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URBAN AG NEWS

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Jose "Pepe" Calderon

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URBAN AG NEWS

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Urban Ag News is an ***information resource*** dedicated to helping the **vertical farming, controlled environment, and urban agriculture industries** ***grow*** and ***change*** through education, collaboration and innovation.

Urban Ag News actively seeks to become a connector for niche agricultural industries, **bringing together growers with growers, growers with manufacturers, growers with suppliers and growers with consumers**.

Urban Ag News is an ***educator*** providing content through a variety of different media. Through its educational efforts, including its online quarterly magazine and blog, Urban Ag News seeks to provide its users with a basic understanding of the industry and to **keep them informed** of the ***latest technologies***.

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This Crazy Tree Grows 40 Kinds of Fruit

Sam Van Aken, an artist and professor at Syracuse University, uses "chip grafting" to create trees that each bear 40 different varieties of stone fruits, or fruits with pits. The grafting process involves slicing a bit of a branch with a bud from a tree of one of the varieties and inserting it into a slit in a branch on the "working tree," then wrapping the wound with tape until it heals and the bud starts to grow into a new branch. Over several years he adds slices of branches from other varieties to the working tree. In the spring the "Tree of 40 Fruit" has blossoms in many hues of pink and purple, and in the summer it begins to bear the fruits in sequence—Van Aken says it's both a work of art and a time line of the varieties' blossoming and fruiting. He's created more than a dozen of the trees that have been planted at sites such as museums around the U.S., which he sees as a way to spread diversity on a small scale.

NATIONAL GEOGRAPHIC

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WITH JOHN OLIVER

JULY 2015

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FARMER TYLER TALKS WITH BRETT ELLIOTT, FARM MANAGER AT ELLIOTT GARDENS

FARMER TYLER

SPECIAL REPORTS: INNOVATIVE GROWERS

BY FARMER TYLER

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This one-of-a-kind collaborative event unites the most significant brands and influencers in the fresh produce industry for a four-day cycling event that raises funds to benefit the Let's Move Salad Bars to Schools campaign. The inaugural 2014 event raised over $142,000 and placed over 40 salads bars in communities in 11 states, including California, Colorado, Florida, Illinois, Michigan, Minnesota, Missouri, New York, Ohio, Texas, Wisconsin and the District of Columbia.

This year's 300+ mile ride will take place Oct. 19-22. The ride will go through the Great Smoky Mountains of North Carolina and Tennessee and will finish in Atlanta, Ga.

The goal of Tour de Fresh 2015 and its participants is to privately finance 100+ new salad bars in school districts across the country. At a cost of less than $3,000 per salad bar per school, sponsors and participants strongly believe that providing healthy eating opportunities for school children should be a requirement and is the foundation of creating positive change for our future.

This year Hort Americas efforts are also being supported by Village Farms, Riococo, Houweling's Tomatoes, Grodan, Age Old Organics, UrbanAgNews.com as well countless other friends and family. All of our efforts will directly benefit the Earl Nance Sr. Elementary in the St. Louis Public School system.

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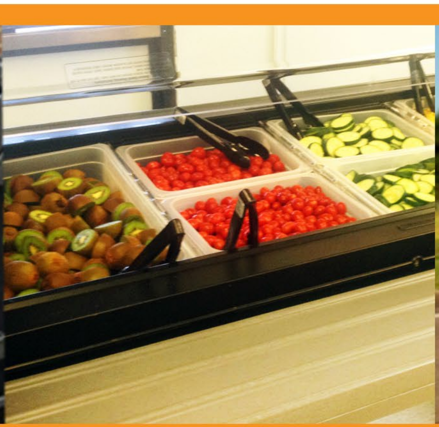

Chris Higgins, General Manager of Hort Americas

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INDOOR VERTICAL FARMING & VENTURE CAPITAL:

A PRO'S VIEW ON HOW TO GET YOUR VERTICAL FARM FUNDED

BY JIM PANTALEO

What a thrill it was to sit down with venture capitalist and ecologically responsible investor, Will Kain of Rusheen Capital Partners for lunch on a warm Santa Monica afternoon in August. RCP is the brainchild of visionary, Jim McDermott (see his latest venture, Fulcrum BioEnergy).

Mr. Kain graciously agreed to meet to discuss the current state of institutional capital flowing into the nascent indoor vertical farming industry, specifically technologies incorporating controlled environment agriculture or CEA. In its most basic definition, CEA is the growing of plants within a closed or semi-closed environment utilizing light emitting diode (LED) technology, irrigation, heating, ventilation and air conditioning (HVAC), and nutrient and substrate methodologies. Hydroponic, Aeroponic and Aquaponic growing techniques and the proven science behind indoor vertical farming answer the challenge of the planet's finite water, resource and land uses. It is estimated by the year 2050 Earth's population will increase from 7 billion inhabitants presently to nearly 10 billion. Traditional agriculture is an unsustainable proposition.

Currently, residing in Venice with his wife and dog, Mr. Kain is living the dream, California Style. This is a rather different lifestyle than his upbringing in often maligned Cleveland, Ohio. The added pain of living through so much local sports team sadness has been "a difficult cross to bear" he concedes between bites at The Lazy Daisy Café on Pico.

Entering the work world from the University of Virginia, Mr. Kain spent five years "on a traditional Wall Street track" at UBS Investment Bank, before landing at Nano H2O, the water desalination firm, as one of the company's earliest employees. Nano H2O would later be acquired by South Korea's LG Chem in May of 2014. It was with Nano H2O however that he finally found his groove with the understanding that Nano's technology would make a real and positive difference in the lives of thousands of people...and for a water-challenged planet.

Let's not mince words; Mr. Kain is looking to save the world.

His goal is simple: Find and invest in those technologies and companies who will markedly 'improve efficiencies' and reverse the ecological damage and environmental harm modern agriculture and industry have wrought upon planet earth in the 21st century. Small effort considering Mr. Kain's focused eye is upon the unproven indoor vertical farming industry. In fact, in mid-2015 there are less than 50 commercial-scale indoor vertical farms in the United States. Those seeking entry into the indoor vertical farming business are challenged with high capital entry costs and everything from unproven business models and grow configurations to a lack of knowledgeable and credentialed master growers and established industry policy and regulatory guidelines.

Admittedly, the sports-minded Mr. Kain understands there will be winners and losers in the vertical farming game, optimistically stating "There are going to be a lot of winners. This is not a winner-take-all business." Such optimism, however, is tempered by the recent bankruptcy of 'plant factory' Mirai Ltd. in

Japan ($10mn in losses) and rumblings of another well-funded, US-based vertical farm headed for the chopping block. Insiders know it was hubris and poor management rather than a lack of market demand or adequate technology or a profitable business model that led to the demise of these once-promising companies. As in the dot-com era, there are some poseurs providing a daily dose of reality...and efficacy...to indoor vertical farming.

I asked Mr. Kain a number of questions focused primarily on where his energies (and capital) are directed and what advice he would give to those seeking to enter the indoor vertical farming business either as investors or operators:

UAN: Tell me how you became interested in this industry and what is your overall sense of the viability, "layers"and geographic "hot spots" for potential proliferation of VFs?

Will Kain: My interest emanates from my most recent experience prior to Rusheen; I was the Vice President of Corporate Development for a company called Nano H2O. We made reverse osmosis membranes for water desalination. That means we made filters that turned seawater into drinking water. Being in the desalination business, you are in the business of managing water scarcity. You don't have to go very far to understand that agricultural uses take up 70% of global freshwater withdrawals; that's a staggering number. We understand that water scarcity is a problem that's coming home to roost in developed countries now, not just developing countries where water scarcity has been an issue populations have been dealing with for years and years.

As you dig into the water story, other resource inefficiencies associated with traditional agriculture [surface], among which about 30% of greenhouse gas emissions come from agricultural sources. You read about groundwater contamination, overuse of chemical fertilizers, the harmful effects of pesticides, herbicides, fungicides, etc. What really occurred to me was the understanding that there is a need for resource efficiencies [in agriculture] as the world grows from 7 to nearly 10 billion people (projected within the next 35 years).

