern Region conference in Tulsa, Oklahoma - about 40% of responders use guesswork – based on the weather or seasoned intuition to determine the run-times for their daily irrigation.

Framework for choosing a modern irrigation system

In deciding what to consider to improve your irrigation system and approach, this quote lays out the criteria quite nicely for a container nursery:

"An irrigation model well-suited for the nursery industry would: (1) use a physiological basis to accurately estimate water use to prevent over- and under-irrigation,

thus conserving water and minimizing leaching, (2) be demand-based, (3) be non-invasive, (4) easily configured to a large number of crops, (5) not increase production time over current irrigation scheduling, and (6) be automated" (Fulcher et al., 2012).

Key components of an optimized irrigation model include:

- *Demand-Based* - accurately estimates water needs using a physiological and demand-based approach.
- *Non-Intrusive and Configurable* - be non-intrusive to the existing operation and easily configurable for a variety of crops.
- *Maintains Production Timelines and is Automated* - maintains production timelines, while leveraging automation for efficiency.

Each component addresses key considerations in creating an irrigation system tailored to nursery needs.

Demand-based irrigation

Firstly, you have to get a handle on your water use and in turn, what each crop needs. No more guessing games. Key considerations include: evapotranspiration, leachate fraction, and real time adjustments.

Evapotranspiration (ET). Accurate Water Use**.** To manage water effectively, nurseries need data on evapotranspiration (ET) rates, which consider factors like temperature, humidity, and other weather conditions. Measured in millimeters, ET tells you how much water is lost from the soil surface through evaporation and through the plants via transpiration, helping you better understand your irrigation needs.

Leaching Fraction - Conserves Water and Minimizes Leaching**.** Leachate is like filling a glass with water until it overflows—the water spilling over is not being used. In a container nursery, this overflow represents the extra water draining out of pots after irrigation. This excess water, along with valuable nutrients, is essentially wasted if not managed properly. Measuring leachate allows growers to see how much water is not being absorbed by plants, helping them adjust irrigation to reduce waste and improve efficiency.

The leaching fraction, on the other hand, quantifies this process. It is calculated as the amount of water that drains out of a container after irrigation, divided by the total water applied. This metric is key to assessing the efficiency of an irrigation system (Saunders, 2024a).

Volume-Based Measure of Leaching Fraction. To measure the volume of water applied, an open container is placed near the plants being irrigated to capture the applied water. Place a similarly sized container (lined with plastic) or a bucket with tight seal under the test plants to make sure that no water enters either the empty or planted container from the sides. One hour after the entire irrigation cycle is completed (e.g., if using cyclic irrigation, wait until the last cycle is complete), measure the volume of the water leached from the planted container and the empty container. From these two measurements, the leaching fraction can be determined. For example, if 1,000 mL of water is applied via irrigation (empty container) and 250mL leaches from the bottom of the planted container – this is a leaching fraction of 0.25 (i.e., 25% of the total volume of water applied was leached from the container) (Stanley et al., 2019).

It is recommended that you maintain a leaching fraction of ~10-15%, but it depends on the crop and is ultimately up to the grower. Additionally, according to AgriFi.AI (2024), reducing water usage also lowers energy costs, while minimizing runoff helps protect aquatic ecosystems. With less water leaching out, the runoff is better managed.

Demand-Based Adjustments. Adjusts in Real-Time. A demand-based system operates dynamically, adjusting in real-time to the plants' evolving needs throughout the growing season and based on weather on a daily basis, rather than adhering to a fixed schedule. This approach minimizes both over- and under-watering, optimizing water usage and promoting plant health. In essence, a demand-based system responds directly to what the plant requires, rather than following a pre-set timer schedule.

Non-intrusive and configurable

Irrigation needs to be configurable. You need to be able to tweak it; set it up to handle a bunch of different crops all with their own quirks and water needs. This might mean setting up different irrigation zones, for example, to give each plant group exactly what it needs. Customization is king when you have so many different plant types.

Maintains production timelines and is automated

So, I am sure you are wondering about the bottom line here: does switching to a more modern system slow down finishing your crops on time? The last thing you want is for a new system to change your entire shipping schedule. The answer is no, not if it's done right. You have to find the balance between innovation and running a smooth operation. Switching to advanced irrigation methods should not delay existing production timelines. If implemented correctly, these systems will keep crop schedules intact and enhance overall productivity for your employees.

