insideGROWER
February 2015
CONTROLLED ENVIRONMENT AGRICULTURE

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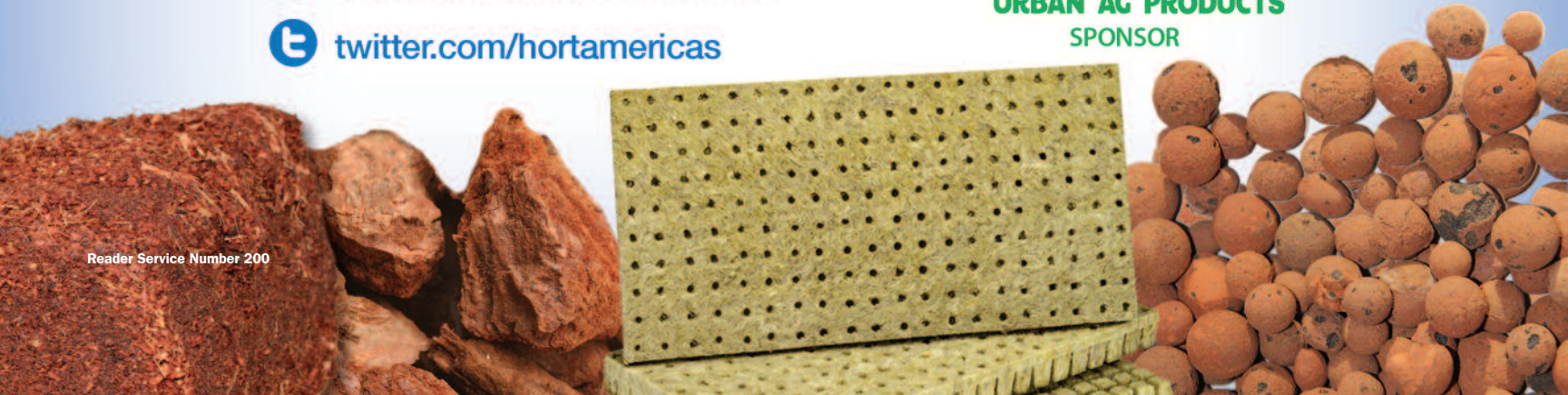

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I split my time between

industry and academia, so I know all too well the benefits and challenges of working and researching in both arenas. While industry is stereotypically fast-paced and profit-driven—an advantage in some respects—academia has the advantage of being able to commit to longer-term projects and projects with the prospect of big humanitarian rewards rather than big profits.

University of Pennsylvania Professor Dr. Henry Daniell continues to pursue his long-term goal of creating plant-derived and orally delivered pharmaceuticals to fight the worst and most widespread illnesses and diseases, and moreover, be widely available in developing countries at prices people can afford.

In our cover story, I interview Dr. Daniell about the groundbreaking research he's conducting with the help of modern greenhouse technology and how "green vaccines" could inspire new market opportunities in controlled environment agriculture (page 10).

With so many inspiring stories of successful CEA startups and innovations, *Inside Grower* is admittedly guilty of favoring a positive tone. Plus, it's natural for all of us to want to talk about and share our successes, but remain tight-lipped when it comes to our shortcomings. The truth is, the challenges growers face in CEA are plentiful, as are the misconceptions. We turned to the highly experienced Cornell University CEA Research Group to highlight the top misconceptions about CEA production, marketing and labor (page 32).

Four of the main ingredients to produce a successful crop of greenhouse edibles include top-notch plant varieties, good sanitation practices, an appropriate fertilizer regime and sufficient lighting. We've packed this issue with practical knowledge about each of these essential topics. Read a roundup of new vegetable varieties available for 2015 on page 24. Then turn to page 18 for a rundown on the different methods to grow indoor edible crops hydroponically and how fertilizer works. Flip over to page 26 for the fundamentals of good sanitation practices. Then catch the 411 on LED horticulture lighting on page 14.

We always like to feature the good work of growers. Sundial Farm got its start as an orchid company in 1980, growing specialty Phalaenopsis orchids in southern California. Water restriction predictions inspired them to consider hydroponic growing methods. Today, Sundial Farm grows 15,000 sq. ft. of hydroponic greens. You'll find their water-saving success story on page 22.

We hope you enjoy this special publication of *Inside Grower*. As always, we welcome your questions and feedback.

Annie

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CONTROLLED ENVIRONMENT AGRICULTURE

ON THE COVER

Dr. Henry Daniell's little greenhouse full of special lettuce plants has huge potential to be a paradigm shift in the pharmaceutical world—and maybe even in the controlled environment agriculture industry. Turn to page 10. Photo by Candace diCarlo.

DEPARTMENTS

FEATURES

Hydroponic Strawberry Information Website

Want to learn more about hydroponic strawberry production in the U.S.? Check out the University of Arizona CEAC Hydroponic Strawberry Information Website. Led by Professor Chieri Kubota and Research Specialist Mark Kroggel, their goal is to share relevant information and conduct research to support the development of the greenhouse strawberry industry in Arizona and beyond.

"In the U.S., only a negligible amount is produced in greenhouses using substrates (hydroponics), although the use of hydroponics has many advantages," writes Chieri on the website, adding, "While other countries expanded greenhouse hydroponic strawberry production over many years, the U.S. was left behind by long relying on open-field production capacity."

The U.S. grows approximately 22 acres of greenhouse strawberries (USDA 2009 census), out of 56,140 harvested acres (USDA ERS 2012). In comparison, Japan grows 12,990 acres of greenhouse strawberries out of 14,876 total acres of strawberry production (MAFF 2011 data).

Visit the website at http://cals.arizona.edu/strawberry/Hydroponic_Strawberry_Information_Website to learn more about establishing sustainable off-season hydroponic strawberry production in the Desert Southwest and beyond.

New Online Guide Helps Farmers and Food Advocates Navigate USDA Programs

The National Sustainable Agriculture Coalition (NSAC) has published a comprehensive digital guide to the key federal farm and food programs that support sustainable farm and food systems. The "Grassroots Guide to Federal Farm and Food Programs" will help farmers and non-profit organizations navigate the numerous farm bill and other U.S. Department of Agriculture programs.

National Sustainable Agriculture Coalition

The guide walks you through more than 40 federal food and farm programs that provide funding to farmers and organizations for conservation assistance, farm real estate and operating loans, outreach to minority and veteran farmers, beginning farmer training programs, value-added enterprises, support for farmer's markets and farm-to-school programs, and more.

For each program included, the guide provides plain-language explanations of how the program works, who can utilize the program, examples of the program in action and step-by-step application instructions.

To check it out, visit NSAC's website at http://sustainableagriculture.net/publications.

Better Insurance Coverage for Fruit and Vegetable Crops

For years, commodity crop farmers in the U.S. have been able to purchase federal insurance to protect their crops from losses associated with natural disasters. Now, fruit and vegetable farmers, as well as other specialty crop growers, can obtain similar levels of protection through the USDA's Noninsured Crop Disaster Assistance Program.

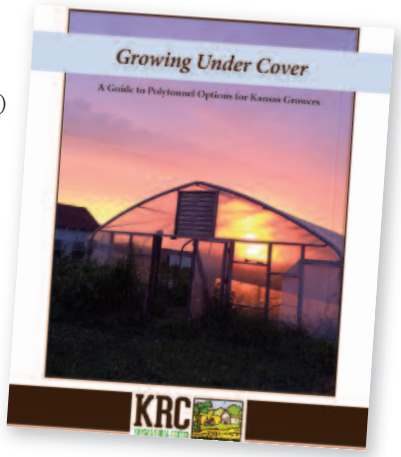
The new options, created by the 2014 Farm Bill, provide greater coverage for losses when natural disasters affect specialty crops such as vegetables, fruits, mushrooms, floriculture, ornamental nursery, aquaculture, turf grass, ginseng, honey, syrup and energy crops.

"For years, commodity crop farmers have had the ability to purchase insurance to keep their crops protected, and it only makes sense that fruit and vegetable, and other specialty crop growers, should be able to purchase similar levels of protection," said Secretary Tom Vilsack.

Previously, the program offered coverage at 55% of the average market price for crop losses that exceed 50% of expected production. The new options, created by the 2014 Farm Bill, provide greater coverage. Producers can now choose higher levels of coverage, up to 65% of their expected production at 100% of the average market price. More crops are now eligible for the program, including aquaculture production practices.

To help producers learn more about the Noninsured Crop Disaster Assistance Program and how it can help them, USDA, in partnership with Michigan State University and the University of Illinois, created an online resource. Check out the Web tool at www.fsa.usda.gov/nap.

Guide to Polytunnel Options



Kansas growers (or growers in similar climates) who use or are interested in using polytunnels, there's a brand new guide to help you explore the options in polytunnel growing.

"Growing Under Cover: Guide to Polytunnel Options for Kansas Growers," written by Dan Phelps, researcher and educator for Kansas Rural Center's specialty crop programs, reflects input from more than 60 experienced Kansas high tunnel growers. The manual offers practical information and resources to assist growers in avoiding common mistakes and tunnel disaster, in order to maximize their return on investment.

According to Dan, polytunnels, such as high or low tunnels, offer growers innovative tools to extend the growing season, help reduce risk and increase yields, while mitigating extreme and "normal" weather conditions across all seasons. However, Dan admits that plastic-covered tunnels are no silver-bullet solution. They require significant financial investment, can be labor intensive to manage and may be damaged or destroyed by extreme weather, such as high winds, heavy snow or hail.

It's good to know your options before leaping into a polytunnel investment and this guide is a great place to start your research.

You can access the guide at http://kansasruralcenter.org/growing-under-cover/.

Plantagon to Build Vertical Greenhouse in Sweden

Plans are moving forward for Plantagon's vertical greenhouse for urban agriculture in Linköping, Sweden. The project has been given the green light by Linköping's Administrative Board and construction is slated to begin in late 2015.

Plantagon is a global innovation leader in urban agriculture and the concept of vertical farming. The 200 ft.-tall greenhouse will be the first building of its kind in the world.

The outer part of the building will be used for urban agriculture and the inner part of the construction will be a 16-story office building.

The Plantagon Greenhouse in Linköping will feature methods, symbiotic systems and technologies developed by Plantagon and its partners.

"The Plantagon Greenhouse will be a model for the whole world to demonstrate that you can actually grow food efficiently and safely in a large city," says Owe Pettersson, COO of Plantagon.

Read more about the project on Plantagon's www.plantagon.com.

Gotham Greens Receives "Best" Rating from Whole Foods Market

Gotham Greens, the Brooklyn, New York-based grower of greenhouse vegetables, has received the highest rating possible from Whole Foods Market's new Responsibly Grown Rating System.

The produce rating system provides consumers with an at-a-glance rating for sustainable farming practices. The first-of-its-kind program seeks to bring transparency to farming practices by rating growers as "Good," "Better" and "Best" while taking into account everything from pest management and water conservancy to farm worker welfare.