UAN: What are the key factors you consider as "must-haves" for any investment in an indoor, vertical farming operation/start-up?

WK: It's an important question and as with any investment, it's hard to have a specific prescription: if this opportunity does not meet "criteria A, B or C" we're not going to look at it... But... You have to have guidelines and general rules of thumb that help to inform the way you think.

I would say... One is technical know-how or said a little differently, domain expertise. [That] doesn't necessarily mean you have to have someone on your team who is a grizzled CEA veteran because as we all know, there aren't a lot of those. But somebody who is part of the team who has experience with growing; experience with the distribution logistics associated with getting food from the field to a customer base. Be they traditional growers, greenhouse growers or folks who have been in or around those businesses, I think that's a really important factor. And it speaks to a larger, overall investment belief that I have which is TEAM is critical. This is one thing that helps to put a good team together, having some of that domain expertise.

The second thing is you have to have a good sense of what the opportunity is. Some type of market segmentation, whereby you can express to me that you understand what the market looks like. We're not just going to grow something indoors because we can and we think we can sell it but "what why and where" are you growing? Who are you going to sell to? Are you going to have a better price? Are you going to help your customers save costs and increase revenues? Will you help them meet some type of regulatory requirement? There are any number of factors that would allow you to offer a value proposition but what is your value proposition? Why are you different? Why would a customer substitute for you?

With my experience in finance, I look at things through a dollar and cents lens with an understanding of financial projections. They don't have to be particularly robust. They don't have to be really detailed and really granular because we're talking about new businesses and new market opportunities, but a basic understanding of the financial projections for the business would be another thing that's very valuable for me to see.

UAN: Are you averse to investing in any particular geographic region based on political/ social instability? Regions such as the Middle East.

WK: No. At Nano H2O, in the water desalination business, the Middle East is a very important market. We actually did a lot of business in the Middle East in my time at Nano. So I would under no circumstances write any particular region off. Now, there are some legal ramifications associated with doing business with certain, specific countries that you'd want to avoid but as a general matter, I'd say no. There is not any specific region I'd write off for political reasons, the Middle East being a prime example. You've got to be careful. You've got to be smart. You've got to be diligent as to how you enter the market but without question there is money to be made. Look, there are major water scarcity issues in the Middle East. I don't know the specific numbers, but they must import massive amounts of fresh produce, etc. so it seems to me there are real market opportunities there.

UAN: Are you of the mindset "I need to get in on this industry while in its infancy" or are you taking a prudent, "Wait and See" attitude?

WK: I think in general if you are in a rush to find a conclusion that supports your own thesis, you set yourself up for some potential trouble. Everybody has their own bias, I look at CEA as an area I'm interested in but if I'm just looking for self-reinforcing stuff, then I think that's a recipe for getting yourself in trouble from an investment point of view. I'm not in a rush. But I think now is a great time to be looking at the CEA space. I think it's early, but I think it's the right kind of early. There are smart people, there's money flowing into the space, but it doesn't appear as though there is a Gold Rush yet into the CEA space that would in turn drive up valuations and make it tougher to make some returns. I would say I'm taking a "wait and see" approach, but I am positively predisposed to the business and would like to invest sooner as opposed to later.

UAN: Among the "6 Pillars" of vertical farms (Nutrients, Substrates, Lighting, Irrigation, HVAC and Building/Structure), where do you see the strongest areas for investment?

WK: I would say Lighting, HVAC and Building/ Structure and I tend to think HVAC and buildings/ structures are pretty closely related. Understanding efficient building structures allows you to potentially bring down your HVAC costs. I think those three are THE critical pieces of the cost structure of controlled environment agriculture, and cost is what I believe we all need to be laser-focused on today. Because if CEA is going to make a big difference and we are going to feed tens of millions of people through CEA, cost has to be chief in our mind.

I also do think, though, from an investment perspective we have to weigh risks and rewards. As an investor if I'm investing in an HVAC or a building/structural efficiency company, there are other potential outlets for those technologies. Lighting, HVAC, building/structural efficiencies all are very large industries within themselves today, so if we're developing technologies that are helpful for CEA, I believe those are potentially portable into other areas which, from an investment case, that just helps to hedge risk.

The flip side of there being a lot of

winners is that there also are going to be some losers. It's not as though this is guaranteed success for everybody who dips their toe in this controlled environment agriculture space.

This will be competitive and not everybody gets to win. Depending upon what you read, global agriculture is a 3, 5, 7 trillion dollar global market. There's not any one model. There's not any one company. There's not any one solution that is going to be the winner. There will be multiple winners which is good and exciting, but that means that in a market that size there is competition, and with competition you have to execute, you have to be focused on cost, you have to be focused on managing your team in the right way, raising the right type of money…there are a lot of things to making a success.

UAN: In your view, how strongly can technology move the industry forward? Meaning, the use of software, robotics and automation incorporated into networks, server farms (no pun), etc. Based on this symbiosis, are there areas for investment in tech as well?

WK: Absolutely. I think tech has a significant opportunity to move CEA forward, more so than it does to move conventional agriculture through (the use of) precision agriculture or precision farming.

In these controlled environments, advanced sensing, software programs can create instantaneous feedback loops where you understand what is going on at the plant level at all times and (to) be able to adjust things like nutrient, temperature, water or light levels, whatever the case may be. Automation has a huge role to play in indoor agriculture that I don't believe it can play in a conventional farming setting, if for no other reason than sometimes it rains outside and sometimes the wind blows. There are things that can get in the way in the field, whereas in an indoor setting the automation is left to its own devices.

I think there are real investment opportunities in robotics, infrastructure sensing equipment and (software) programs that leverage advanced sensing in the actual growing chamber and then, as I said, that goes through some type of software analysis. I think there's absolutely opportunity there… Including genetics and genomic technology. I don't mean GMOs.

Smart plant scientists understand how to breed seeds and advance plant performance and responses to things like varied nutrient, temperature or light levels. I think there's real opportunity there that hasn't even begun to be explored. How do you optimize seeds and plants for growth in indoor spaces? That's a direction I think is compelling and interesting, but I don't know if there are specific investment opportunities today.

UAN: What are your thoughts on the recent Goldman Sachs/Prudential $39mn funding of AeroFarms in New Jersey?

WK: I think it's all great for this business. I think it's very important. I think it's a really beneficial initial step into the "spotlight." Obviously there are a lot of people who have been working really hard in CEA for a long time so it's not as though AeroFarms is the first one (to receive institutional capital) but it's the biggest one. It's got the biggest names in terms of financial backers when you talk Goldman Sachs and Prudential, so I think it's a great development for the business. I think it's an important use case for us to continue to look at and I'm rooting hard for them because if they win, I believe CEA in general wins.

UAN: Does the involvement of Eric Schmidt (Farm2050), Syngenta and, again, companies like Goldman Sachs and Prudential infusing capital into this embryonic industry mean there's hope for mass adoption of the indoor VF and, conversely, the ability for a company like Rusheen Capital to see strong ROI?

WK: Great investors make bad investments all the time. They'll tell you that! So I don't think the mere fact of the involvement of that impressive list of names that you just laid out means there is an ROI story for them, for any other investor or a body like Rusheen. But what it does do is it builds attention. It builds buzz. It gets you into press and starts to help to disseminate the story which I believe as the story proliferates and more and more people see it and understand it and start to recognize these types of names, you have the chance to get smart people and some additional smart money into the space, like an Eric Schmidt and his Farm2050 initiative. When they launched it maybe a year ago, it was on the cover of the Wall Street Journal and the New York Times and that's great. That catches a lot of folk's attention. Then you follow that reasonably quickly with Goldman and Prudential investing in AeroFarms. These are all things that just help to build the case that there is potentially something here. And as we know, the way that markets work, if we know there is something in the 'offing' in CEA, attention, money, resources go into businesses where there's potential for ROI. Ultimately, yes, the involvement of guys like Goldman helps.

But it all comes down to execution. And a rising tide does raise all boats, sure, but those boats have to be executing well. They have to have the right fundraising strategy, the right commercial strategy. They have to build a good team. Simply by having Investor X or Investor Y, it doesn't guarantee success by any stretch of the imagination.