Automation - as a labor and cost saver

Labor availability is a constant challenge in nurseries, often leaving little time for getting everything done in time. As one nursery mentioned, they have 20 workers applying plastic to the greenhouses to prepare for winter over a period of weeks. Automation presents a valuable opportunity to streamline these repetitive tasks, improving efficiency and free-up staff for more critical work **(Fig. 1)**.

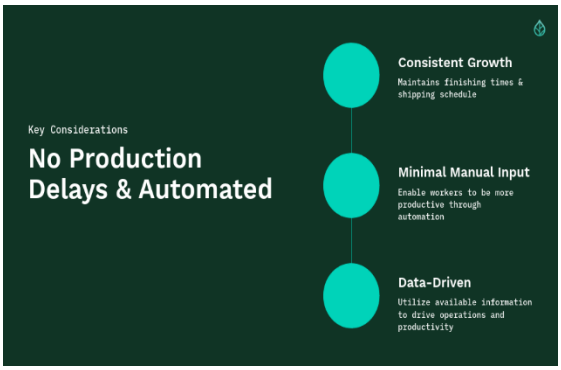

Figure 1. Last set of considerations include maintaining production timelines and being automated.

As noted by Fulcher et al. (2023), "Nursery production is inherently reliant on a scarce and unreliable manual labor workforce. Therefore, the nursery industry must take opportunities to continue developing automation strategies and innovations that address this critical issue." Tilt (2000) adds that "computerized systems can save miles of running each week and reduce the strain on nursery managers," further illustrating how automation benefits labor efficiency and irrigation effectiveness.

By reducing manual tasks, automation saves you time, reduces costs, and allows your team to focus on what truly matters: actual plant care, pest management, and propagation. This can make everyone happier and more productive in the long run. It's a win, win.

CURRENT TRENDS: From guesswork to data-driven irrigation

As mentioned earlier, 40% of nurseries utilize guesswork or intuition to adjust irrigation schedules. Additionally, 30% of the attendees at the IPPS conference mentioned they hand-water or manually turn valves on and off. These traditional methods, though familiar, are often inefficient, leading to higher water usage, labor demands, and inconsistent plant health.

Manually irrigating and guessing how long to irrigate is not optimal, because it ***fails to***:

- *Irrigate efficiently*, based on real-time changes to plant needs and weather conditions
- *Mitigate knowledge gaps*, when folks leave your nursery
- *Reduce costs*, associated with water, fertilizer, and labor
- *Limit water consumption* and deal with regulatory legislation

Ultimately, it's not optimal to efficiently produce and ship quality crops (**Fig. 2).**