Gotham Greens says their "Best" rating is a direct result of their mission to advance sustainable urban agriculture and their commitment to responsible growing practices. According to the company, the cornerstones of their greenhouse operations include water recycling and conservation; integrated pest management and the use of beneficial insects instead of pesticides; renewable energy use; and proximity to the marketplace, which reduces long-distance shipping and the associated carbon emissions and pollution.

Gotham Greens says their sterile greenhouses and comprehensive food safety, food security and traceability plans allow the company to exceed industry standards to ensure it supplies the market with the freshest, safest and most flavorful greens available.

"We're extremely proud of the greenhouse design considerations and ongoing operational practices that have enabled us to achieve this rating," said Jenn Nelkin Frymark, Chief Agriculture Officer of Gotham Greens. "That being said, we're never content with the status quo; we continually strive to make our operations even more ecologically efficient."

It's been a big year for Gotham Greens! Earlier this year, they partnered with Whole Foods Market to build the world's first commercial-scale greenhouse integrated into a retail store located in Brooklyn. In April 2014, Gotham Greens received Whole Foods Market's Annual Supplier Award in the produce category. Gotham Greens also recently announced plans to expand to Chicago, Illinois.

Kick Starting Home Hydroponic Systems

More and more hydroponic and aquaponic kits for home veggie growing are hitting the market, many of which are kick starting their businesses on—you guessed it—Kickstarter and other crowdfunding sites. With often lofty price tags, these novelties certainly aren't accessible to everyone, and the sustainability of a micro farm is arguable, but they do look fun and they allow families to grow food while tinkering with hydroponic technologies.

Urban Cultivator takes hydroponic growing technology and packages it in an attractive high-quality appliance. Taking up the same footprint as a dishwasher, and being plumbed to water and electric in the same way, the "Urban Cultivator Home" makes growing hydroponic herbs and microgreens look easy and attractive. Pre-programmed with optimal growing cycles, the unit automatically controls light, water, temperature and humidity.

Similar to an ebb-and-flow hydroponic system, the cultivator waters plants automatically by flooding the growing trays with water and nutrients from the main reservoir. After a set time, the cultivator drains the water.

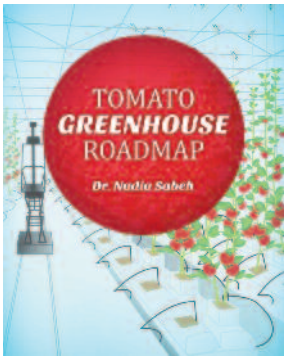
Urban Cultivators aren't new, but they've recently had more press for launching a franchise opportunity called Living Produce Aisle. The store franchise offers businesses and individuals the opportunity to drop in and purchase organic microgreens grown in Urban Cultivator's hydroponic cultivating chambers.

The commercial version of the Urban Cultivator is sized similar to a commercial refrigerator and is being marketed primarily to high-end restaurants that have a desire for ultra-fresh herbs and microgreens. It's priced at upwards of $2,200 for a home unit or $6,000 for the commercial scale.

Here's another fun one for far fewer dollars: It's called an "Ecofarm" and it's a tabletop home aquaponics system where you can grow plants and herbs atop your fish tank. Developed by two European entrepreneurs, the company has launched a crowdfunding campaign on Kickstarter.

Tomato Greenhouse Roadmap Helps Growers Plan Their Business

Hort Americas has published a new guide for growers called the "Tomato Greenhouse Roadmap." The guide, written by Dr. Nadia Sabeh, is designed to help new greenhouse growers, farmers and investors who are interested in entering the world of controlled environment agriculture and greenhouse tomato production.



Hort Americas emphasizes that "The Roadmap" is not a production guide, but rather provides specific industry terminology, production concepts and cultivation options that must be understood in order to make important investment decisions. You'll also find worksheets and resources that will assist in organizing and planning a professional hydroponic or urban greenhouse tomato range.

Topics include an overview of greenhouse planning, design and operation, as well as tomato selection and crop management. The information presented is based on current research and accepted design management and operational strategies.

You can order a Kindle edition of the guide on Amazon for $99 or order straight from the good folks at Hort Americas at www.hortamericas.com.

Managing Tomato Diseases in High Tunnel Greenhouses

A new webcast distributed by the Plant Management Network is now available on the topic of tomato diseases in high tunnel greenhouses.

Presented by Judson Reid, extension vegetable specialist at Cornell University, the webcast aims to help consultants, growers and other practitioners in the Northern U.S. understand how high tunnels are susceptible to certain tomato diseases and how these diseases can be managed.

Brown leaf mold, tobacco mosaic virus and fusarium wilt are used as examples of how the unique environment of a high tunnel creates management challenges. Varietal resistance, grafting, fungicide applications and rotations are discussed in the webcast, as well as best management practices for healthy crops in general.

Check out the 30-minute webcast at www.plantmanagementnetwork.org/edcenter/seminars/Tomato/HighTunnelGreenhouses/. You can also read a version of Judson's paper on biocontrols for high tunnels on page 28.

GreenTech Agro Builds Vertical Indoor Farm on Wheels

GreenTech Agro, the company that brought us "Growtainers," has a new product and you might just pass it on a U.S. highway. The "Growvan" is a state-of-the-art, 24-ft. mobile hydroponic vegetable production environment specifically designed for delivering sustainability and healthy eating education to students.

"By bringing the farm to the family," says Glenn Behrman, "the Growvan will play an important role in delivering key food, nutrition and sustainability messages effectively and economically across the U.S."

Based on the same technology as the Growtainer, each Growvan contains a fully functional, climate-controlled vertical indoor farm. The growing system includes the water-conserving Growrack setup from GreenTech Agro, LED lighting from Philips, complete climate and environmental controls, and technology-based monitoring and production systems.

Using curriculum materials developed by educators from Texas A&M University and Texas A&M AgriLife Research and Extension, the Growvan is outfitted as a mobile education tool. The Growvan offers opportunities for students to learn about water conservation, hydroponic production, rainwater harvesting, healthy eating, nutrition and sustainability.

Growvan visits will be coordinated through schools, community organizations, state Extension Services, 4H and other interested groups. For more information, visit www.growvan.com.

Panama City to Host First International Congress on CEA

Mark your calendars for May 20-22, 2015. That's when the first ever International Controlled Environment Agriculture Conference is set to take place in Panama City, Panama.

If you're involved in—or just interested in learning more about—indoor agriculture, vertical farming, city farming, plant factory production or hydroponic greenhouses, this is an event to consider attending. (Plus, it's in exciting Panama City!)

This first-of-its-kind conference will be an opportunity to learn from some of the most innovative minds in the industry. Speakers will focus on the skills and knowledge needed to finance, design and operate a successful and innovative farm.

The event is organized by the Foundation for Development of Controlled Environment Agriculture and is sponsored by Urban Farms, The University of Panama, Hort Americas, visitpanama.com, Chiba University, The Technical University of Panama, Urban Ag Products and Congrex.

Learn more at fdcea.com.

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Reader Service Number 202

Lifesaving Lettuce

by **ANNIE WHITE**

How researchers are developing plant-based vaccines that could change global health and our industry.

On the University of Pennsylvania's South Bank campus—an old industrial area characterized by retired factory buildings—a glimmering $2 million greenhouse is bringing new life to the area and beyond. The domain of Dr. Henry Daniell, the greenhouse has all the high-tech bells and whistles of a new controlled environment greenhouse and then some. But Henry isn't growing salad greens for the local market; he's growing vaccines.

A professor in the departments of biochemistry and pathology and director of translational research in the School of Dental Medicine, Henry's doing groundbreaking research that could change the way drugs and vaccinations are delivered. It could also change the controlled environment agriculture industry, providing new opportunities for growers and greenhouse facilities.

These greenhouse-grown pharmaceuticals have the potential to become the superhero of global public health. Henry's research has demonstrated the effectiveness of plant-based vaccines and therapeutics in treating nearly 30 conditions, from

infectious diseases—such as cholera, malaria, and anthrax—to autoimmune diseases—such as diabetes and hemophilia. The hope is that these plant-derived and orally-delivered drugs will be able to fight the worst and most widespread illnesses and diseases, and moreover, would be widely available in developing countries at prices people can afford.

For the past three decades, since first developing the concept of plant-based vaccines, Henry has slowly and methodically researched and tested every step in the process. Basically, he injects therapeutic proteins into lettuce cells and the genetically modified plant produces the proteins for the vaccines. The lettuce leaves are dried and made into capsules that can be taken orally, don't require refrigeration and can be stored for years.

"The concept pioneered in our lab is to produce human pharmaceuticals and vaccines in plant cells," Henry explained to me from his UPenn office. "We have shown plant cells can produce any human therapeutic protein and can deliver the drug without purification. This dramatically reduces the cost over traditional vaccines and pharmaceuticals made and purified in the lab."

Motivated to make pharmaceuticals affordable

Born and raised in Tamil Nadu, the southernmost state of India, Henry grew up in an environment where child deaths from cholera and other preventable diseases were common. He wondered why so many children were dying from preventable diseases and soon learned the answer was they couldn't afford the vaccines or treatments.

Traditional vaccines that are injected into the bloodstream are inherently expensive to make and distribute. They contain inactivated versions of the bacteria, viruses or other microorganisms that cause the illness. Being delivered directly to the bloodstream, the drugs must undergo an expensive purification process and they must be continuously kept in cold storage—a luxury that much of the developing world doesn't have.

Motivated to find a better and more affordable way to make and deliver vaccines and other drugs, Henry looked beyond the lab and into the greenhouse. That's where he found plants.

Why plants are great vehicles for pharmaceuticals

It turns out that plants have several remarkable properties that make them great candidates for growing pharmaceuticals. Plant cells are what's called "totipotent." That is, all the different tissues of a plant can be grown from a single cell in a culture dish. So scientists can modify one plant cell, and from that one cell, grow an entire plant with the modifications.

Once scientists create the genetically modified lettuce plants expressing the desired therapeutic protein, the seeds can be collected and used to continue to propagate more plants with the same therapeutic properties. Following all the research and trialing,

Greenhouse-grown pharmaceuticals have the potential to become the superhero of global public health.

the bulk of the work shifts to simply growing plants from seed in a controlled environment greenhouse. Meanwhile, traditional vaccines need to be tediously manufactured in expensive laboratories.

Why lettuce?

Originally, Henry focused on genetically modifying tobacco plants to grow vaccines and other drugs. I asked him to explain what made tobacco the best candidate for his work and his answer was surprisingly simple. Tobacco is extremely well researched and was one of the very first plants to have their genome sequenced. Although Henry has had good success genetically modifying tobacco, the nicotine content and inedibility of tobacco make it less-ideal for his pharmaceuticals. His focus has now shifted to edible crops, and lettuce in particular.

Leafy lettuce plants are currently Henry's top pick for greenhouse-grown pharmaceuticals. The plants are edible, making them a safe and non-allergenic vehicle for the therapeutic proteins. He tried working with carrots and tomatoes, and although he successfully modified the plants, they contained too much water to easily freeze-dry and stuff into capsules. Of the numerous lettuce cultivars he's worked with, Henry prefers Simpson Elite, a widely available, fast-growing crinkly lettuce with medium-green leaves that "works nicely in our hands," added Henry.