The author would like to thank Will Kain for his time and insight in participating in this interview. Further gratitude goes to Chris Higgins of Hort Americas and the founder and editor of Urban Ag News.

Jim Pantaleo works to develop all aspects of indoor vertical farming and writes as an industry advocate.

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Urban Ag News is a *connector* for a niche industry. We bring together farmers, growers, researchers, educators, manufacturers, suppliers, as well as everyone else interested in controlled environment agriculture (CEA). Our goal is *education.* By providing a unique blend of entertaining and educational content our readers and viewers will get basic understanding of the science, leaders and technology shaping the industry and leading us into the future.

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INDOOR AG-CON NEW YORK
OCTOBER 15

We wanted to encourage you to join us at an upcoming event; Indoor Ag-Con New York. Indoor Ag-Con hosts events about indoor agriculture; growing produce and raising fish using hydroponic, aquaponic and aeroponic techniques in greenhouses, warehouses and containers, and will be hosting its first New York event on October 15, 2015 . Now in its fourth year, Indoor Ag-Con's two day annual event is hosted in Las Vegas in the spring, and has welcomed participants from as far afield as Sweden, Israel and New Zealand. It has featured keynotes from industry leaders such as Priva, Village Farms and Freight Farms, has sold out each of its events, and looks forward to building on this success as the indoor agriculture industry matures. For the first time, Indoor Ag-Con is coming to New York in fall 2015 with a one day event that looks at indoor agriculture differently, asking 12 industry leaders to talk not about their companies or academic studies, but about their wider visions, whether that's bringing open source big data to all farmers or placing their company in the context of the circular economy. Confirmed speakers include the CEOs of Aerofarms, Bright Farms, FarmedHere, Gotham Greens, Illumitex, Sundrop Farms and Zero Carbon Food, as well as leading researchers from Cornell University and Wageningen UR. They'll be covering topics as diverse as the impact of drought on agriculture and the use of robotics in greenhouse and vertical farm environments. The event is exclusive, at no more than 120 participants, to ensure that everyone has a chance to have their voice heard, and there will be extended discussion periods. In short, it's your chance to hear what's driving the indoor agriculture's visionaries, and to throw your own opinions into the mix. Registration at $399 is available now at Indoor Ag-Con's website.We hope that you'll be able to join us!

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Photos courtesy of Houweling's Tomatoes

HOUWELING'S TOMATOES SHOWCASES "THE FUTURE OF FARMING" AT ITS NEW GREENHOUSE FACILITY

HOUWELING'S TOMATOES' NEW 28-ACRE GREENHOUSE OPERATION IN MONA, UTAH, IS USING WASTE HEAT AND CARBON DIOXIDE FROM A NEARBY POWER PLANT TO SUSTAINABLY PRODUCE TOMATOES YEAR-ROUND.

BY DAVID KUACK

Houweling's Tomatoes' 28-acre greenhouse facility in Mona, Utah, is equipped with 13,500 high pressure sodium lamps that that generate 17,000 lux.

During the second week of February this year Houweling's Tomatoes began harvesting tomatoes at its new 28-acre greenhouse facility in Mona, Utah. This is the first of four phases to be constructed at the site, which includes 5 acres of packing house. The facility employs around 160 people.

Houweling's is promoting its "Utah Grown" tomatoes, which include tomatoes on the vine, heritage beefsteak, grape tomatoes, cocktail and roma tomatoes. Located 75 miles south of Salt Lake City, 95 percent of the tomatoes are sold within the state with some being shipped to Florida and California. Its main customers include Smith's, Costco, Albertsons, Sam's and Walmart.

Using waste carbon dioxide, heat

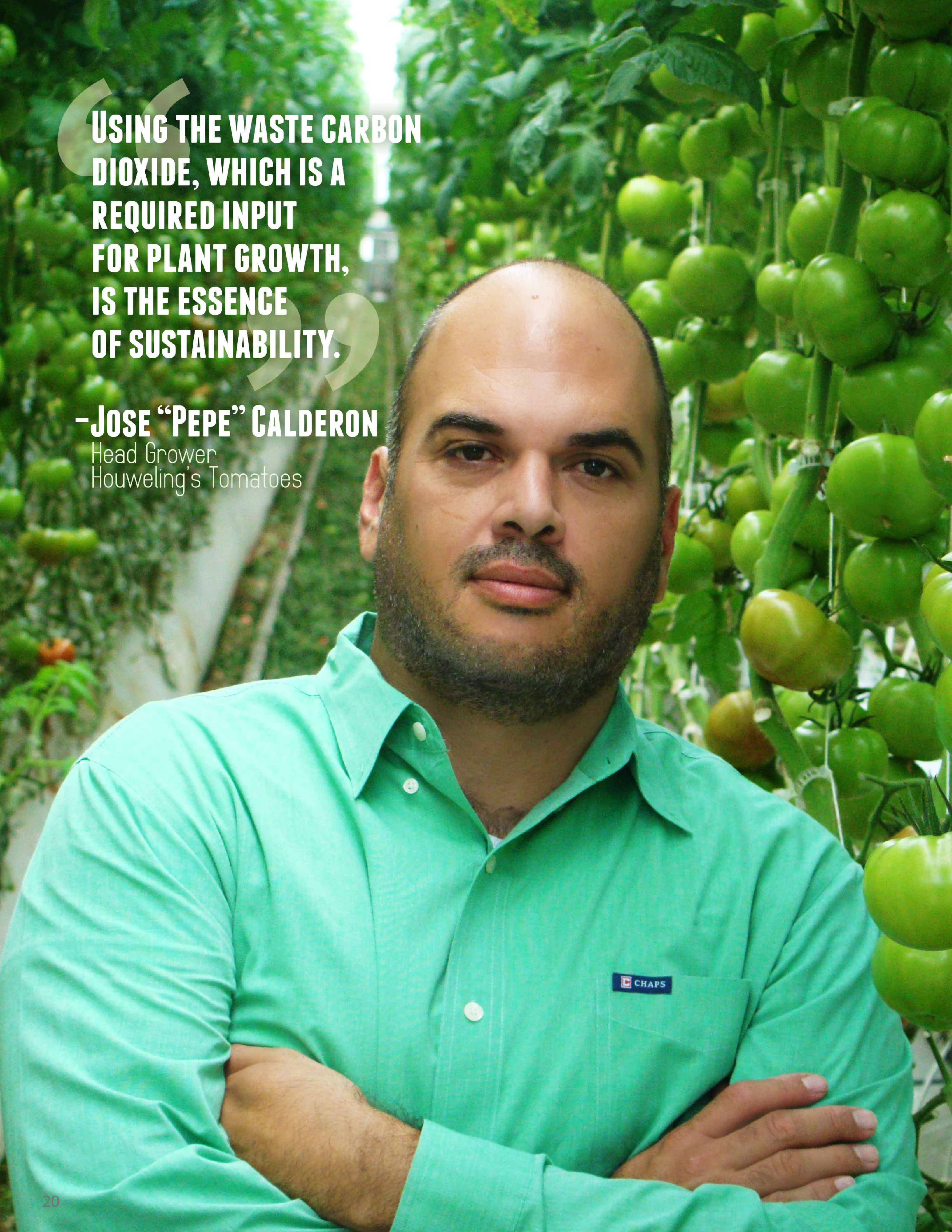
The family-owned company also has production facilities in Camarillo, Calif., and its headquarters in Delta, British Columbia. What makes the Utah facility unique from Houweling's other two operations is it's built adjacent to an electrical power plant. Through patent-pending technology, the company will extract waste heat and carbon dioxide from the power plant's exhaust stacks, which will be used to grow tomatoes year round. "Our greenhouses are about 50 meters from the Rocky Mountain Currant Creek power plant," said head grower Jose "Pepe" Calderon. "We will capture carbon dioxide generated by the power plant and use it to promote plant growth. Using the waste carbon dioxide, which is a required input for plant growth, is the essence of sustainability."

By interplanting tomato plants, Houweling's is able to have continuous year-round production. Timed right, this allows picking of the new crop right after picking of the old crop is finished.