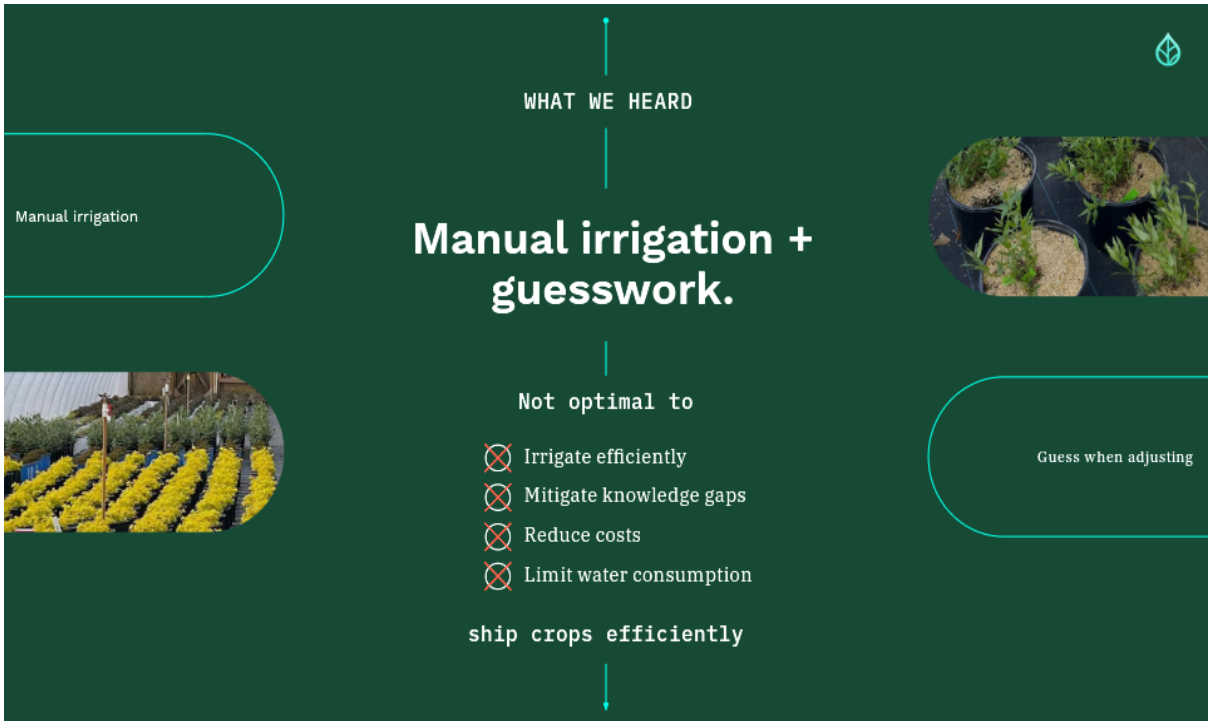

Figure 2. Manual irrigation and guesswork are not optimal to ship crops efficiently.

Adaptive change requires proper attention. As Million et al. (2010) mentions, "The container nursery industry is continuously seeking new irrigation and fertilization strategies to improve efficiencies and reduce negative environmental impacts… [while striking] a balance between the rewards of reduced … inputs and the risks of reduced plant growth and quality."

To make the case, much of the research points towards trends in a few key areas: from removing the guesswork, reducing the inputs by better managing the soil moisture, to using automation (**Fig. 3)**.

Figure 3. Research and industry trends point towards removing guesswork, reducing inputs, and automating.

SHAPING THE FUTURE: INNOVATIVE TRENDS

1. *Irrigation Delivery System Improvements*: Nurseries have adopted drip irrigation and manage overhead systems better using technology.
2. *Irrigation Schedule Improvements*: ET models and leaching fraction systems refine watering schedules.
3. *Technology and Infrastructure*: Making infrastructure investments enables fine-tuned control over water delivery per zone, along with the use of Artificial Intelligence (AI) / Machine Learning (ML) and Internet of Things (IoT) (see definitions below).

Focus on the irrigation delivery system improvements, such as drip or using technology to better manage your overhead irrigation. Secondly, improve your irrigation schedule itself, whether that be from using the ET based models mentioned and/or leaching fraction measurements.

You can also incorporate soil sensors, as Bayer et al. (2015) suggests, "Automated irrigation using soil moisture sensor-controlled systems ensures efficient water use,

reducing waste while maintaining plant quality. This system can optimize irrigation by applying only the necessary water based on real-time soil moisture levels, leading to improved growth and reduced environmental impact." Soil moisture sensors are best used in places where there is minimal movement to keep in mind the consideration around being "non-intrusive", e.g. field grown crops, larger crops like trees, or other crops which will be fairly static for a longer period of time. Soil sensors are not optimal in 1–5-gal container nursery settings where the sensors can get lost, stepped on, or shipped when the plant is sold.

Lastly, adjust your technology and infrastructure. By better controlling each individual valve associated with individual irrigation zones or plant groups, you yield better quality and gain a return on your investment over time and reduce time related to irrigation related activities, as well as water, per Zazueta et al. (1992).

THE POWER OF TECHNOLOGY: AI, ML, AND IOT IN IRRIGATION

Technologies of great potential include artificial intelligence (AI), machine learning (ML), and the internet of things (IoT). Think of the thermostats in your home you can control from your phone as an example of an IoT device, which may use artificial intelligence and machine learning to determine when you normally get home to turn on the air conditioning in advance and how to save you electricity, while keeping you comfortable. The cool thing about AI is it is always learning, always getting smarter. The more data, the better it gets at figuring out what your plants need - and making those little changes that make all the difference in your production. This opens up the possibility of proactively sending irrigation schedules out in advance, based on historical weather data, plant information (such as container size, age, etc.) and being able to predict the run-time needed with accuracy.

Additionally, if you have your water-usage dialed in - you have the ability to experiment with using irrigation as a growth regulator, so you do not need as much production time producing a finished crops before shipping them. As one nursery mentioned, using a leaching fraction of 0% for hydrangeas.