The lettuce is proving to hold up well to the freeze-drying, concentrating and homogenizing, and has a shelf life exceeding 15 months, says Henry.

The greenhouse

At less than 5,000 sq. ft. and costing nearly $2 million, Henry's greenhouse facility is no hobby house. It may sound extravagant, but inside this small greenhouse, about 40 different plant-based drugs are being grown. Many of these have the potential to save lives around the globe.

As Henry works toward FDA approval for his pharmaceuticals, the greenhouse environment he researches in must be closely monitored. The state-of-the-art mechanical, electrical and lighting control systems maintain >>>

an environmentally consistent growing environment in all four seasons. Everything in the research greenhouse is computerized and capable of being controlled remotely, including the fans, irrigation, cooling, heating, humidity levels, lighting, and the opening and closing of the roof and wall louvers.

The greenhouse is maintained with a stringent 1F variability. To accomplish this, the standard greenhouse mechanical systems were supplemented with an HVAC system.

Henry says that the next generation of his research greenhouses will likely include LED lighting and a hydroponic growing system. He currently uses a soil-substrate for growing his lettuce plants for research; however, the presence of soil and all the microorganisms that come along with soil, are detrimental to getting FDA approval for human pharmaceutical consumption. Henry is subcontracting with FDA-approved, but undisclosed, controlled environment hydroponic greenhouse facilities that are growing the therapeutic plants on a larger scale.

Opportunities for greenhouse growers

Could demand for plant-based pharmaceuticals (cannabis aside) provide a new opportunity for indoor farmers in controlled environment greenhouses? Henry is optimistic.

"I think in the next one to five years, we'll be ready for much larger scale production," he said. "There will absolutely be a demand for contained hydroponic growing facilities."

It's difficult to predict just what the future demand for plant-based vaccines will be because there's still a long journey ahead with clinical trials and FDA approvals.

The amount of growing space needed for each drug or vaccine will vary. Henry says that just an acre of genetically modified tobacco plants, for example, could produce enough anthrax vaccine to immunize every person in the U.S. However, Henry notes that his insulin drug for diabetes could demand thousands of acres.

Are these plants safe for the environment?

Given the widespread concern about genetically engineered crops and their potential to contaminate wild and non-GMO plant populations, Henry is frequently asked if his drug-making plants could be hazardous to the environment. He says they're safe—safer, he believes, than other GMO crops.

Henry isn't genetically engineering the lettuce plants the same way agro-biotech giants like Monsanto and Dow do. Most scientists insert cloned genes into a plant's nuclear genome—this is how we get transgenic corn, soybeans and cotton. The engineered genes are dispersed through the pollen the plants produce. But Henry works with the plant's genome found in chloroplasts. Cloroplasts are inherited maternally in flowering plants, meaning that no engineered genes are transferred though the pollen—the genes are only transferred through seeds. The leafy portion of the plant is harvested to make the drugs, not the seeds, but if the lettuce does set seed, it would be within the confines of a controlled environment greenhouse.

Although the process of developing (researching and trialing) the genetically engineered plants is costly, once the science is done, the drug-making plants can be easily grown from seed. Henry says that some estimates say plant-derived vaccines could be 50 to 100 times less expensive to manufacture than conventional treatments.

The pharmaceutical industry

Where do big pharmaceutical companies fit into this picture? Pharmaceutical and biotech companies are always looking for new cost-effective ways to make therapeutic proteins and Henry says their support is crucial in terms of financing costly clinical trials. But these companies are stereotypically profit-driven with short-term fiscal goals. Many of Henry's drugs may not be big money-makers, but could save lives around the world. This is where foundations, such as the Bill and Melinda Gates Foundation, are stepping up.

The Bill and Melinda Gates Foundation is, for example, funding Henry's development of a plant-derived polio vaccine that's low-cost and orally delivered. The Juvenile Diabetes Research Foundation supports Henry's plant-derived therapy to prevent Type I diabetes.

Trials & tribulations

Henry isn't alone on the quest to use plants as vehicles for vaccines and other pharmaceuticals. Other university and industry labs are also conducting related research, but Henry is leading the movement in terms of the amount of published literature and the intellectual property.

So far, Henry's research trials are impressive. In his lab, you'll find rodents that have been successfully immunized against malaria, cholera, polio and the plague. Mice with Type I diabetes have been cured and others with Alzheimer's disease show that plaques in their brain tissue has cleared. Although Henry's work has earned him more than 150 patents, there's still a long process ahead for FDA approval.

There's only one existing plant-derived therapy approved by the FDA. This is a treatment for Type I Gaucher Disease produced by carrot cells, but still manufactured in the lab. Producing therapeutic treatments for numerous diseases and illnesses in greenhouse-grown lettuce plants would be a big step towards making treatments more affordable and more widely accessible.

The reality is, the majority of new drugs don't make it though clinical trials, and even fewer make it to market, but there's a lot of optimism supporting Henry's work. That little greenhouse full of special lettuce plants has huge potential to be a paradigm shift in the pharmaceutical world—and maybe even in the controlled environment agriculture industry.

The 411 on LEDs

Growers looking to install grow lights need to compare the photon efficiencies, along with determining how the lights are going to be used.

by **DAVID KUACK**

Grow lights, particularly light emitting diodes (LEDs), have been receiving a lot of interest recently. There have been numerous trade press and research journal articles published about the lights for a multitude of uses, including photoperiod control and production in both greenhouses and controlled indoor environments.

Along with the press coverage has come plenty of advertising and claims made by the manufacturers about the benefits of their lighting fixtures. In order to provide clarification about the properties of these lights, Utah State University professor Bruce Bugbee and graduate student Jacob Nelson did an extensive study of 22 fixtures in five lighting categories. The lights included two double-ended high-pressure sodium (HPS) fixtures, five mogul-base HPS fixtures, 10 LED fixtures, three metal halide fixtures and two fluorescent fixtures.

A double-ended high-pressure sodium (HPS) lamp that shows the unique connection of the bulb in the fixture. HPS lights are a good choice for large greenhouses full of plants. The light from 1,000-watt HPS fixtures is so concentrated that the fixtures need to be placed higher, so the light is distributed uniformly over a larger area.

"There has been much confusion about LED lighting," said Bruce. "People were suspicious about the claims, but they had no reference standard to go on. That's why we started the research."

COMPARING PHOTON EFFICIENCIES

Efficiency shouldn't be based on perception by the human eye. Instead, efficiency should be measured in terms of photosynthesis, which is determined by moles of photons. Bruce said lights should be compared on photon efficiency, which is measured in units of micromoles of photosynthetic photons per joule (µmol/J) of energy input.

"We carefully measured the electric input to each of the fixtures and then we measured the photons coming out," Bruce said. "Some of the fixtures were big, some were small. There were all different shapes and sizes."

Based on the measurements, Bruce found that the photon efficiency of the best HPS fixtures was equal to the best LED fixtures at 1.7 micromoles per joule.

"What this fundamentally tells us is that the best LED fixtures are not more efficient than the best HPS fixtures," Bruce said. "They are equal. In some LED advertising, manufacturers claim their lights are far superior to other kinds of lights.

"If growers are going to compare lights, they need to compare the latest technology in each class. A 1,000-watt double-ended HPS lamp equipped with an electronic ballast has a photon efficiency of 1.7 micromoles per joule. If this lamp was compared to some of the less efficient LEDs, one would conclude the HPS lamp is far superior. But it wouldn't be a fair comparison. The comparisons need to be made with the best in class for each light category."

The fluorescent light fixtures that Bruce tested had the lowest photon efficiency, below 1 micromole per joule.

"LEDs are more efficient than fluorescent lights," he said. "They're almost double the photon efficiency."

Bruce said HPS lights with lower wattages (i.e., 400 watts) are less efficient than high-wattage HPS lights (i.e., 1,000 watts). He said growers typically use 1,000-watt bulbs because they're the most efficient.

TECHNOLOGY IMPROVEMENTS

Bruce said not all growers are aware of the improvements that have been made in lighting for plant growth, especially HPS lights.

"In my experience only a few growers realize the dramatic increase in efficiency that has occurred in HPS lighting," he said. "HPS lights have gone from 1.0 to 1.7 micromoles per joule in efficiency. That is an astonishing increase."

Bruce said the university greenhouses in which he conducts his research are equipped with 10- to 20-year-old 1,000-watt HPS lights with magnetic ballasts.

"The photon efficiency of our current HPS lights is less than 1 micromole per joule," he said. "We have over 100 of these lights in our greenhouses. This same HPS light has been the workhorse standard in most commercial greenhouses for 20 years.

"We are in the process of replacing all of the HPS lights in our greenhouses with double-ended HPS fixtures. The new lights have a nearly identical light spectrum, but they have an electronic ballast, which makes them more efficient."

Even though Bruce found that LEDs and HPS lights are equal in photon efficiency, he said the reason he's replacing old HPS fixtures with new ones is because of the cost difference.

"The initial capital cost of LEDs per unit of light is five to 10 times more than HPS, but they aren't any more efficient," he said. "The extra cost of LED fixtures can't be made up on the electric bill because the two types of lights are equally efficient."

OUTPUT AND REPLACEMENT

Although modern HPS lights maintain their output longer than older HPS lights (at 10,000 hours, the output is rated at 95% of initial), Bruce said the new HPS lights are still not as good as LEDs.

"A well-designed LED fixture can have excellent maintenance of photon output," he said. "The number most commonly advertised for LEDs is 50,000 hours. At 50,000 hours, LEDs are at 70% of their initial out-

put. LEDs don't usually burn out; they just gradually get dimmer. However, at 50,000 hours it may be difficult to replace. The old fixture would likely have to be replaced with a new fixture."

Bruce said new style HPS bulbs can last 15,000 hours before needing to be replaced. But with HPS lights, only the bulb has to be replaced.

"HPS bulbs might last one-third as long as LED fixtures," Bruce said. "But it is not difficult to replace the bulbs. A new 1,000-watt bulb might cost $100. A new 400-watt LED fixture would cost around $1,200. Over the lifetime of a 400-watt LED, three bulbs might be replaced in a 1,000-watt HPS light."

Bruce said the average lifetime for old style magnetic HPS ballasts is at least 10 years, which is typically more than 50,000 hours. He said the newer electronic ballasts have the potential to last even longer.

"The ballasts for both HPS and LEDs should last much longer than the lights themselves," he said. "With the LEDs, once the lights go out, it doesn't matter if the ballast lasts longer because the whole fixture may have to be replaced."

EFFECTIVE USE OF LIGHTS

Bruce said one of the advantages of LEDs is the ability for growers to change the spectrum of light based on the production needs of the plants.

"Because the spectrum of light, the ratio of the colors of LEDs can be changed; they can be used to make plants shorter or taller," he said. "They can change plant shape. That can be very valuable in plug production. Growers usually don't want tall skinny plants. They want to produce short, sturdy plants. That can be done with light intensity, but it can also be done by altering the colors of light. LEDs are especially effective in plug production where high-value plants have a quick turn around."