Photos courtesy of Houweling's Tomatoes

> Using the waste carbon dioxide, which is a required input for plant growth, is the essence of sustainability.

–Jose "Pepe" Calderon
Head Grower
Houweling's Tomatoes



The greenhouses also capture thermal energy generated by the natural gas burning power plant. The temperature of the flue gases is approximately 210ºF. The connection for collecting the waste heat will be completed in November. The greenhouse facility has been equipped with boilers that burn propane gas. The boilers will be used as a back-up heat source once the flue gas connection is completed. Calderon said it was most cost effective for the company to burn propane in it is boilers. A heating system has also been installed in the roof to melt snow, which is collected and stored for irrigation.

Top photo: **Through patent-pending technology, Houweling's Tomatoes will extract waste heat and carbon dioxide from a neighboring power plant's exhaust stacks.**

Middle photo: **The 28-acre greenhouse facility has been equipped with boilers that burn propane gas. The boilers will be used as a back-up heat source.**

Bottom photo: **Recirculated water is filtered, heat sterilized and treated with chlorine dioxide to ensure all disease pathogens and biofilm are eliminated from the drain water.**

Continuous production

Houweling's patented Ultra Clima semi-closed greenhouses have also been equipped with 13,500 high pressure sodium lamps that generate 17,000 lux. The lamps are used to provide 12-16 hours of supplemental light as needed.

"We start to use the lights in September," Calderon said. "When we plant a new crop we turn on the lights to enable the plants to get a strong start. At times during the summer when the light levels are over 1,100 watts, we shade the plants because certain varieties are weakened by too much light and can affect fruit quality."

Coco coir grow bags is the substrate used in all three of the Houweling's tomato operations.

Plants are watered with drip irrigation tubes. The recirculated water is filtered, heat sterilized and treated with chlorine dioxide to ensure all disease pathogens and biofilm are eliminated from the drain water and ready to reuse.

"In order to have continuous year-round production we interplant the plants," Calderon said.

"While the old crop is still in production, toward the end of its production lifecycle, we plant a new crop. Timed right, this allows us to start picking the new crop right after we finish picking the old crop."

Calderon said an advantage to growing the tomatoes in Utah is the cold winter helps to break the life cycle of insect pests.

"We have some pressure from whitefly," he said. "We use the biological controls, including Encarsia and Eretmocerus predatory wasps. We introduce the wasps and other predators every week. We also maintain banker plants at the edge of each plant row to provide a habitat for the predators.

"We have been successful in using only biological controls so far. The use of biologicals continues to advance and is an area of focus for our IPM team."

For more: Houweling's in Utah, info@houwelings.com; http://www.houwelings.com.

David Kuack is a freelance technical writer in Fort Worth, Texas; dkuack@gmail.com.

Ninety-five percent of the tomatoes grown at the Houweling's operation in Mona, Utah, are sold within the state.

GREENVILLE INVENTOR'S WORK GROWS GARDENING INDUSTRY

When Mill Village Farms announced their plans for a rooftop farm last year, it created quite a buzz. Growing food on the roof of a building in the heart of downtown? Could it actually be done?

A year later, the army of 50 11-foot vertical growing towers, now sprouting lettuce and tomatoes, arugula and herbs, are proof not only that it can be done, but that the Upstate is leading the way.

When the rooftop farm officially opened in April, the crowd included representatives from the Hughes Development Corp., the City of Greenville and the executive director of Mill Village Farms. But standing there too, almost unnoticed, was another person who had played a huge role in the farm's creation, the man who invented the towers, Morris Bryan.

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{NEWS FROM THE INDUSTRY}

MICROGREENS... NOT ONLY HEALTHY AND DELICIOUS, BUT FUN TO GROW

Vegetable producers, health-minded consumers, and many inventive chefs have realized the advantages of microgreens - tiny leaves of vegetable plants less than 14 days old. Microgreens, which are smaller than "baby greens" and harvested later than sprouts, offer intense flavor and vibrant color and add an appealing touch to garnishes for salads, sandwiches and soups. Whether they're spinach, arugula, beet or lettuce, microgreens are believed to be exceptionally nutritious, even more so than the "baby" versions of these vegetables.

Microgreens grown in a controlled environment such as a hydroponic greenhouse system are of consistent quantity and quality, and are available 52 weeks a year, in any climate. Marilyn Brentlinger, Chief Operating Officer and owner of CropKing says there is already a market for microgreens. "Many of CropKing's hydroponic customers are successfully cultivating and selling microgreens to area markets and local chefs, and many are delivering the greens in the tray that they're grown in – a great Farm to Consumer concept!"

>> Click for more >>

CROPKING INTRODUCTORY GROWER WORKSHOP

CropKing is a supplier of quality hydroponic growing supplies and equipment. But more than just supplying the best equipment for growing, it is important to educate both new growers and potential growers about the industry that they are venturing into. A good understanding of what is involved in the growing process, as well as the options that are available gives a potential customer the ability to make smart decisions.

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HYDROGARDEN: ZERO FOOD MILES!

Horticulture and hospitality students at Peterborough Regional College have embarked on a collaborative initiative with Local Roots Limited which will reduce the food miles associated with some of the ingredients used in the College's own Parcs Restaurant to zero.

Led by sustainability experts Dr. Ian Tennant and Gloria McNeil, Local Roots Limited provides expertise and a fully serviced solution to allow caterers and organizations to grow their own food on site.

Local Roots Limited has set up a small version of a new vertical farming system, VydroFarm, recently launched by hydroponics innovator HydroGarden, based in Coventry. Installed in the College's on-site restaurant, the horticultural department will participate in a two to three month trial to grow fresh ingredients that can be used in the College's Parcs Restaurant, before the system is relocated to other local establishments.

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JAPAN SPECIAL REPORT

Plant Factories with Artificial Light (PFAL)

After the 1980s and 1990s, Japan has been experiencing its third boom of commercial plant factories equipped with artificial light (PFAL). This has been occurring since 2009.

Besides government-funded projects, many Japanese companies started to enter the PFAL industry as growers and/or system manufacturers. Not only agri-preneurs (agri-ventures) and food companies, but many firms from a wide variety of industries including electronics, chemical, energy, engineering and transportation have become active in the Japanese PFAL market. These companies include major players in the various industry sectors. Some have even started expanding overseas.

So far, more than 150 PFALs are operating in Japan, which is the largest number worldwide. They are growing and selling vegetables, using multiple business models. In addition to leafy greens, crops of head lettuce, herbs, strawberries and highly nutritious plants are being cultivated on a commercial basis.

There are two main points to describe Japanese PFAL market trends:

1. Lowering the cost of leafy greens in mass production.

2. Developing value-added plant markets, i.e., applying higher functional plants to health foods or pharmaceuticals, apart from fresh vegetables.

In regards to R&D, many companies have been working on LED grow light systems, cultivation recipes to enrich plant nutrition, automation, robotics, efficient use of energy resources, cultivation techniques and developing new systems/materials to PFAL specification, etc. It looks like more potential entrants would bring in diversity and expand the market globally.

— Eri Hayashi
Japanese Plant Factory
Industry Expert

La Minga: Episode 101
of The Perennial Plate

THE PERENNIAL PLATE

BECAUSE YOU HAVE TO HAVE A LITTLE FUN SOMETIMES

Orchid Greenhouse Dance

TAKING A "HANDS ON" APPROACH TO FERTIGATION

BY DAVID KUACK

GROWERS WHO INCORPORATE

WATER-DRIVEN INJECTORS INTO

THEIR PRODUCTION SYSTEMS

ARE USUALLY LOOKING FOR

SIMPLICITY

AND FLEXIBILITY.

Whether fertilizing greenhouse ornamental or vegetable crops, many growers use an injector to take up fertilizer concentrate and mix it with water and apply it to the plants.

"From an application standpoint the same type of information related to water flow, pressure and dilution rate is going to be used whether a grower is producing ornamentals or vegetables," said Chris Lundgren, national sales manager for horticulture at Dosatron International Inc. "The difference with greenhouse vegetable production compared to traditional bedding plant production is sometimes vegetable growers want more flexibility in their control over the rates of nitrogen, phosphorus and potassium. In vegetable operations, growers sometimes operate multiple injector units in line or in series. There is a tank A, a tank B and a tank for a diluted acid or some other supplement like a calcium-magnesium product that provides them with more control.