WHY TRANSITION TO MODERN IRRIGATION SYSTEMS NOW?

The Old World of Irrigation. In this old world, irrigation decisions are made based on single tasks, and gut instincts rather than data (**Fig. 4**). This task-centric mindset leads to fragmented operations and missed opportunities for efficiency. With traditional watering methods, you tend to overwater and accidentally create the perfect breeding ground for fungus or disease. I am sure you can recall the image of someone dragging hoses around or moving those big clunky sprinklers… all of that is automated with modern irrigation. With traditional overhead irrigation, there is wasted water, fertilizer, and unhappy plants. And instead of spending hours on manual watering, those workers can focus on tasks that actually require a human touch. No more picking up pots to see if they are dry, adjusting irrigation based on a guess of how much the weather or pruning and spacing affected the water needs, or manually turning on and off valves in the Quonset house or greenhouse.

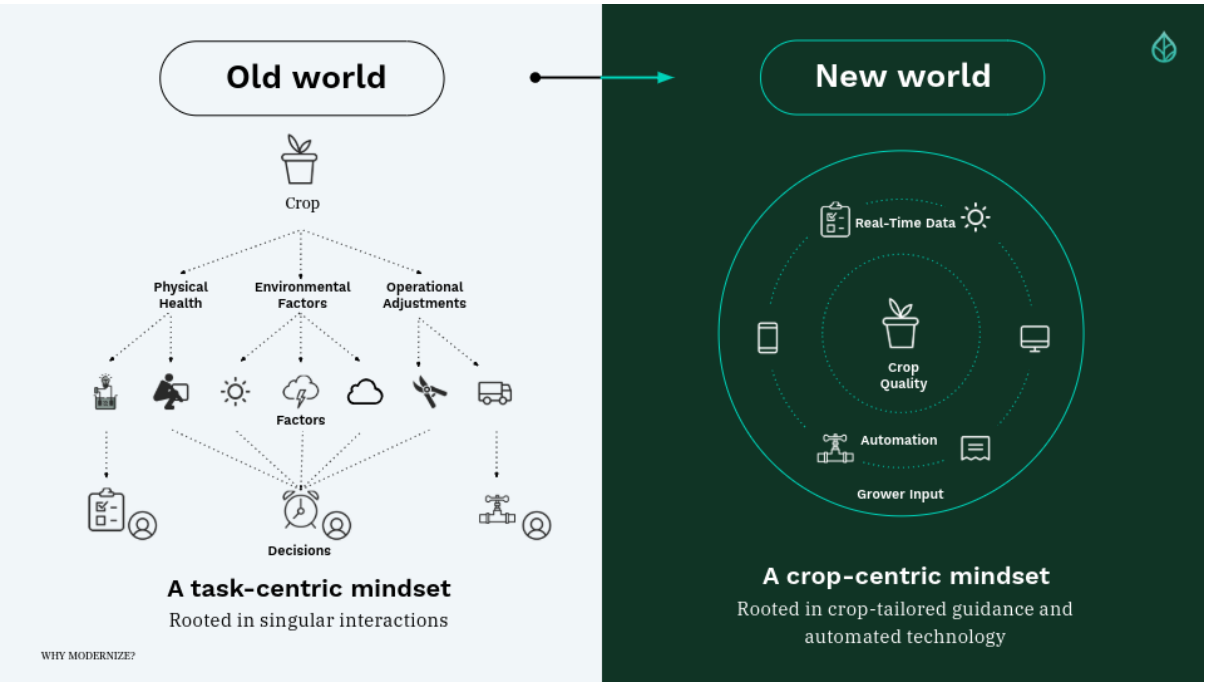

Figure 4. Old vs new world in irrigation, with the focus moving from tasks to crop quality.

IMAGINE THE NEW WORLD OF IRRIGATION – The future is already here

Imagine walking into your nursery in the morning. Instead of checking timers or manually adjusting irrigation, you know that real-time data from a weather station placed around your nursery has already been gathered overnight—measuring rainfall, humidity, wind speed, and even sunlight intensity. This data is automatically sent to a central system that analyzes it and makes real-time adjustments to your irrigation schedule. It's like having a 24/7 irrigation manager that never takes a break.

Now, think about what this means for your day. Instead of managing watering schedules manually or responding to plant issues after they have already occurred, you have time to focus on what really matters—propagation, quality checks, and optimizing crop yield to reduce shrinkage. Automation is not just a time-saver; it puts consistent crop quality at the center, using technology and real-time data to support your decisions. With your grower input holding it all together!