>>>

Table 1. Light fixture manufacturer and model numbers included in the Utah State University study.*

Lamp type and ballast	Fixture producer	Model number
High Pressure Sodium		
400 W magnetic	Sunlight Supply	Sunstar
1000 W magnetic	Sunlight Supply	Sunstar
1000 W magnetic	PARsource GLXI	GLX I
1000 W electronic	PARsource GLXI	GLX I
1000 W electronic	PARsource GLXII	GLX II
1000 W electronic	Gavita	GAN Electronic 1000W
1000 W electronic	ePapillon	ePapillon 1000W
LED		
390 W red / blue	LSG (Lighting Sciences Group)	Violet
333 W red / white	BML	SPYDR 600
390 W red / white	LSG (Lighting Sciences Group)	Vivid White
300 W red / white	Illumitex	NeoSol NS
325 W red / white / blue	Lumigrow (Pro 325)	Pro 325
350 W red / white	California Lightworks	SolarStorm 440
340 W multiple	Black Dog	BD360-U
120 W red / white	Apache	AT120WR
330 W red / blue	Lumigrow (ES330) *discontinued 2013*	ES 330
450 W red / white	Hydrogrow	Sol 9
Ceramic Metal Halide		
315 W 3100 K	Cycloptics	All-Bright
315 W 4200 K	Cycloptics	All-Bright w/ 4200k lamp
2@315 W 3100 K	Boulderlamp	Sun-Bright 630W
Fluorescent		
400 W induction	iGrow	IGF-400W
60 W T8 tubes	General Electric	F32T8 SP41 ECO

Table 2. Photon efficiency and cost per mole of photons, assuming all photons (180 degrees) are captured by plants.*

		Assuming all radiation (180°) is captured		Assuming radiation within a 1 to 2.38 height to width ratio (100°) is captured		Assuming radiation within a 1 to 1.35 height to width ratio (68°) is captured	
Lamp type and ballast	Fixture producer[z]	Fixtures needed per mmol/s[y]	Five year electric cost per µmol photons[x] $/(µmol/s)yr	Fixtures needed per mmol/s[y]	Five year electric cost per µmol photons[x] $/(µmol/s)yr	Fixtures needed per mmol/s[y]	Five year electric cost per µmol photons[x] $/(µmol/s)yr
High Pressure Sodium							
400 W magnetic	Sunlight Supply	2.4	$0.40	3.99	$0.66	8.51	$1.42
1000 W magnetic	Sunlight Supply	0.92	$0.33	1.71	$0.61	3.6	$1.30
1000 W magnetic	PARsource GLXI	0.86	$0.31	1.31	$0.47	2.82	$1.01
1000 W electronic	PARsource GLXI	0.75	$0.28	1.14	$0.42	2.49	$0.92
1000 W electronic	PARsource GLXII	0.75	$0.27	1.33	$0.47	2.81	$1.00
1000 W electronic	Gavita	0.57	$0.23	0.96	$0.38	2.12	$0.84
1000 W electronic	ePapillon	0.57	$0.24	1.46	$0.61	3.47	$1.45
LED							
red / blue	LSG	1.53	$0.54	1.62	$0.57	2.03	$0.71
red / white	BML	1.85	$0.54	2.13	$0.62	3.17	$0.93
red / white	LSG	1.58	$0.55	1.67	$0.59	2.09	$0.73
red / white	Illumitex	2.56	$0.92	2.66	$0.96	3.82	$1.37
red / white / blue	Lumigrow (Pro 325)	2.56	$0.73	3.05	$0.87	4.95	$1.42
red / white	California Lightworks	2.85	$0.85	3.09	$0.92	4.92	$1.46
multiple	Black Dog	2.95	$0.85	4.43	$1.27	8.64	$2.48
red / white	Apache	6.14	$1.35	6.58	$1.45	8.21	$1.81
red / blue	Lumigrow (ES330)	2.64	$1.01	2.82	$1.07	4.33	$1.65
red / white	Hydrogrow	3.52	$1.16	5.05	$1.67	10.7	$3.54
Ceramic Metal Halide							
315 W 3100 K	Cycloptics	2.04	$0.46	5.43	$1.22	19.55	$4.38
315 W 4200 K	Cycloptics	2.14	$0.48	5.72	$1.29	20.71	$4.66
2@315 W 3100 K	Boulderlamp	1.22	$0.47	1.56	$0.60	2.9	$1.12
Fluorescent							
400 W induction	iGrow	2.68	$0.94	4.69	$1.65	10.17	$3.58
60 W	T8	20.77	$0.51	38.03	$0.93	83.81	$2.05

[z] See Table 1 for a list of fixture manufacturers and model numbers.
[y] The number of fixtures to get 1 millimol (1000 µmol) of photons per second.
[x] Cost of fixture (multiplied by fixtures needed) plus cost of electricity over 5 years. We used a discounted cash flow model assuming a 5% per year cost of capital. Installation and maintenance costs were assumed to be similiar for all lamp types and were not included in this calculation.

* Tables appeared in a *Plos One* article titled, "Economic Analysis of Greenhouse Lighting: Light Emitting Diodes vs. High Intensity Discharge Fixtures."

Below: Utah State University professor Bruce Bugbee (left) and graduate student Jacob Nelson recently published the results of a study on the economic analysis of greenhouse lighting.

Photo courtesy of Bruce Bugbee, Utah State University.

Above, right: Red and blue LEDs are more efficient than white LEDs, so the best LEDs for plant lighting are purple. This causes the plants to appear purple, but they're healthy and green when the LEDs are turned off. Studies in Bruce's laboratory indicate that the purple light from LEDs can be equally efficient compared to HPS lighting, but it can make diagnosis of plant disorders more difficult.

Bruce said LEDs "really shine" when plants are grown on shelves.

"For indoor production, if the plants are grown on shelves, a grower isn't going to put a 1,000-watt HPS fixture on each shelf. The light would be too concentrated," he said. "Because LEDs can be designed to be less concentrated, they can be kept closer to the plants. The light from LEDs can be distributed on shelves much better than the light from HPS lights."

Bruce said HPS lights are most effective when a grower is trying to light a large area in a greenhouse.

"If a grower has a larger greenhouse full of plants, then HPS lights are an excellent choice," he said. "With 1,000-watt HPS fixtures, the light is so concentrated that the fixtures have to be placed higher, which enables them to uniformly light up a larger area.

"If a grower is trying to light only a small area on a bench, then LEDs would be a better fit because their light is more focused and the light can be directed right at the plants."

For more, email Bruce at bruce.bugbee@usu.edu.

DAVID KUACK is a freelance technical writer in Fort Worth, Texas. He can be reached at dkuack@gmail.com.

Fertilizer In Hydroponic Systems

A quick rundown on the different methods to grow hydroponically and how fertilizer works in each one.

by **MARK F. FREEMAN**

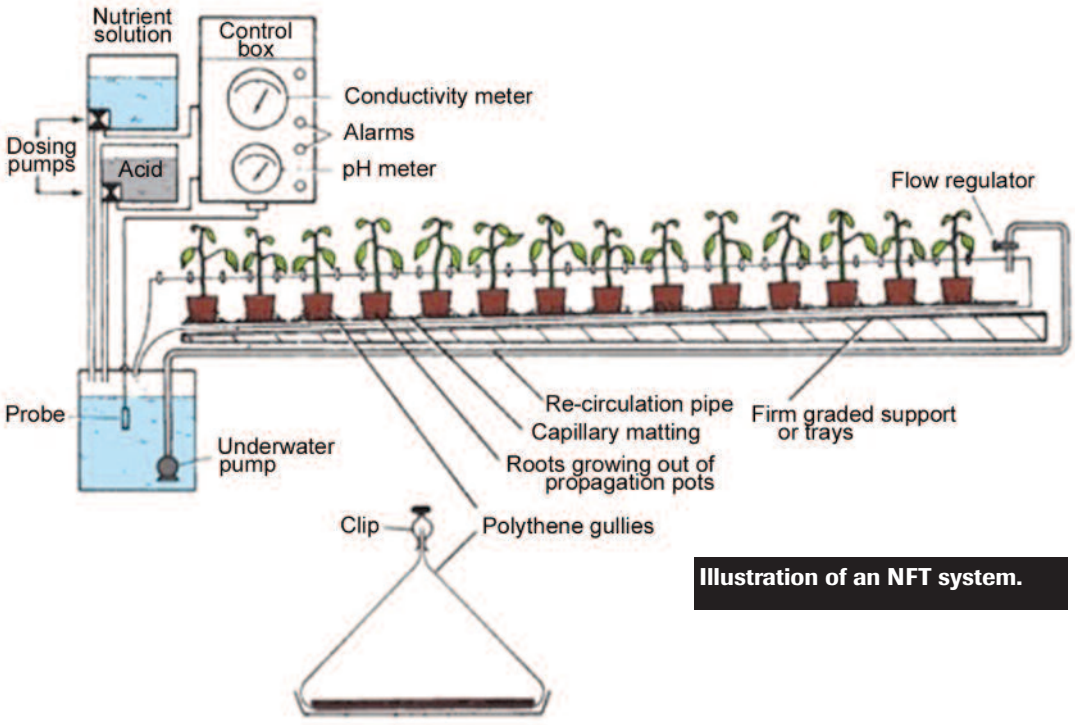


Illustration of an NFT system.

Traditional hydroponic systems are based on synthetic water-soluble fertilizer and/or liquid sources of nitrogen, phosphorus and potassium, plus secondary and micronutrients. Depending on your definition of hydroponics, these specific essential elements for plant production can also be partially supplied in a dry form, when substrates are allowed within the definition. In fact, the definition of hydroponics can be stretched to include all programmed fertigation. This could include all types of irrigated crops, both ornamental and edible, grown outside or indoor, although we don't typically refer to drip systems for nursery production or hanging basket production systems as hydroponic. Since these systems are developed around specific substrates or soil media, which require programmed fertigation practices, they're quite similar to what we typically refer to as hydroponic systems.

For the sake of brevity, this article will focus on a definition of hydroponics that only includes indoor growing of edible crops. This will exclude some clearly hydroponic systems used in outdoor production of both edibles and ornamentals. Be aware that irrigation technology is evolving swiftly in outdoor production systems, with substrate hydroponic systems currently used in vegetable transplant production and finished edible crops, such as strawberry, blueberry, tomatoes and pepper, and permanent crops like almond, citrus and avocado. Many of these production systems use some major technological tools, which include programmed and/or pulse irrigation incorporating metrics, such as vapor pressure deficit (VPD), joules of light and water tensiometers.

The hydroponic fertilizer solutions explored in this article are based on the following production systems: nutrient film technique (NFT), deep water/float, aeroponics and substrate hydroponics. Although the work in aquaponics is also closely related, this article will leave that topic as an aside, since the fertilizer solution incorporates a significant complexity due to variables using fish waste as a source of plant nutrition. Also note that all of the systems can be used for either conventional (synthetic) or organic production systems.