"The traditional bedding plant grower may be using a bag of 20-10-20 or 17-5-17, mixing the fertilizer and using one injector to deliver it to the whole production facility in a constant liquid feed program. In the vegetable greenhouse, the grower is looking for more variable control."

Lundgren said as vegetable crops like tomato and cucumber go from the vegetative stage to the flowering and fruiting stages that most growers are going to want to have more control over how much nitrogen, phosphorus and potassium and any other supplements are going to be provided to the plants. He said this is the major difference between fertigation of traditional greenhouse/nursery crops and greenhouse vegetable production.

Adding edibles to the product mix

Lundgren said ornamental plant growers who want to try their hand at producing edibles usually start with crops like lettuce, leafy greens and microgreens.

"The crop turnaround time is quick," he said. "It's a onetime harvest and the crop doesn't have to be held for very long. The grower is trying to harvest as much off of one plant as possible. This is the quickest, easiest way to go from flowers to food."

Lundgren said for crops like leafy greens only one fertilizer solution is usually needed because growers are trying to keep the plants vegetative.

"Because of the way these crops are produced, growers can get away with the same single bag fertilizer program that they are using to grow bedding plants," he said. One change that Lundgren has seen bedding plant growers make when adding edible crops is to install some type of water treatment system.

"Bedding plants growers who are adding short-term crops like leafy greens have to be sure they are successful with those crops from the start," he said. "Bedding plant growers are installing hydroponic production systems like nutrient film technique because that is going to be the quickest way to turn around these crops. The growers are being advised that water treatment is an important part of an edible crop program because the water is now being used as part of or as the substrate. This means the water's contaminants are much more highly concentrated in the root zone compared to a soilless medium that is used for bedding plants."

Lundgren said growing poinsettias, tomatoes,

> Growers who incorporate water-driven injectors like Dosatrons into their production systems are usually looking for simplicity and flexibility. Other growers need something that is not as mechanical that is tied in more to an automated environmental control system.

Photos courtesy of Dosatron International Inc.

Water treatment is an important part of an edible crop program because the water is used as part of or as the substrate. The water's contaminants are much more highly concentrated in the root zone compared to a soilless medium that is used for ornamental crops.

cucumbers and peppers, are similar in that they are long-term crops.

"Typically for poinsettia, it's a six month crop from stick date to out the door," he said. "Six months of pest control monitoring and the IPM program has to be pretty much spot on as well as the plants having to ship on time. Tomatoes are more like a poinsettia crop.

"With long term crops, growers have more flexibility to make changes to rectify issues that occur. With a quick crop like leafy greens, a grower doesn't have as much flexibility to fix mistakes."

An intimate, hands-on relationship

Lundgren said growers who incorporate water-driven injectors like Dosatrons into their production systems are usually looking for simplicity and flexibility."Growers who are using Dosatrons tend to be more of hands-on growers," he said. "The injectors become an integral part of how growers are doing things. Because these injectors are mechanical, growers have to physically make adjustments to change the ratios. There is an intimate relationship that happens between something mechanical, even though it is automating the process, and the users. That, in and of itself, becomes a reason why people are so attached to their injectors."

Lundgren said proper maintenance can go a long way in extending the lifespan of the injectors. Some growers are operating injectors that are 15-20 years old.

"Water-driven injectors are mechanical devices and need maintenance just like a car," he said.

"The harder an injector is run the quicker it has to be serviced. Those that are used to apply the same product all the time and aren't used frequently don't need maintenance as often. The longer injectors are operated, the harsher the chemicals that are run through them, and the more chemical diversity injectors are exposed to, the more frequently maintenance will be needed. Injectors are used to apply everything from fertilizers, PGRs, sanitizers, insecticides and fungicides."

Level of control

Lundgren said fully-automated environmental control systems that incorporate chemical injection usually require someone with technical expertise to do maintenance or repairs because of the complexity of these systems.

"Some growers desire more control and prefer using injectors," he said. "Typically the growers who use injectors are out in the greenhouse manually testing the EC (electrical conductivity) and pH. Other growers need something that is not as mechanical that is tied in more to an automated environmental control system. These automated systems give them the capacity to make changes on the fly, using a phone or a computer. These systems are going to typically be provided by the environmental control companies."

Lundgren said many of the large greenhouse vegetable operations have so much diversity that they need to rely on an automated system that is going to do a large capacity and be centralized.

"These growers are not going to want a lot of Dosatron stations throughout their facilities," he said. "They don't want to have to make mechanical adjustments in every pump house. It is much more sensible to use a fully integrated system in these operations. They might use some mechanical injectors for certain applications."

Lundgren said fully integrated, automated environmental control systems have the ability to monitor the system and the plants, as long as the system is maintained. These systems can provide a lot of data including pH, EC, temperature and relative humidity.

"One of the greatest pros with fully integrated systems is growers can sit at home and monitor the greenhouses from their smart phones knowing that the fertigation program is spot on," he said. "That definitely is an advantage.

"The discussion for growers using any type of fertigation technology comes down to: what makes sense for their operation and what makes sense for their business plan? Secondly, what level of technology are they ready for? If growers are more mechanical in nature and go out and monitor their crops daily, injectors probably better fit their production system. If they are a grower who wants an automated streamlined production facility and prefers working on a computer, then a fully integrated control system is likely a better choice."

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David Kuack is a freelance technical writer in Fort Worth, Texas; dkuack@gmail.com.

Photo courtesy of de Bruin Greenhouse Consulting

Photo courtesy of Mark Kroggel, University of Arizona

SNEAK PEAK

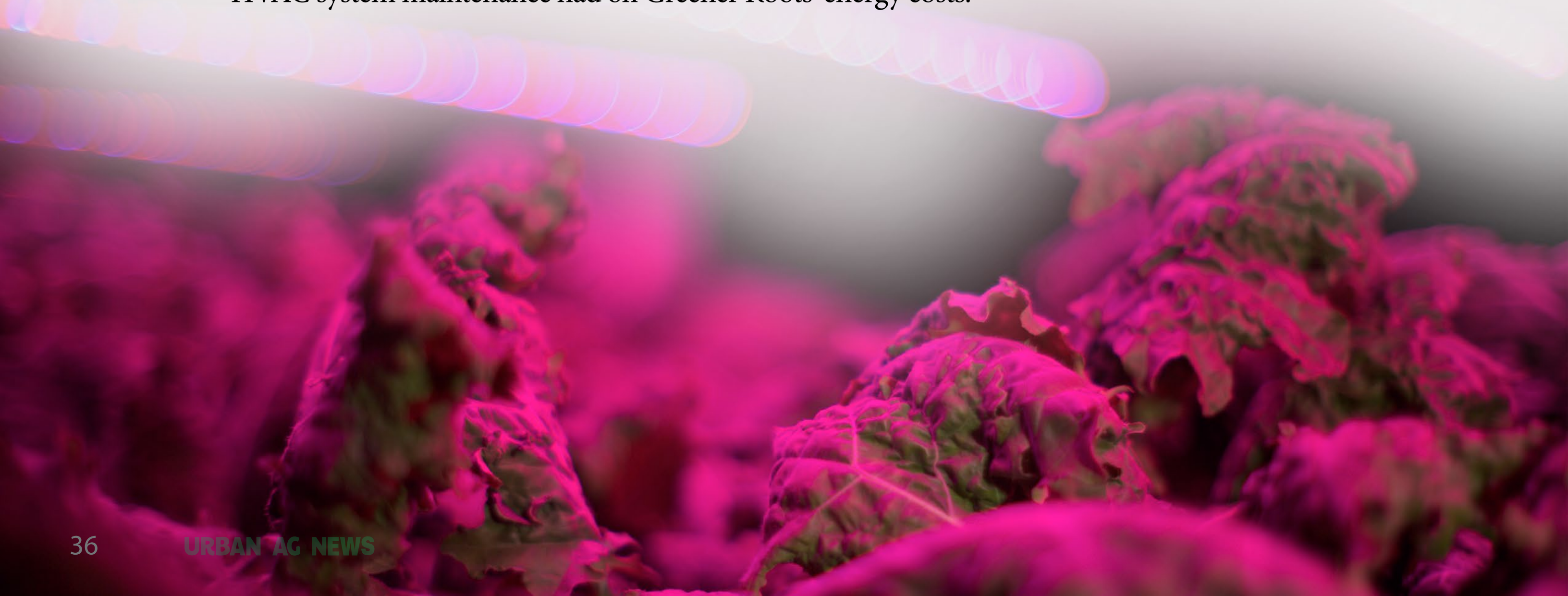
Vertical Farm Climate Management Case Study