Picture this: no more guesswork, no more reacting to plant stress - too late! Instead, your crops receive the exact amount of water they need, when they need it. This system prevents both over- and under-watering, saving water, avoiding nutrient loss, and preventing root rot. The result? Healthier plants, better growth, and no wasted resources. So, what does a day in the life look like with modern irrigation? It is a day where you spend less time troubleshooting irrigation and more time nurturing healthier, more profitable plants, all while your system works in the background to optimize water-use and ensure your crops thrive.

So, why not invest in modern irrigation solutions? One can boost your efficiency with faster adjustments, improve your crop quality and nutrient retention, while lowering your operational costs, and enhancing sustainability (**Fig. 5**). Technol-

ogy is already giving some nurseries a cutting edge, while allowing them to stay ahead of labor risks and regulatory decisions. Water, an increasingly scarce resource, is being consumed far faster than it can regenerate.

"The availability of water for nursery irrigation is expected to decline, as urban expansion and drought conditions increase competition for water resources, forcing nurseries to adopt more efficient irrigation technologies (Beeson et al., 2004)."

Figure 5. Making the case for investing in modern solutions.

Regulations around water use are tightening in many regions, with some areas mandating significant reductions. For example, a Canadian nursery we spoke with must reduce their water usage by 50% in 2024 compared to 2023. Why not take proactive steps to meet these challenges before they restrict your production? "The integration of advanced technologies such as AI, ML, IoT, and renewable energy solutions offers significant opportunities to improve irrigation efficiency. These innovations enable precise water management, reduce resource wastage, and enhance agricultural productivity (Ejaz et al., 2024)."

REAL-WORLD SUCCESS STORIES

Saunders Brothers. Diving into a few of the real-world success stories, let's start with Saunders Brothers, a nursery close to my heart! This is related to the project I mentioned at the start. They were really looking to tackle this issue of over-watering and fertilizer waste. This entailed using ET-based irrigation, the leaching fraction system, automation, and an infrastructure investment.

This resulted in a 43% water and chlorine savings in the first year alone. Fertilizer use dropped by 33% on some crops, showing the return on investment achievable through modern irrigation (Stanley et al., 2019).

The system Saunders Brothers uses was developed through a partnership with the University of Florida and an electrical engineer, custom building the components. Canopy (Canopygrow.tech) is focusing on taking knowledge from this implementation to provide similar solutions to other nurseries.

Holden Nursery. Holden Nursery also utilized the leaching fraction system, cutting their water usage by 50%. Less water has to have some trade off in quality, right? No! Not only did they use less water, but their plants are greener and healthier than before (Yeary et al., 2014).

Hibernia Nursery. The last example, Hibernia Nursery, also with leaching fraction testing and automation estimated $35,000 to $40,000 annually on labor costs because they need fewer people to manage the irrigation now. That savings does not include the electricity savings on top of that (Million and Yeager, 2019). These small changes can make a big difference, less waste, lower costs and it's better for the environment!

PRACTICAL STEPS FOR YOUR NURSERY

In candor, not every nursery can go from zero to fully automated overnight. It is definitely a process. But even making a few small changes, like adding leaching fraction measurements or tweaking your watering schedule based on the weather forecast, can make a difference.

Choosing a plug-and-play technology, one can tailor the irrigation to each crop - allowing a nursery to reach scale. By separating plant groups into irrigation zones, one can customize the amount of watering per each group throughout the growing season. And as those smaller steps are taken, look into automation to remotely control your irrigation system without needing to send a person around to turn the valves on and off. These changes might look different for each nursery, so depending on your current setup:

- *Valves* > *Solenoids* + *Timers* - changing from valves to solenoids with timers.
- *Solenoids* + *Timers* > *Automated* - upgrading from solenoids and timers to an automated system that turns the solenoid on and off based on weather and grower inputs.

In discussions with nurseries, it became evident that selecting the right solenoid is crucial to achieving optimal performance. Solenoids vary in functionality, with some electrically activated, such as Rainbird models, and others pressure-activated. Choosing a solenoid that aligns with your system's pressure availability ensures the desired irrigation outcomes and prevents operational inefficiencies. For instance, using a pressure-activated solenoid without sufficient pressure in the pipe can prevent the valve from opening, resulting in no water delivery to that zone. Ensuring the solenoid matches the system's pressure requirements is essential for reliable irrigation performance.