Hydroponic systems & general fertilizer solutions

NUTRIENT FILM TECHNIQUE (NFT)

NFT typically involves a substrate only at sowing to create a transplant that's placed into a trough with continuous or very frequent watering cycles. There are modifications of this production system that use small containers of media, especially for crops that are quite sensitive to variations in the nutrient solution or need additional media to meet some organic certification requirements. This method is most common in leafy greens and herb production, but has been adapted for many other crops using various amounts of substrate and intermittent irrigation. The key qualifier is that the irrigation system is recirculating using a sloped small bench or trough.

Since the NFT method is strictly liquid, dry organic nutrients aren't an option—not even at the sowing stage—due to the delay in nutrient release. Transplants for this production also depend on organic liquids.

Management of the nutrient solution in an NFT system has a number of critical metrics in addition to the ones already commonly used (EC, pH, nitrate and temperature). Growers must also become familiar with dissolved oxygen (DO), chemical oxygen demand (COD) and water insoluble nitrogen (WIN). Plus, there's a requirement to have a water sanitation protocol that's suitable for a re-circulated water irrigation system.

DEEP WATER/FLOAT

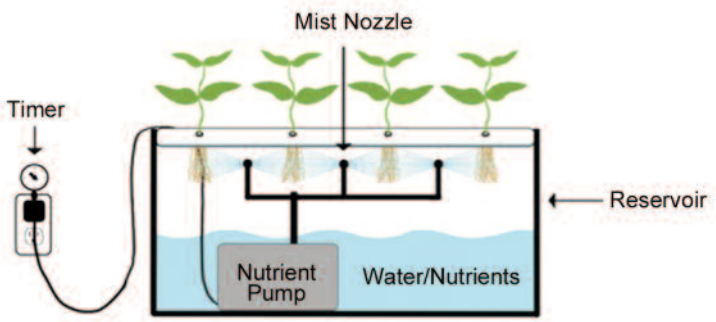
This system is mainly used only for leafy green production and is mainly considered "run to waste." This means once the crop or multiple crop cycles are completed, the solution is disposed of or recycled. It allows for relatively simple nutrient and water management since it's based on a large volume of solution that's fairly constant. Many greenhouse growers are currently converting existing unused or unprofitable production capacity to this system; it's relatively inexpensive in capital and very well suited for quick turnover of greenhouse space. The main limitation of this opportunity for greenhouse operators is in the local market development.

Substrate hydroponic systems are good for longer-term crops, like tomatoes.

Deep water hydroponic lettuce.

AEROPONICS

Many of our first encounters with this hydroponic method were at Disney's EPCOT Center. There is now a huge selection of commercial and consumer production systems available as kits. This is one of the leading hydroponic systems used in many urban gardens.



An example of how an aeroponics system works.

SUBSTRATE HYDROPONICS

Substrate hydroponics is exactly as the term appears: nutrient solutions are applied to substrate or soil substitute medium. Substrates chosen for many commercial greenhouse operations have typically been synthetic, like rock wool, and are evolving toward more natural mediums, like peat and coir. The obvious advantage of using a substrate is in water management and irrigation timing. These systems also have clear differences in nutrition management and are more likely to be seen in greenhouses growing longer-term crops, such as tomato, pepper and cucumber. Be aware that this is also the preferred method for the hydroponic production of berries, which are becoming quite prevalent in high tunnels and other less intensive greenhouse structures. This is also the hydroponic system that, when defined broadly, can include other programmable irrigation systems: flood, pulse, drip, capillary and overhead. Each of these methods include an engineered media for containerized production, which is well drained, allowing for consistent water relationships to permit predictable programming of irrigation. Most substrate production systems are considered "run to waste" and not recirculating, although many of them do collect the leachate for some recycling.

The nutrient programs for substrate hydroponics are very well developed and documented for conventional production using synthetic fertilizers. Many of these programs used by major commercial greenhouse vegetable growers are proprietary and linked to specific cultivars that are branded and/or patented. The intricacy of these programs are now governed by computers that will monitor, track and manage a long list of metrics from EC, pH, nitrate, water tension, humidity, temperature, crop cycle status and joules of light that are used to program irrigation cycles and nutrient injection. >>>

Organic Fertilizer Solutions

Organic nutrient hydroponics is still in the early stages of development. There are actually still a few organic certifying agents that don't recognize this as organic production since there's technically no soil. Substrate hydroponic culture lends itself well to organic greenhouse vegetable production mainly because of the ability to incorporate dry sources of organic nutrition in the media, as well as a top dress. These dry sources are readily available at relatively low cost derived from a wide variety of OMRI-listed products.

Obviously, the key to maximizing any of the hydroponic production systems is the organic liquid nutrition source and, fortunately, there have been significant technological advances in the past decade. Although most of the published research is still based on substrate hydroponics, it's still quite applicable to the other systems. The main difference to remember is that substrate hydroponics, whether synthetic or organic, is able to tolerate small errors in the solution due to the natural buffer that it provides. Water management and oxygen relationships, as well as the actual nutrient solution pH, EC and nutrient content, are much less tolerant of any issues than the strictly nutrient solution systems, NFT, deep water and aeroponics.

The most important aspect in the initial comparison of fertilizers is to note the nutrient sources in the "Derived From" statement within the "Guaranteed Analysis" on the fertilizer label. These standards are used for both synthetic and organic fertilizer. In addition to the general guide the label information provides for simple economic decisions, it's also critical when comparing the actual value the product may have within a given production system.

All registered fertilizer products are required to list the sources of the nutrition. Although the format of this portion of the label is fairly standardized, there are different regulations in each state. Most professional growers are quite familiar with the major sources of synthetic nutrients; it's the organic sources and their relative merits that are still mysterious to growers, researchers and many manufacturers.

Some of the organic nutrient source definitions currently approved in derived-from statements can be grouped as animal derived, plant derived, seaweed derived and mined. Examples of these are:

- Plant Derived: Cottonseed meal, corn gluten, wood ash, hydrolyzed soy and oilseed extract
- Animal Derived: Blood meal, feather meal, bone meal, manure and fish emulsion
- Seaweed Derived: Kelp, (mainly Laminaria and Ecklonia) and bladderwrack (*Fucus vesiculosus*)
- Mined (with specific limitations): Sodium nitrate, rock phosphate, muriate of potash, potassium sulfate, potassium magnesium sulfate and greensand

The relative merits of each of these organic liquid nutrient sources are currently one of the hottest research topics in organic hydroponic systems. Most of the conventional wisdom is still based on historical data of synthetic nutrition—particularly nitrate nitrogen. Essentially all of the organic sources listed above that provide nitrogen have some percentage of nitrate nitrogen, which is recognized as one of the most available sources of nitrogen to plants. Recent research, much of it still unpublished, points to the high probability that many amino acids are readily available to plants. These amino acids, when provided in a hydroponic nutrient solution, may actually be used more efficiently than our current knowledge base recognizes, since it's built on generations of synthetic nutrition research.

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Embracing a Sustainable Future

by ANNE-MARIE HARDIE

Sundial Farm, a family-owned and operated orchid company for years, decided to step outside of the box and launch into a sustainable business. One that could save water and help feed a community.

Sean Keany turned one of his parents' orchid greenhouses into Sundial Farm, a hydroponic growing operation that produces leafy greens.

It was 1980 and Laura and Dennis Keany decided to delve into orchid farming with their business South Coast Orchid, producing specialty Phalaenopsis orchids. During a routine agricultural inspection, the Keanys were advised of impending water restrictions due to the existing water pressure on California's water supply. Cymbidium orchids relied heavily on water and use, and so Dennis and his family began to consider alternative options.

At the same time, the Keany's son, Sean—who was just finishing school at the University of California-Santa Barbara—was researching an effective way to use the existing space. The idea was to use the growing space to its maximum potential while minimizing the environmental impact. The space was already available; the concern was how to make it a sustainable operation that both conserved water and was profitable.

Sean's research led him to the world of hydroponics and other soilless medium growing, whose main focus was water conversation. This project evolved from an inkling of an idea to a full-blown company in a relatively short period of time and Sundial Farm was born. Today, just over a quarter of the original property is appointed for Sundial Farm operations with plans for continued growth. The project began by converting one of their major houses originally used for orchids to a hydroponic growing operation.

Hydroponics paves the way

"Hydroponics uses much less water. The industry standard for hydroponics is anywhere from 75% to 90% less water than a conventional farm," said Tarek Hijazi, Director of Regulatory Affairs and Operations for Sundial Farm. To avoid contamination from bacteria, the water is thoroughly filtered with a UV light for bacteria and to remove any inorganic solids that could contribute to contamination.

Although not certified organic, Sundial Farm tries to follow the organic guidelines, using fertilizer that's been approved by the Organic Materials Review Institute (OMRI). To combat pests, the farm incorporates both natural oils, beneficial insects and unrefined minerals that are sourced naturally.

Evolving for a better tomorrow

Tarek became involved in Sundial Farm just over two years ago, when he was approached by Sean to help him brainstorm ideas on how to take the hydroponic business to the next level. His goal was to not only formalize the process, but help organize this quickly growing branch of the company.

The main product for Sundial Farm remains leafy greens, including butter lettuce, romaine and arugula.

"Sean established a groundwork and then I sort of distilled it all in, and it's been expanding—adding traceability and cohesiveness to a program that is trying to demonstrate to our customers and all of our clients that we are committed to providing an excellent sustainable product," said Tarek.

Still relatively new to hydroponics, Sundial Farm is in a continual state of evolution with both Sean and Tarek constantly reviewing how the process can be improved, whether it's using new technology, reducing costs, increasing sustainability and increasing productivity.

"We try to keep our ears to the ground, as far as innovative technology goes. And that consists of keeping our ears open, keeping our ears open," said Tarek.

In five years, the business has grown from a handful of customers to upwards of 15 wholesale customers during the summer. Today, Sundial Farm's hydroponic customers include restaurants, wholesale clientele and an expanded market presence at local farmer's markets. As a direct response of this growing demand, Sundial recently expanded to three 5,000-ft. hydroponic bays and 15,000 ft. of growing space.

The main product remains leafy greens; however, the varieties have tripled from butter lettuce, romaine and arugula to 12 different varieties. One of the additional benefits is being able to grow what was traditionally seasonal produce year-round, including butter lettuce and basil. Being able to offer fresh local produce to the community less than two and a half miles away from Sundial Farms is something that Tarek is extremely proud of.

Sundial Farm is part of a supportive community of hydroponic growers. Their neighboring greenhouse, Wonderland Produce, grows hydroponic tomatoes, cucumbers, pepper and eggplants.

"We support [them] in his mission, as he supports us in ours. We're both hydroponic growers," said Tarek.

Tarek is extremely grateful for the opportunity to not only apply his business skills, but to be involved in an agricultural business that will help sustain future generations. For those interested in venturing into hydroponics, he recommends beginning small, with a hobby project to learn the process and visiting local farmer's markets, particularly other hydroponic growers.

"Come up, ask questions and learn," said Tarek. "That's all I want you guys to do, everybody to do, is just to learn. That's what I'm doing."

ANNE-MARIE HARDIE is a freelance writer/speaker from Barrie, Ontario, and part of the third generation of the family-owned garden center/wholesale business Bradford Greenhouses in Barrie/Bradford, Ontario.