By John Zimmerman

Upon launching Harvest Air, I was introduced to Jeffrey Orkin, founder of Greener Roots Farm, a hydroponic vertical farm in Nashville, TN. At the time, Jeffrey was having issues with his energy costs and he thought that his Heating, Ventilating, and Air Conditioning (HVAC) system was the main source of the problem. The timing could not have been better since I was looking to gain exposure in the industry, so I asked Jeffrey if I could use his farm to gather some data in exchange for and energy audit; Jeffrey was more than accommodating.

From an HVAC system design perspective, Controlled Environment Agriculture (CEA) facilities are similar to a manufacturing facility, or a data center: 1) the operations are 24 hours per day, 7 days per week, and 2) The system primarily serves things and not people. However, it appears that many of the HVAC systems that I have seen in the CEA industry were designed for a comfort-cooling application, much like you would expect in a residence or an office building; Greener Roots' HVAC system was no exception.

The objective with Greener Roots was to establish an energy usage baseline for their HVAC system, then to implement Energy Conservation Measures (ECMs), with the goal of quantifying the impact of the ECMs. One week into our power monitoring efforts, one of the compressors in Greener Roots' HVAC system had failed as a result of poor system-wide maintenance (I should note, Jeffrey had a maintenance agreement with a local contractor). Luckily for Greener Roots, we were monitoring and recording the power consumption of the HVAC system and were able to analyze the power consumption before and after the failure. In the next edition of Urban Ag News, find out the reasons leading to the compressor failure and the financial impact that poor HVAC system maintenance had on Greener Roots' energy costs.



About Harvest Air

www.harvestairllc.com

Harvest Air was founded by Chris Whaley and John Zimmerman in July 2015. Both Chris and John are registered Professional Engineers with a combined 30+ years of experience designing, estimating, and managing the installation of large-scale commercial Heating, Ventilating, and Air Conditioning (HVAC) systems for a wide range of industries. Controlled Environment Agriculture (CEA) requires a sophisticated farming process to ensure that the crops are getting the proper amount of water and nutrients in order to optimize yield, and while it appeared that the farming techniques used in CEA are well designed and sophisticated, Chris and John discovered that the HVAC systems used are anything but. By applying proven principles and knowledge gained from our experience, Harvest Air's HVAC solutions are extremely efficient and reliable, allowing the farmer to focus on their crops and not the infrastructure that supports them.

John Zimmerman, PE

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Chris Whaley, PE

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Mr. Zimmerman obtained a Bachelor's Degree in Mechanical Engineering from the University of Texas at Austin and a Master's degree in Building Construction Management from Purdue University, and is a registered Professional Engineer in the state of Texas.

Mr. Whaley obtained a Bachelor's Degree in Mechanical Engineering from the University of Oklahoma, and is a registered Professional Engineer in the state of Texas.

Both John and Chris have spent their entire careers designing, selling, and managing the installation of mechanical systems for large-scale commercial buildings for some of the largest Mechanical Design-Build firms in the nation.

greener roots FARM

Harvest AIR

GROW NORTH TEXAS

HOW A DALLAS BASED NON-PROFIT PLANS TO CHANGE THE WAY TEXAS EAT

Grow North Texas is a nonprofit that seeks to connect North Texans to food, farms, and community in order to create a sustainable, secure regional food system that enriches the land, encourages economic opportunity through food and agriculture, and supports equitable access to healthy, nutritious food for all.

In this video ***Susie Marshall***, Executive Director of Grow North Texas, shares more about their mission.

AN URBAN AG NEWS VIDEO PRODUCTION

GROWERS ARE RESPONSIBLE FOR PRODUCING SAFE FOOD

As the rules of the Food Safety Modernization Act are finalized, greenhouse growers will be required to ensure the edible crops they produce are safe for human consumption.

By David Kuack

Recent data from the U.S. Centers for Disease Control and Prevention estimates 48 million people are sickened each year by foodborne pathogens. That's one in six Americans. Of those people about 128,000 are hospitalized and 3,000 die each year.

The Food Safety Modernization Act (FSMA) was signed into law by President Obama on Jan. 4, 2011. The purpose of the law, according to the U.S. Food and Drug Administration, is "to ensure the U.S. food supply is safe by shifting the focus from responding to contamination to preventing it." In September 2015, two of the FSMA's rules, referred to as preventive controls rules, were finalized. These rules, according to FDA, "focus on implementing modern food manufacturing processes for both human and animal foods."

"We've been working with states, food companies, farmers and consumers to create smart, practical and meaningful rules," said Michael Taylor, FDA deputy commissioner for foods and veterinary medicine. "And we have made a firm commitment to provide guidance, technical assistance and training to advance a food safety culture that puts prevention first."

FSMA's seven rules are scheduled to be finalized in 2016. FDA said the rules "will work together to systematically strengthen the food safety system and better protect public health."

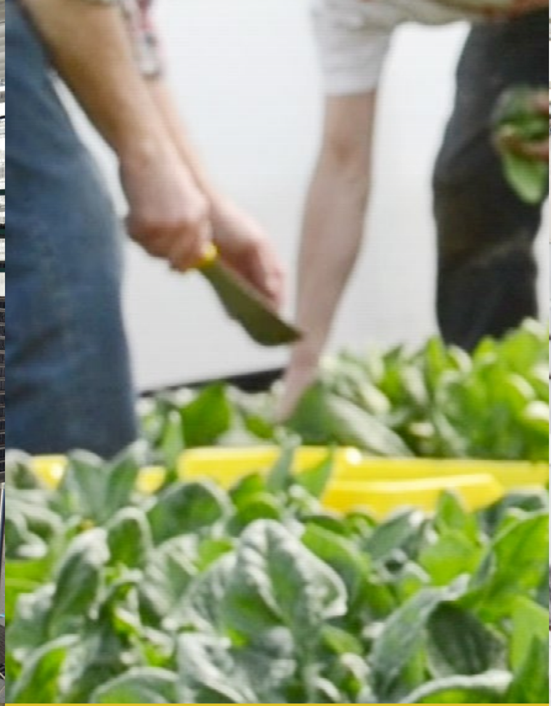
The rules are changing

Phil Tocco, food safety educator at Michigan State University Extension, said FSMA is the first law in the United States to regulate food production, harvest and the movement of fresh produce at the farm gate.

"Up until now if you were a retail grocer, a retail restaurant, or if you were preparing food, you had regulations placed upon you and how you did things," Tocco said. "If you were manufacturing a food product from raw materials, there were rules that you had to follow, particularly if you were working with potentially hazardous foods such as seafood or if there was a potential issue if you were slaughtering animals. There were regulations in place. However, there were no regulations for the harvest and transport of fresh produce at all. If you were harvesting fresh produce you didn't have to follow any rules to do so."

The Food Safety Modernization Act is the first law in the United States to regulate food production, harvest and the movement of fresh produce at the farm gate.

Photos courtesy of Phil Tocco, Michigan State University Extension



"If a grower sells his product at a farmers market, he better be able to answer the questions that consumers are going to ask about food handling and food safety."

— Phil Tocco,
Michigan State University Extension

Growers should treat packing areas as if they were cooking in a kitchen.

Understanding food safety

Tocco said growers need to think strategically about food safety when they first start out.