Summarizing the actions you should invest towards (Fig. 6):

1. *Start Small:* Implement leaching fraction testing or adjust schedules based on weather.
2. *Aim for Scalable Solutions*: Zone-based irrigation allows for growth, while meeting specific crop needs.
3. *Invest in Automation*: Remote controls for irrigation reduce manual intervention, ensuring consistency and efficiency.

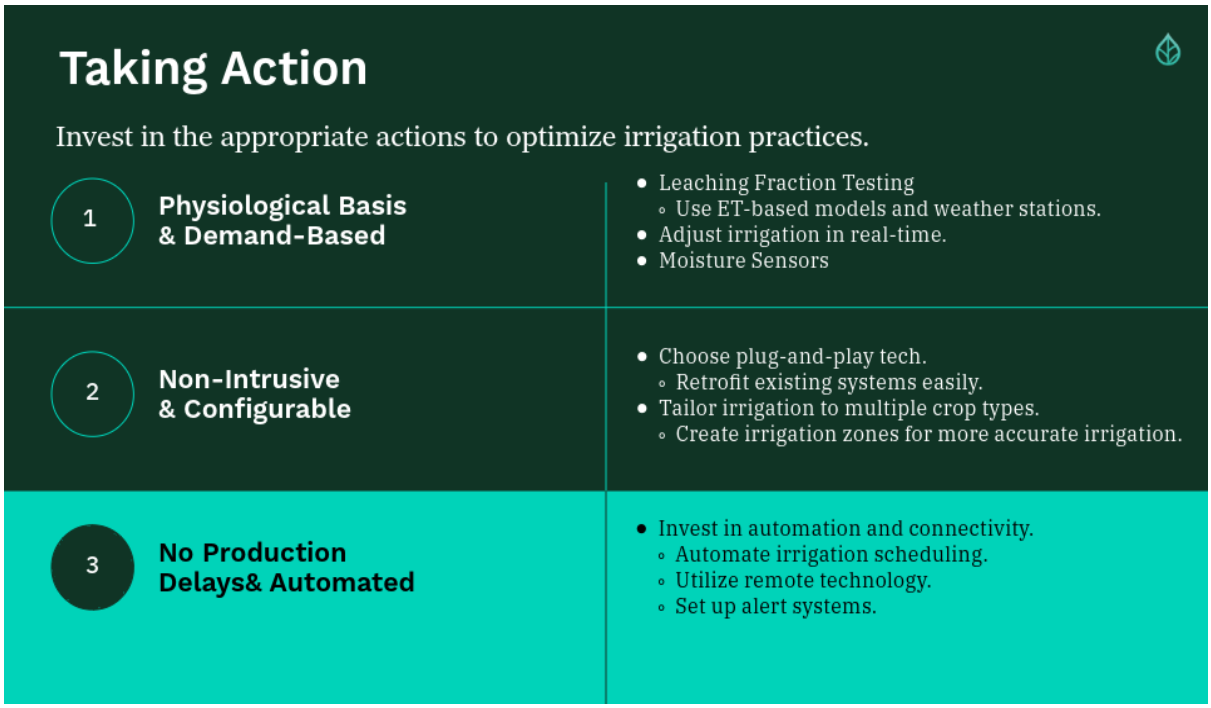

Figure 6. Taking the right actions can start small and build from there.

MEASURING OUTCOMES (Fig. 7)

Never be afraid to try new things and stay curious. That is what we are all about at IPPS. Learning from each other and sharing new ideas. As the latest *IPPS International Newsletter* advocated: becoming the beacon for fostering sustainable, resilient, and productive plant ecosystems.

I have covered water savings, healthier plants with reduced waste, versatility across your entire nursery, and ensuring no delay in finishing your crops. But what also needs to be emphasized are personnel – people who are out there doing the work day in and day out. You have to consider the human-side of things. Especially, when it comes to improving the growers' knowledge! By having a system inform them how the weather affects the irrigation, how the adjusted watering affects the salt levels when taking EC (electro-conductivity) measurements, how growth of the plant increases or decreases the amount of irrigation needed due to the canopy of the crop (after taking a leaching fraction measurement), - and what all of that means in the

amount of time they should recommend to water that plant each day. That is a lot for a grower or irrigation manager to keep in their head!