Notable Variety

Here's a roundup of a few of the new vegetable varieties for 2015. It's not a comprehensive list, but it will give you a flavor of what's out there.

by **JENNIFER DUFFIELD WHITE**

While growers and breeders have always geeked out, to a certain extent, over the introductions of new varieties, the general public is now attuned to—and excited by—the nuances of plant breeding. And thus, each season's introductions now have the added attribute of exciting the vegetable-eating public with their unique traits. It might be an entirely new cross of vegetables, like the Kalette, a unique color, or a "mini" version of a standard or an improvement on an old favorite.

Photo courtesy of PanAmerican Seed.

▲ Two new mixtures join the SimplySalad series, notable for being the first multi-species, multi-seed pellet for salad. PanAmerican Seed introduced the Summer Picnic mixture, giving you a season extender and red and green lettuces that are heat resistant and late bolting. The new Wonder Wok mixture features a mix of Asian greens, including mustards, kale and bok choy.

◀ For a lettuce variety with a sweet taste, dark-green leaves and notable disease resistance, check out Sandy lettuce, bred by Seeds by Design. It's the first lettuce to win an AAS national award in 20 years, thanks in part to its exceptional resistance to powdery mildew and its slow-to-bolt nature.

▲ Seminis Vegetable Seeds has a winner in their Emerald Fire jalapeño pepper. Featuring thick walls with little cracking, it's a prolific producer on a compact plant. Emerald Fire secured a 2015 AAS Award for its positive attributes, which also include disease resistance.

▼ Get ready to turn some heads with trademarked Kalettes—the result of years of breeding work that started with crosses between Brussels sprouts and kale. They grow on a stalk, like Brussels sprouts, but they produce open, flower-like florets, which you harvest when they're 2 in. in diameter. Johnny's Selected Seeds offers three bicolor varieties, each for a different harvest window. Autumn Star Kalettes, their newest introduction, is best for an early season harvest.

Autumn Star Kalettes

Photo courtesy of Johnny's Selected Seeds.

▲ Another Seminis variety to look out for is Flaming Flare, a Fresno pepper that adapts to a number of climates and offers a sweeter flavor than is typical. It's also an AAS Winner and boasts large fruits and a strong yield.

▲ In a category all its own, Pretty N Sweet is remarkable in that it's both an ornamental pepper and edible. Seeds by Design bred this multi-colored pepper to be compact (18 in.), prolific and sweet tasting. Its impressive garden performance and taste earned it a 2015 AAS Award.

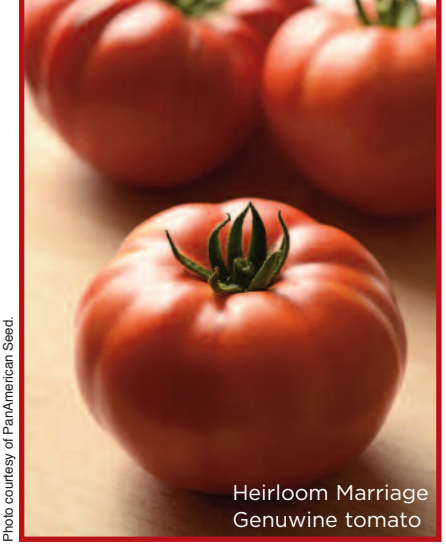

Photo courtesy of PanAmerican Seed.

◀ Call them new, or hybrid heirlooms, or—as PanAmerican Seed calls them—Heirloom Marriage tomatoes. These new additions to the Handpicked Vegetables series from PanAmerican Seed are the result of crosses between classic heirlooms. The New Perfect Flame F1 is a cross between Early Peron and Flammé. Meanwhile, Brandywine and Big Dwarf were combined to get the pink beefsteak, Big Brandy F1. And don't forget slicer tomato Genuwine F1 (a cross between Costoluto Genovese and Brandywine), which is ready to harvest 12 to 19 days earlier than the traditional Brandywine.

▶ Butterscotch butternut squash from Johnny's Selected Seeds will attract attention with its "cute" factor—its small fruit (6 in. long) produces just one or two servings. It'll make a good space-saving option with its compact vines, but also expect a sweet taste and excellent powdery mildew resistance. It's also an AAS Winner.

Photo courtesy of Syngenta.

▲ In the ground or on the patio, the new Summerpick hybrid beefsteak tomato presents a balanced taste—of sweetness and acid—and impressive 11-oz. fruit. Syngenta's Summerpick falls in the early mid-season category and offers high disease resistance.

▶ Another AAS winner in the squash category is Bossa Nova, an eye-catching zucchini with mottled dark- and light-green skin and an improved taste. Seminis Vegetable Seeds bred this long-producing variety. Compact plants will be ready to harvest earlier and longer than most zucchinis.

◀ A radish that will receive some press this year is Roxanne radish from Bejo Seeds. An AAS national winner, it's received accolades for both its taste and form. Bright red in color, with a nice shape and good uniformity.

Photo courtesy of Johnny's Selected Seeds.

▲ Johnny's Selected Seeds came out with an entire series of blocky bell peppers suited for heated greenhouse production. The F1 peppers stand out with their high yield and big, bold fruits. Choose from Orangela (orange, pictured), Felicitas (red) and Bentley (yellow). They'll do best in high-tech greenhouses or lower-tech greenhouses in mild climates. (If you do any growing in heated tunnels, check out their new Moonset and Sprinter peppers, instead.)

Photo courtesy of Syngenta.

▲ Another variety joining the ranks of sweet bell peppers is Bayonet from Syngenta. You'll find bountiful harvests with this one, as its continuous fruiting nature provides for multiple harvests throughout the season. Combine that with a strong, open plant structure, good leaf coverage and high yields. Once it's been picked, look forward to a long shelf life.

▶ Compact cuteness combines with high yields in the new Patio Baby Compact Black eggplant. This new introduction from PanAmerican Seed was also a 2014 All-America Selections Regional Winner. It produces baby-size eggplants, starting early, with a wide harvest window. Plug crops finish in four to five weeks. Plug to finish is four to seven weeks.

Photo courtesy of PanAmerican Seed.

Taking the Right Steps

Following these simple sanitation protocols may help you prevent pest outbreaks.

by **KRISTIN GETTER**

In light of recent floriculture disease outbreaks during the last two production years, like impatiens downy mildew and tobacco mosaic virus, now may be a good time to review your greenhouse sanitation protocols.

A good and easy first step in greenhouse sanitation is to physically remove all crop debris. Weeds, plant debris and unsalable plants can serve as sites for insects and mites to live and for diseases to develop, progress or spread. Remove all weeds and crop debris and place them in a tightly sealed, covered garbage bin so that pests and pathogens are not able to migrate out of the trash and into your crop (Figure 1).

Remember to remove the trash daily. Also, remove spilled media because organic residues from plants and growing media reduce the effectiveness of disinfectants (Figure 2).

If you ultimately compost the removed organic material, make sure the compost pile is at least 30 ft. away from the greenhouse and not uphill or downwind from the greenhouse (Figure 3). Situating the compost pile in this manner will prevent pests from migrating from the compost pile back to the greenhouse. When removing diseased or infested plants, discard them into containers or bags that are immediately adjacent to the plants and seal the container or bag to transport them out of the greenhouse immediately. In this way, inoculum or insects are contained and not spread throughout the greenhouse during transport.

Once all surfaces are free of organic matter, consider power-washing structures and walkways with soap and water when in between cropping cycles. Then, clean those same surfaces with a disinfectant. Make sure propagation or pruning tools, such as knives, scissors, etc., are properly disinfected after being used on each bench or each variety or cultivar.

It's also best not to reuse pots, as some diseases, like Thielaviopsis, are capable of surviving on recycled trays and thus infecting new crops. However, if you must use recycled containers, be sure that all organic matter is removed from the pots first and then disinfect them properly with a bleach, quartinery ammonium or peroxide product (Figure 4). Some of these cleaning products have a short life span, so you may need to create new batches of disinfectant frequently while using it.

Also, remember to train employees to keep all irrigation hose nozzles off the ground. In fact, any tool that touches the floor should be disinfected before it touches any growing surfaces. While it may be tempting to do so, don't reuse growing media that's fallen on the floor during potting or during container filling operations due to the potential for contamination.

Once the greenhouse is sufficiently sanitized, to maintain the cleanliness, consider restricting entry into growing areas to nec-

Figure 1. Organic plant debris that's left discarded in an uncovered container may be a breeding ground for pests and pathogens that could potentially infect your crop.

Figure 2. Removing plant debris and spilled media from this stone greenhouse bench will make disinfectants more effective.

essary personnel and supervise all visitors. Consider requiring everyone to clean their shoes before entering growing areas by first removing any soil on the shoes and then using a foot bath or foot mat that contains disinfectant. Remember to change the disinfectant daily in these footbaths or mats. Also, make sure employees wash their hands thoroughly with warm, soapy water, and perhaps other sanitizing products as well, before work and at intervals throughout the day before handling plants. Think about having employees use protective clothing, such as disposable or sterile coveralls (Figure 5), gloves or shoe coverings, during potting or transplanting, when taking cuttings or when rouging diseased plants. Remove and dispose of used protective clothing before working with healthy plants.

Now that proper cleanliness protocols are in place, be sure not to introduce new problems from plant materials being brought into the greenhouse. Purchase high-quality, certified, disease-free stock whenever possible. Consider arranging a visit to your plant supplier to see their sanitation program. When new plant material is brought into your greenhouses, quarantine it in a separate area at first to inspect for disease and insects.

KRISTIN GETTER works for the Michigan State University Extension in the Department of Horticulture.

Figure 4. While it's best to not reuse plant cotainers because of potential disease carry-over, removing all organic debris from the pots and soaking them in a disinfecting solution will help minimize this disease risk.

Figure 5. Consider having employees and visitors wear protective gear when entering sensitive propagation areas of the greenhouse.

Figure 3. A compost pile that's situated too close to the greenhouse may allow pests and pathogens to migrate from the pile back into the greenhouse.

Sustainable Pest Management in Greenhouses and High Tunnels

Researchers at Cornell University find out if insect outbreaks can still be controlled with biologicals even in unheated structures.

by **JUDSON REID**

Growers using greenhouses in which temperature, light and relative humidity are controlled have relied for many years on releases of natural enemies to manage aphids, thrips and two-spotted spider mites. However, many of the natural enemies used to manage these pests in heated structures are too sensitive to swings in air temperature and relative humidity to be used in cool structures, such as minimally heated greenhouses and unheated high tunnels.

Because these season extension tools are widely used by organic and sustainable vegetable growers, SARE (Sustainable Agriculture Research & Education) funded a project to study the efficacy of biological insect control in minimally heated greenhouses and high tunnels. Researchers conducted 23 case studies involving tomatoes, cucumbers, eggplants, winter greens and peppers grown in greenhouses and high tunnels at nine locations in upstate New York from 2007 to 2009. This article reports the results and provides detailed advice on how growers can use natural enemies to manage insect pests in minimally heated greenhouses and unheated high tunnels.