"Some of the best growers I know actually came from the retail restaurant side that went through a program like ServSafe," he said. "All restaurants have to have at least one person on staff that has ServSafe certification. They have taken a test indicating that they are ServSafe certified. They understand the concepts related to food safety."

Tocco said many growers he has met were successful chefs before they moved to food crop production.

"These former chefs brought their knowledge of food safety with them," he said. "It makes a huge difference because these growers start evaluating the practices that they do. They can ask themselves if their food handling practices pass muster.

"If a grower sells his product at a farmers market, he better be able to answer the questions that consumers are going to ask about food handling and food safety. A grower can't answer "Nobody has ever gotten sick eating any of my produce so I don't have any problems.""

Reduce the risk of pathogens

Tocco said growers should treat packing areas as if they were cooking in a kitchen.

"Packing areas should be clean and sanitary," he said. "The bottom line is growers are dealing with a fresh product. There is only one way to really ensure the elimination of the overall pathogen load and that is to cook them. A lot of the things that are grown, especially in a greenhouse, are meant to be eaten fresh and raw. Greens are meant to be eaten fresh and raw. Growers can't eliminate the risk. But they can reduce the risk."

Tocco said people are really good at spreading disease and the diseases that people pick up tend to spread relatively well.

"Outdoors on small farms there may only be one to two people that come into direct contact with the plants," he said. "Those people may not be exposed to a lot of other people outside of their social network. I expect there are more indoor growing facilities doing production in urban areas. There is a greater likelihood that individuals who deal with indoor environments would come into contact with people with norovirus or people would come into contact with environments that could be contaminated with norovirus. The chance of someone accidently bringing in contamination into the production area is probably somewhat greater.

"We say "wash your hands" and "if you're sick, don't pick." Washing your hands can only go so far. There is a potential if you come in contact with a norovirus that you're asymptomatic."

Water source, production site safety

Tocco said greenhouse growers who are using municipal water to irrigate and package their crops are using the absolute safest water source. The next safest water source is well water followed by pond water, considered a static water source, and water sources that move like streams, lakes and rivers.

"A water source in motion varies because the water taken out right now is very different than the water taken out 10 minutes later," Tocco said. "If a pond is the water source, the water taken out now is usually the same water taken out 10 minutes later. With well water, the water that is taken out now is going to be the same 10 minutes from now. I can expect that a water test of well water is going to be the same whenever the test is taken."

Tocco said many greenhouse growers who are using a closed recirculation system often treat their water. Also, the production system a grower is using will determine whether the water even touches the edible parts of the plants.

"A lot of the production systems that use water recirculation have a substrate like rockwool that gets between the actual edible portion of the plant and the roots. The water may never touch the leaves of the plants let alone the edible portion of the plants, such as a cucumber or a tomato crop. Even if a grower is producing greens, the water typically is only going to be touching the root system. The water is not going to be sprayed on the leaves."

Tocco said the food safety risks encountered by an outdoor field grower are much reduced in a controlled environment warehouse or greenhouse.

"A greenhouse or warehouse grower is going to have much more control over wildlife," he said. "There are some vertical set ups where it is going to be difficult for wildlife to climb up to eat leafy greens or to mess with the production area. Those kinds of things make a huge difference in maintaining food safety."

Tocco said one of the factors that help outdoor production systems is sunlight, which is a good disinfectant.

"Another food safety issue is previous uses," Tocco said. "If a grower is moving into a warehouse that has had some industrial uses there may be some existing contamination within the building. Starting to grow plants in these structures, there potentially could be a problem.

"Another issue with these old buildings is cost of conveyances. Some warehouses may have older pipes that may leach chemicals into the water supply that are coming into the production area. This wouldn't happen in a new construction area. There are some things that growers should be cautious of when they're taking on an indoor environment."

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Packing areas should be clean and sanitary. Growers can't eliminate the risk of disease pathogens, but they can reduce the risk.

NY SUN WORKS

BACK TO SCHOOL WITH 7 NEW LABS BUILT OVER THE SUMMER: *NY SUN WORKS WELCOMES ITS NEW SCHOOL PARTNERS IN NY AND NJ AND CELEBRATES 26 LABS UP AND RUNNING!*

BY YOUTH PRESS TEAM
(LANNI HARRIS, TINA ZHAO, EQUEM ROEL, AINSLEY B, ERICA MORALES-ARMSTRONG, GIOVANNA MOUZOURAS, JAELYN FELTON, WERONIKA, EMANUEL GRANJA, MARSELA DOKO, AND FINN BRENNAN)

PHOTOS COURTESY OF NY SUN WORKS YOUTH PRESS TEAM

SPONSORED BY HORTAMERICAS

This summer was NY Sun Works' busiest yet! We are thrilled to welcome all our new school partners into the Greenhouse Project family. With the help of our amazing team of interns--Jorge Burgos, Josh Brosnan, Maishah Salam, and Kevin Olson--we have built seven new labs. Here's what we have been up to:

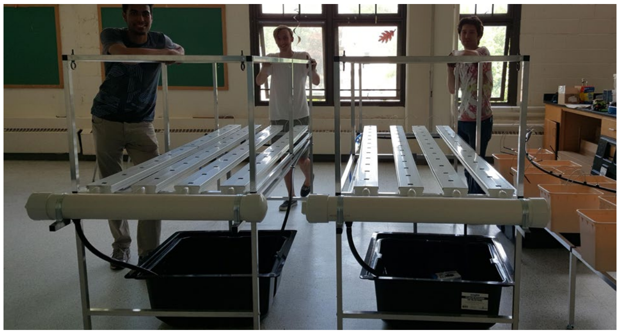
BRONXDALE HIGH SCHOOL added hydroponics to their amazing hands-on programming, which already ranges from game design to comic book literature under the leadership of Principal Carolyn Quintana. With classes taught by teacher Mike Duggan, their grow lab will feature 4 systems for leafy greens, herbs and fruiting plants. Bronxdale students will help reduce the lab's carbon footprint through their use of an energy producing bicycle.

WATCHUNG ELEMENTARY in Montclair, NJ is going hydro! After 15 years of operating a traditional greenhouse, Watchung Elementary teacher Amy Armstrong is adding an 3 systems to their lineup. We can't wait to see what delicious food sprouts up there!

PS 212 also known as then **MIDTOWN WEST SCHOOL**, is bringing urban farming education into the heart of Midtown Manhattan. Using their hydroponic systems they'll be growing fresh herbs and greens in no time.

PS 84 JOSE DE DIEGO. We are finally ready to unvail our biggest project of the year: a 1200sq ft rooftop greenhouse at PS 84 - José de Diego in Williamsburg. Complete with a 500 gallon aquaponic tank, 6 hydroponic systems, including a NY Sun Works VIG (Vertically Integrated Growing system), this greenhouse will be home to 300 plants at a time. If you don't believe us, keep track on Instagram @nysunworks as this urban forest develops.

SOJOURNER TRUTH MIDDLE SCHOOL in East Orange, NJ is named after Sojourner Truth, a venerated 19th century African-American abolitionist and women's right activist. Following in her tradition, Sojourner Truth Middle School is joining the movement to create a generation of health and sustainability leaders. Through their lab's hydroponic systems, students will learn about food systems, systems design, urban sustainability as well as health and nutrition, all while growing fresh greens and fruits.



PS 354 Q Thanks to the leadership of Principal Raeven Askew, Jenna Ferrante, and teacher Christine Rinaldi – The Greenhouse Project is coming to Queens! PS 354Q in Jamaica will be receiving 4 growing systems and an energy bike that will surely keep students busy! NY Sun Works Discovering Sustainability Currilculum will create endless opportunities for disocvery.

UNITED NATIONS INTERNATIONAL SCHOOL
At UNIS, we have built a small-scale 200-gallon rainwater catchment system, as well as 2 hydroponic growing systems. Additionally, the students at UNIS will have worm compost and Integrated Pest Management stations. UNIS will be seeding for their first cycle of crops in the next week. Teacher Vanessa Go is getting started with her students with her already existing soil planters, and is looking forward to hydroponic vs. conventional growth comparisons.