It is also about making your jobs a little easier. When you can automate these tasks that are tedious and physically demanding - it frees up your team to use their brains and skills on tasks that are more interesting and rewarding. You know what happy employees mean?

They stick around, less turnover - which means less time and money spent on training new people. I am sure you have heard the saying that: The employee that opens and closes your valves controls the crop quality. Who is opening and closing your valves?

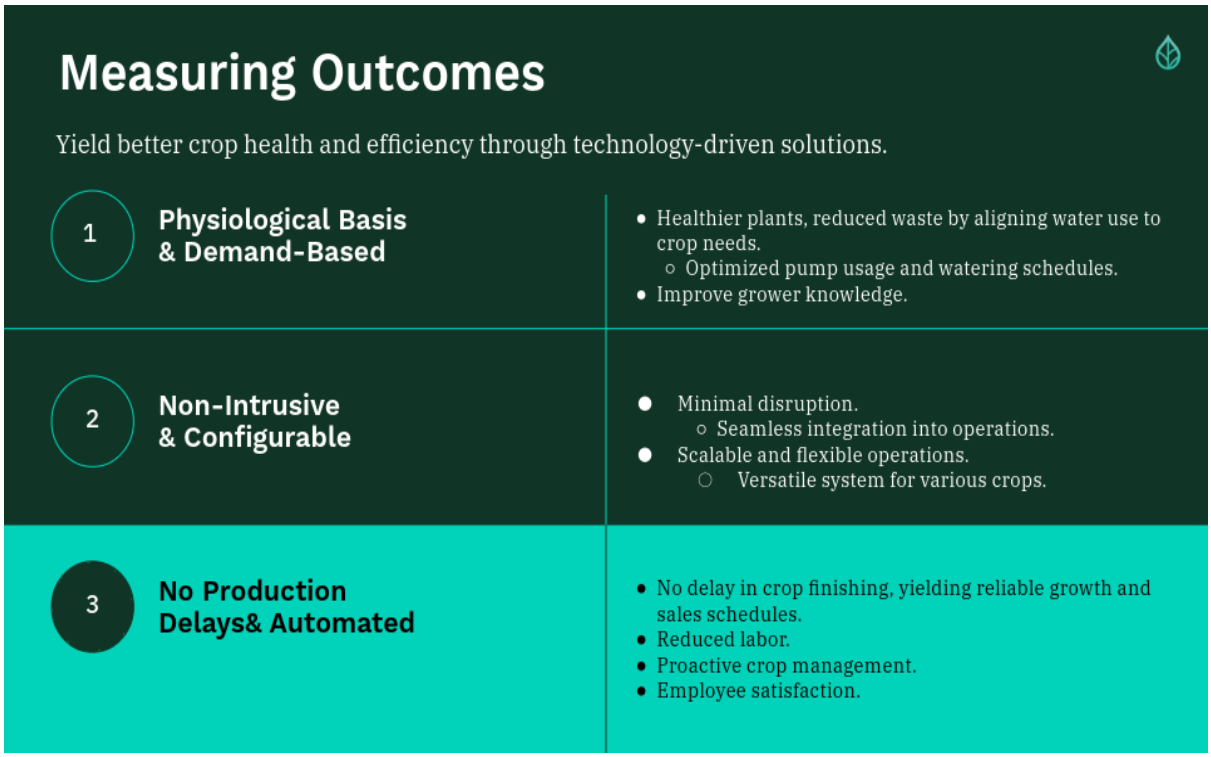

Figure 7. Measuring the outcomes related to your investments can lead to better crop health

CONCLUSION

There is a quality, smarter future for nurseries. “The future of irrigation lies in the continued integration of advanced technologies and effective collaboration across stakeholders to ensure sustainable water use (Ejaz et al., 2024).” Progress will depend on partnerships, universities driving research, nursery professionals sharing practical insights, and the commercial sector developing solutions tailored to industry needs. Hopefully this gives good insight into ways you can grow healthier plants, meaning you can get your products to market more effectively. Because in a seasonal business like a nursery, timing is everything!

And with these investments towards your future irrigation system of ET and leaching fraction-based systems and/or automation and technology, you can save time, water, fertilizer, and labor. Which in turn, you can use to grow your business by reinvesting those resources to get more of your crops in customers hands each season

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