TWO-SPOTTED SPIDER MITES

The most common spider mite pest in greenhouses and high tunnels in the Northeast is the two-spotted spider mite (*Tetranychus urticae*). This mite prefers hot, dry environments. It damages plants by puncturing plant cells and draining the contents of the cells, causing the leaves to become spotted or stippled. In the SARE study, the predatory mites *P. persimilis, A. californicus* and *A. cucumeris* were used to manage the two-spotted spider mite on tomatoes and cucumbers in greenhouses and high tunnels.

Researchers found that spider mite populations increase rapidly and recommend releasing controls at the first sign of mites. They also found that it was useful to make a second release, use higher rates and/or release several generalist predators at one time.

Scouting for two-spotted spider mites

- Look for the characteristic spotting on plant leaves.
- All spider mites have four pairs of legs. The two-spotted spider mite has two prominent spots on the upper surface of its body.
- Look for mites on the undersides of leaves. Also look for their silken webbing.

Natural enemies

Phytoseiulus persimilis, a highly specialized predator mite, works best at a temperature of 65 to 80F (18 to 26C) and a relative humidity of at least 60%. This predatory mite preys only on the two-spotted spider mite, so in the absence of the spider mite, the predatory mite will perish. It can be cannibalistic when spider mite prey is unavailable. For this reason, highly specialized predators such as *P. persimilis* are difficult to use in preventive programs and are more effective after pest populations become established.

This predatory mite is one of the mainstays of greenhouse biological control programs for management of spider mites on vegetables and ornamentals, but the SARE-funded researchers found that in high tunnels the temperature and humidity fluctuated too widely to support this species except for several weeks in spring and summer. *P. persimilis* was the natural enemy most commonly released to manage the two-spotted spider mite in the SARE study, but results were inconsistent.

Application

In tomatoes and cucumbers, release 1,000 mites per 10,000 sq. ft. Release *P. persimilis* at the first sign of an infestation of two-spotted spider mites. It may be necessary to remove heavily infested plants or apply a knockdown spray before releasing this predatory mite. After releasing, continue to monitor the mites, as well as the predatory mites. Repeat releases as needed.

Amblyseius californicus is a general predator that's most efficient at a temperature of 60 to 80F (15 to 26C) and a relative humidity of at least 60%. It feeds on spider mites, thrips, aphids and other pests, but it prefers the two-spotted spider mite and will consume all life stages of this pest. This predatory mite can survive longer than *P. persimilis* in the absence of prey and has been shown to successfully control the two-spotted spider mite in greenhouses and high tunnels.

The SARE study results indicated that A. californicus can be used in both greenhouses and high tunnels and can sustain itself better than *P. persimilis* because it can be released when pest numbers are still low and sustain itself on pollen, insects and mites while pest numbers are still growing.

Application

Release this beneficial mite when a combination of pest species, such as two-spotted spider mites and thrips, are present and require action. Release 1,000 mites per 4,500 sq. ft. of infested area on tomatoes, cucumbers and most other crops in greenhouses and high tunnels. Release *A. californicus* at the first sign of an infestation of two-spotted spider mites. It may be necessary to remove


Spider mite damage on cucumbers.

heavily infested plants or apply a knock-down spray before releasing the beneficial mite. After releasing, continue to monitor the two-spotted mites as well as the predatory mites. Repeat releases as needed.

Researchers recommend using a combination of tools to manage one or more pests at the same time, or when pest numbers are very high. Strategies can include spraying with a pesticide to knock down pest numbers, followed by releases of one or more species of natural enemies. A combined release of *P. persimilis* and *A. californicus* provided a low level of control of the two-spotted spider mite on tomatoes in a greenhouse at one location in 2009.

The release of *P. persimilis* and *A. cucumeris* also controlled the two-spotted spider mite and thrips, respectively, on tomatoes, cucumbers and blueberries in a high tunnel at one location in 2009.

THRIPS

The most common thrips in greenhouses and high tunnels in the Northeast are flower thrips (species of *Frankliniella*) and onion thrips (*Thrips tabaci*). Flower thrips damage flowers and leaves. Onion thrips are pests on several hundred host plants, including cucumbers, tomatoes, eggplants and peppers. Thrips reduce the yield of crops by puncturing plant cells with their mouthparts. They damage the leaves and blossoms of host plants, as well as transmit viruses.

Scouting for thrips

- Scout weekly and release natural enemies at the first sign of damage or when first detected on sticky cards.
- Look for the characteristic white streaks or spots on leaves, flecked with black spots of feces. Damage is often found on the lower leaves of cucumber and tomato. In sweet peppers, the damage first appears in the upper, youngest leaves. On vegetable flowers, thrips feeding makes silvery white streaks on the petals. Thrips do not leave behind silken webbing.

Natural Enemies of Thrips

Amblyseius cucumeris prefers a diet of thrips but is considered a generalist because it can survive on pollen and spider mites in the absence of thrips. *A. cucumeris* will work best at a temperature of 70F (21C) or above and a relative humidity above 65%.

Results indicate that *A. cucumeris* should be used to manage thrips in spring and summer crops of organic vegetables in high tunnels. In comparison with other predatory mites that prey on thrips, *A. cucumeris* costs less, has greater survivability and a broad range of prey, and works well when released preventively early in the growing season.

Preventive releases are especially important on cucumbers, which are more attractive to thrips than other common high-tunnel crops. *A. cucumeris* is a generalist predatory mite and it lends itself to preventive approaches because it can survive on pollen or other insect and mite pests in the absence of the target pest thrips. Control of thrips was consistent and this predatory mite was a repeated success story.

In 2009 and 2010, releases of *A. cucumeris* controlled thrips on cucumbers in high tunnels at several locations. Overall, thrips levels were reduced by an average of 85% after releases of *A. cucumeris.*

Application

Release *A. cucumeris* at the first sign of an infestation of thrips. It may be necessary to remove heavily infested plants or to apply a knock-down spray before releasing the predatory mite. After releasing, continue to monitor the thrips, as well as the predatory mites. Repeat releases of natural enemies as needed.

Orius insidiosus (minute pirate bug) is a common generalist predator found naturally in many field-grown crops. It preys on thrips, whiteflies, spider mites, aphids and many other pests. It can survive on pollen in the absence of prey. The minute pirate bug will work best at a temperature of 70 to 90F (21 to 32C) and a day length of 11 hours or more.

Application

Make releases at any time, early or late in an infestation of thrips because the minute pirate bug can control heavy infestations quickly. For preventive control, release one to two minute pirate bugs per plant in greenhouses. When treating a heavy infestation of thrips, aphids, or whiteflies release 500 minute pirate bugs per 250 sq. ft. Minute pirate bugs will move efficiently throughout the infested plants and will continue to kill even when they don't need to eat. After releasing, continue to monitor the thrips, as well as the pirate bug.

Use a combination of tools to manage one or more pests at the same time or when pest numbers are high. In 2007, one release of minute pirate bugs together with three releases of the generalist predatory mite *A. cucumeris* eradicated thrips on cucumbers in a greenhouse. Two releases of *A. cucumeris* made earlier in the season likely would have been sufficient.

Releases of *P. persimilis* and *A. cucumeris* successfully controlled the two-spotted spider mite and thrips on tomatoes, cucumbers and blueberries in a high tunnel at one location in 2009.

WHITEFLIES

Several species of whiteflies can be found on vegetable crops and flowering annual plants in the Northeast. Whiteflies suck sap from plants and excrete honeydew. Adults lay eggs on the underside of leaves. The first-stage nymphs crawl on the plant for a short time before becoming immobile scales. The scales are flattened disks, much like one layer of a round cake.

Their feeding may cause stunting, wilting or yellowing of plants, defoliation, reduced yields and plant death. The sticky honeydew they leave behind on the plant can interfere with photosynthesis. Whiteflies can reproduce rapidly in a favorable environment that is absent of natural enemies. >>>

Scouting for whiteflies

- Inspect the upper and lower surfaces of plant leaves weekly for adults, eggs and immobile scales. Look for adults near plant tops or the ends of branches. The adults are tiny, white insects with four wings. If you disturb the plant foliage, adults will fly up and be easier to spot.
- Use a hand lens to identify scales because they're translucent and difficult to see. You can also use yellow sticky cards (one card per 1,000 sq. ft.) to monitor adults. Place the cards just above the tops of plants and record the number counted once or twice each week.

Natural enemies of whiteflies

Encarsia formosa is a tiny wasp that attacks greenhouse and silverleaf whiteflies. Adult female *E. formosa* kill whitefly scales in two ways: by puncturing and feeding on scales, or laying their eggs in scales. *E. formosa* eggs hatch into tiny larvae, causing the whitefly pupae to turn black as the young wasps mature. Suppliers ship the parasites inside the blackened whitefly scales, which are attached to cards in batches of 50 to 100 per card.

E. formosa prefers an average temperature above 64F (17C) and 70% relative humidity. Release *E. formosa* at the first sign of whiteflies on yellow sticky cards. Release at one- to two-week intervals for six to eight weeks.

Researchers used *E. formosa* (Nile Delta) to manage whiteflies on tomatoes in high tunnels at one location in 2008. They made only one release of *E. formosa* when whitefly numbers were high. The release managed, but didn't eradicate, whiteflies. The whitefly population began to grow after several weeks and remained high, but the grower felt this pest was sufficiently controlled.

Application

Release *E. formosa* preventively at a rate of one card per 6 sq. ft. every two weeks. At the first sign of whiteflies on plants, release one card per 3 sq. ft. Suppliers may have additional instructions.


The author, Judson Reid, scouting cucumbers in a high tunnel.

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New Products February 2015

Ball DPF LLC

Now OMRI Listed, Nature's Source Organic Plant Food 3-1-1 can be used for organic production. Use it for consistent, toned growth and for quick green-up. Provides a sustainable option for your organic greenhouse, nursery or farm. **Reader Service Number 225**

BioSafe Systems LLC

BioSafe Disease Control Ready to Spray concentrate is now labeled and EPA registered for use in hydroponic systems. Use BioSafe Disease Control Ready to Spray concentrate in hydroponic and aquaponic systems to prevent algae and plant root rot diseases caused by waterborne and water transmitted plant pathogens, such as pythium and phytophthora*. (*Not approved for use in California.) **Reader Service Number 226**

Hort Americas LLC

The Bato Allround Trough from Hort Americas is suitable for all substrates. The trough can be installed directly on the ground because its two ridged legs provide stability. It features a unique drainage system for substrate moisture control. Plus, the trough offers several drainage options, including customized drain holes and two systems for the collection of drained irrigation water. **Reader Service Number 228**

Dynamic Systems Inc.

Dynamic Systems introduces a mobility option to the SIMBA Produce Packing, Traceability and Labeling System. It provides detailed information for fresh produce companies from the greenhouse, field or truck. Using a rugged mobile tablet, the SIMBA user enters details (species, grade, weight, lot number) into SIMBA and prints a PTI-compliant label on a mobile printer. An enormous amount of detail is available for sales and management in real-time. **Reader Service Number 227**

Johnny's Selected Seeds

Butterscotch PMR Organic (F1) Squash, an AAS Award Winner, is a delicious, single-serving, mini-butternut. Unusually rich, sweet, starchy flavor for a butternut type. Small, 1- to 2-lb. fruits mature early. Limited storage, best up to three months after maturity. Short, space-saving vines resist powdery mildew. Average yield: 3 to 4 fruits/plant. Organically grown. **Reader Service Number 229**

PanAmerican Seed

SimplySalad is a multi-species multi-pellet containing three or more seedlings per pellet. New Summer Picnic contains more heat-tolerant lettuce, including red and green varieties. Its quick crop time can extend your selling season. Visit www.panamseed.com for culture information. **Reader Service Number 230**

Syngenta

Bigdena beefsteak tomato hybrid features a strong, vigorous plant that produces consistently high yields of large, uniform fruits with excellent flavor and shelf life. Due to its vigorous plant and broad disease resistance, it doesn't require grafting. Growers appreciate its ability to tolerate high summer temperatures and marketers appreciate its excellent fruit quality and long shelf life. Go big—grow Bigdena! **Reader Service Number 231**

Top Misconceptions About CEA

Thinking about getting into hydroponic growing or expanding your current business? You need to read this first.

by **NEIL S. MATTSON, LOUIS D. ALBRIGHT, DAVID DE VILLIERS, MELISSA BRECHNER & ROBERT LANGHANS**

Controlled environment agriculture (CEA) uses advanced horticultural and engineering techniques to optimize crop production, quality and production efficiency. A controlled environment allows crop production year-round in regions where they would otherwise be impossible. With today's consumers increasingly demanding a diet that includes fresh, high-quality vegetables, CEA production systems have seen increased attention by both traditional growers and entrepreneurs alike. While CEA greenhouses can supply a tremendous quantity of produce, they also require high capital investment and operating costs. Furthermore, their successful operation demands sound knowledge of a wide range of horticulture, engineering and business skills.

The Cornell University CEA research group has more than 25 years of research experience in CEA greenhouse hydroponic vegetable production. In 1999, the Cornell CEA Program constructed a small commercial scale greenhouse (8,064 sq. ft.) for hydroponic lettuce production in Ithaca, New York. The facility has a production capacity of 1,245 heads of high-quality lettuce per day (see Figure 1).

Below, we provide food for thought in the form of a selection of common CEA misconceptions. Many of the misconceptions noted are based on experience operating the facility as a commercial enterprise. We hope these thoughts will help you to make well-informed decisions when considering beginning or expanding your own CEA operation.

"Anything that can go wrong, will go wrong."
MURPHY'S LAW

"Murphy was an optimist."
BASIC LAW OF CEA

Production misconceptions

We will have full production from the start. Business models look great when you assume full yields from the beginning. In practice, it typically takes a year or two to work out the kinks and ramp up to full-scale production. We think it takes at least an entire year to gain experience as a grower even if you're only producing a single crop. There are problems associated with each season involving excess/lack of light, heat and humidity, occurrence of diseases and insects, and equipment failures.

We recommend growers start small, solve problems, broaden the market for their produce and then scale-up. Our rule of thumb for safety is to be capitalized sufficiently, so that you'll survive with no sales in Year 1 and half sales in Year 2. This is a pessimistic viewpoint, but provides insurance.

We avoid insect or disease problems. We hear this a lot, especially from folks interested in warehouse/factory growing. Despite your best intentions to exclude insects and disease, there will always be insect and disease problems. Some will be persistent and some new issues will show up every year.

Some of the more common problems we've noticed include Pythium root rot, powdery mildew, aphids and thrips. A talented grower will always be on the lookout. Assume there can be a problem at any time. Continually scout. Have specific control plans in place to control each pest.

Failure to understand the importance and cost of providing adequate light. Light is the driving force for photosynthesis and thus yield of hydroponic crops. Humans are very bad at determining how much photosynthetically active radiation (PAR) is available because we perceive light differently than plants. It's important to install multiple quantum sensors in the greenhouse to log PAR. The daily light integral (the total quantity of photosynthetic light plants receive in a day) varies greatly season-to-season and even day-to-day.

In our CEA head lettuce system, we use movable shading and supplemental lighting to provide a DLI of 17 moles of PAR per square meter every day to ensure consistent year-round production. When DLI is supplied at this level, we can produce a 5-oz. head of lettuce in 35 days from seed. Shading is important because lettuce plants develop leaf tip burn when DLI is higher than 17 moles. (Assuming vertical airflow fans [VAF] are operated. Without VAF, the limit is 12 moles. See Figure 2.)

At lower DLI, plants take longer to reach harvestable yield. In Ithaca (one of the cloudiest places in the contiguous 48-states), we provide 30% of the plant's light needs from supplemental light when averaged across the year. Our lighting cost is expensive—about $12 per sq. ft./year. But if we didn't supply it, yields would be markedly lower. In the winter, the DLI in Ithaca is low (averaging 5 moles per square meter per day in the greenhouse). It takes more than 100 days to produce a 5-oz. head of lettuce with no supplemental light. For other crops, such as spinach, low DLI leads to unacceptable crop quality.

Marketing misconceptions

Everything that's grown will be sold. Marketing produce at a price the grower can bear is among the most difficult challenges in CEA production. It takes time to cultivate relationships with customers. Often, you'll need to begin by showing potential buyers examples of the product you can produce. For this reason, it often makes sense to start with a small-scale prototype facility at first then expand as you increase your market. Selling everything you grow requires a complex marketing plan with many contingencies.

Figure 1. Inside the small, commercial scale hydroponic greenhouse developed by Cornell CEA.

Figure 2. Leaf tip burn on head lettuce resulting from a high daily light integral.

Customers will be loyal. Produce managers will promise to take everything you can grow … until they find a better price elsewhere. Restaurants may be more loyal, but outside forces such as seasonal demand may affect their willingness to consistently buy your product. CSAs are a good way to get "loyal" customers, but they pre-pay, so they take what they've already pre-purchased. Contingencies must be set up in case you produce less or more than expected.

Customers will understand if a crop fails. You MUST have a backup plan to deal with crop failures. It may be to purchase someone else's product and stick your label on it. Not having produce that a manager is counting on is a sure way to lose customers.

System misconceptions

Nothing will be broken. Something will almost always be broken. An important part of your job will be learning to fix things on a daily basis—remember the basic law of CEA!

Growing plants is mainly about following fixed recipes and relying on computer control. Greenhouse production is the combination of dozens of interacting systems that must work together to produce a crop (seed, substrate, water, fertilizer, environmental control, pest and disease control, labor). Your conditions are likely very different from those given in the textbook recipe. Systems will need to be >>>

adjusted over the growing season and as conditions change.

For example, perhaps your preferred seed variety is no longer available. Your new variety will require tweaks to all of the above systems. While computerized environmental control is important, don't blindly trust the computer. Never rely on just a single sensor—one sensor can easily lose calibration, become covered with dust, etc. Even in a small greenhouse, two (or better, three) is safer.

Aeroponics saves water compared to other hydroponic systems. This is not true. The main driving forces for water uptake are plant transpiration (evaporation from the leaf surface) and growth. The process of plants taking in carbon dioxide for photosynthesis requires the loss of water by the plant. These processes occur whether the plant is grown in soil or hydroponically. Closed irrigation systems do save water because water is captured and reused, but high-quality water is necessary to use these systems.

LED fixtures make CEA lighting cheap. The operating costs of lights should be considered in terms of wall plug efficacy—light output per kWh of total electricity consumed (including electricity for the power supply, ballast and cooling). In terms of wall plug efficacy, LED overhead greenhouse supplementary lighting systems aren't currently better, or only marginally so, than high-wattage greenhouse high intensity discharge (HID) lighting.

A recent comparison of greenhouse lighting fixtures reported that the best LED lamps had a similar efficacy to the best high-pressure sodium (HPS) fixtures (Nelson and Bugbee, *PLOS ONE*, June 2014.). The same paper reported that the capital cost of LED fixtures was five to ten times more than HPS fixtures when calculated per unit of light delivered. Due to the high capital costs, the five-year electricity plus fixture cost was 2.3 times higher for LED fixtures. Over time, LED fixtures will become more economically viable as capital costs decrease and efficacy further increases.

LED fixtures don't give off heat. Because LED efficacy is similar to HPS efficacy (see above), by definition both lamp types convert about the same amount of electricity to light. The rest of the electricity must (necessarily) be converted to heat. The most notable difference is that HID lighting radiates a significant amount in infrared wavelengths, in addition to longer wave radiation from the hot unit, which heats the crop canopy. Part of the LED heat loss is from the back end of the fixture (through the heat sink/fan).

Magical light spectra combinations exist for greatly improved growth under LEDs. This hasn't been proven in scientific experiments. While specific red and blue wavelengths provide adequately for photosynthesis, plants are relatively good at using all light between 400 and 700 nanometers. Moreover, for greenhouse plant growth, sunlight will still be the major source of light and will provide the full spectrum.

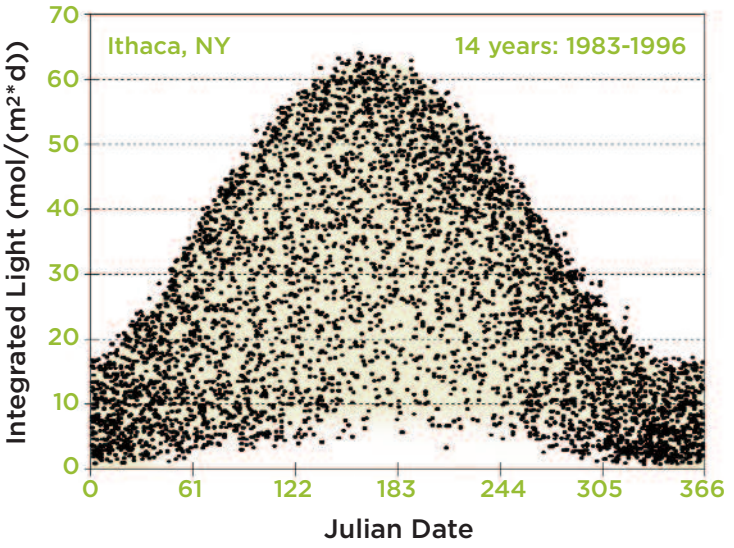

Table 1. Outdoor daily light integral (DLI) in Ithaca, New York, measured over a 14-year period. Each dot represents DLI for one day. Depending on the greenhouse, 50% to 70% of this light will be transmitted into the greenhouse.

Labor misconceptions

Affordable labor will be there when you need it. Intensive agriculture requires a more highly skilled workforce (see "Systems misconceptions"). An inexperienced grower will have a long learning curve and may take several years to reach full production potential. Even with an experienced grower, there's still a learning curve for a new location and new equipment. Many CEA business plans don't take into account that they'll need a highly skilled head grower and haven't taken steps to locate such a person.

We can take weekends and holidays off. You cannot rely on computer control to look after your plants on weekends and holidays. Besides checking the growing environment, daily tasks such as seeding, transplanting, respacing and harvesting will still need to be performed. Your head grower might not want to work 365 days a year; therefore, you must have a plan to provide adequate labor for holidays/weekends.

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