NYSUNWORKS
YOUTH CONFERENCE @MSC
Discovering Sustainability Science

NY Sun Works is a non-profit organization that builds innovative science labs in urban schools. Through their Greenhouse Project Initiative they use hydroponic farming technology to educate students and teachers about the science of sustainability.

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PLANT PRODUCTIVITY IN RESPONSE TO LED LIGHTING

GIOIA D. MASSA1
HYEON-HYE KIM AND RAYMOND M. WHEELER
CARY A. MITCHELL

Permission to reprint this article was provided by Gioia Massa, Project Scientist at NASA Kennedy Space Center, Cape Canaveral, Fla., and American Society for Horticultural Science, Alexandria, Va.; http://www.ashs.org. The article appeared in HortScience, Dec. 2008, Vol. 43 No. 7, 1951-1956.

ABSTRACT

Light-emitting diodes (LEDs) have tremendous potential as supplemental or sole-source lighting systems for crop production both on and off earth. Their small size, durability, long operating lifetime, wavelength specificity, relatively cool emitting surfaces, and linear photon output with electrical input current make these solid-state light sources ideal for use in plant lighting designs. Because the output waveband of LEDs (single color, nonphosphor-coated) is much narrower than that of traditional sources of electric lighting used for plant growth, one challenge in designing an optimum plant lighting system is to determine wavelengths essential for specific crops. Work at NASA's Kennedy Space Center has focused on the proportion of blue light required for normal plant growth as well as the optimum wavelength of red and the red/far-red ratio. The addition of green wavelengths for improved plant growth as well as for visual monitoring of plant status has been addressed. Like with other light sources, spectral quality of LEDs can have dramatic effects on crop anatomy and morphology as well as nutrient uptake and pathogen development. Work at Purdue University has focused on geometry of light delivery to improve energy use efficiency of a crop lighting system. Additionally, foliar intumescence developing in the absence of ultraviolet light or other less understood stimuli could become a serious limitation for some crops lighted solely by narrow-band LEDs. Ways to prevent this condition are being investigated. Potential LED benefits to the controlled environment agriculture industry are numerous and more work needs to be done to position horticulture at the forefront of this promising technology.

Light-emitting diodes (LEDs) have a variety of advantages over traditional forms of horticultural lighting. Their small size, durability, long lifetime, cool emitting temperature, and the option to select specific wavelengths for a targeted plant response make LEDs more suitable for plant-based uses than many other light sources. These advantages, coupled with new developments in wavelength availability, light output, and energy conversion efficiency, place us on the brink of a revolution in horticultural lighting.

For horticultural researchers and crop producers to benefit from LED use, a variety of preliminary findings should be considered. A number of studies have been performed at the University of Wisconsin, at NASA's Kennedy Space Center, and at Purdue University to examine the usefulness of LEDs as a sole source or as supplemental lighting for plant growth in space such as part of a life-support system on Mars. Although the vast majority of LED work thus far has been performed with food crops, observed plant responses likely would benefit ornamental crops as well. The findings of these and other studies can help guide selection of LED types and positioning for a variety of purposes depending on crop type and desired responses. A review of key studies, discussion of potential applications, and posing of open questions follows. For more information on plant responses to light quality, see the reviews by Devlin et al. (2007) and Folta and Childers (2008).

Early Testing and the Potential for LEDs in Plant Growth Systems

Bula et al. (1991) at the University of Wisconsin first suggested using LEDs to grow plants and reported that growth of lettuce plants under red LEDs supplemented with blue fluorescent (BF) lamps was equivalent to that under cool-white fluorescent (CWF) plus incandescent lamps. At the time of that study, blue LEDs were not yet widely available, so BF lamps were used as an alternative. Subsequent testing by that group showed that hypocotyls and cotyledons of lettuce seedlings under red (660 nm) LEDs became elongated, but that effect could be prevented by adding at least 15 μmol·m−2·s−1 of blue light (Hoenecke et al., 1992). These findings inspired continued development of LED lighting systems for small plant growth chambers that flew several times aboard NASA's Space Shuttle (Barta et al., 1992) and which were used to grow wheat (Triticum aestivum L.) and Brassica rapa L. seedlings (Morrow et al., 1995), potato (Solanum tuberosum L.) leaf cuttings (Croxdale et al., 1997), Arabidopsis thaliana (Stankovic et al., 2002), and soybeans [Glycine max (L.) Merr] (Zhou, 2005). The potential of LEDs for terrestrial plant research continued to build, in which comparisons of red LED and xenon-arc-illuminated kudzu [Pueraria lobata (Willd.) Ohwi] leaves showed slight differences in stomatal conductance (g S) but similar photosynthetic responses to photosynthetic photon flux (PPF) and CO2 (Tennessen et al., 1994). A comparison of photosynthetic rates of strawberry (Fragaria ×ananassa L.) leaves with red (660 nm) or blue (450 nm) LEDs showed higher quantum efficiencies under the reds (Yanagi et al., 1996a). Spectral measurements of red (660 nm) LEDs, red LEDs plus BF, red LEDs plus far-red (FR, 735 nm) LEDs, and metal halide (MH) lamps indicated similar phytochrome photostationary states but significantly higher levels of long-wave radiation from the MH lamps, indicating the thermal advantages of using LEDs in plant growth systems (Brown et al., 1995). More recent studies have showed that rice plants grown under a combination of red (660 nm) and blue (470 nm) LEDs sustained higher leaf photosynthetic rates than did leaves from plants grown under red LEDs only (Matsuda et al., 2004). The authors attributed this to higher nitrogen content of the blue light-supplemented plants.

The Importance of Blue Light

The use of red LED light to power photosynthesis has been widely accepted for two primary reasons. First, the McCree curves (Sager and McFarlane, 1997) indicate that red wavelengths (600 to 700 nm) are efficiently absorbed by plant pigments; second, early LEDs were red with the most efficient emitting at 660 nm, close to an absorption peak of chlorophyll. They also saturated phytochrome, creating a high-Pfr photostationary state in the absence of FR or dark reversion. The other main wavelength included in early studies has been in the blue region (400 to 500 nm) of the visible spectrum. The amount of blue light required or optimal for different species is an ongoing question. Blue light has a variety of important photomorphogenic roles in plants, including stomatal control (Schwartz and Zeiger, 1984), which affects water relations and CO2 exchange, stem elongation (Cosgrove, 1981), and phototropism (Blaauw and Blaauw-Jansen, 1970).

Initial studies by the Wisconsin group demonstrated the need to supplement high-output red LEDs with some blue light to get acceptable plant growth (Hoenecke et al., 1992). Subsequent studies at the Kennedy Space Center showed wheat seedlings germinating under 500 μmol·m−2·s−1 of red LED light failed to develop chlorophyll but that supplementation with only 30 μmol·m−2·s−1 of blue light, or just reducing red PPF to 100 μmol·m−2·s−1, restored chlorophyll synthesis (Tripathy and Brown, 1995). Potato plantlets grown in vitro increased in chlorophyll under red LEDs when PPF was increased from 11 to 64 μmol·m−2·s−1, but all plants under red LEDs increased in shoot length compared with control plants under white fluorescent lighting (Miyashita et al., 1997). Studies by Yanagi et al. (1996b) showed that lettuce plants grown under red LEDs alone had more leaves and longer stems than plants grown under blue LEDs only. Goins et al. (1997) used LEDs as sole-source lighting for chamber-grown wheat and compared red LEDs alone, red with 1% BF, and red with 10% BF with daylight fluorescent lamps. Plants were grown under a 24-h photoperiod at 350 μmol·m−2·s−1 PPF in each case. The findings showed that wheat could complete a life cycle with red light alone, although added blue light produced larger plants with greater numbers of seeds. One percent blue (≈3 μmol·m−2·s−1) was sufficient to keep culm-leaf and flag-leaf length equal to control lengths. However, 10% blue (35 μmol·m−2·s−1) was needed to produce the same number of tillers as control plants (Goins et al., 1997). Shoot dry matter and photosynthetic rates increased with increasing levels of blue light.

Yorio et al. (1998) summarized previous blue light work and reported that yield of lettuce, spinach, and radish crops grown under red LEDs alone was reduced compared with when 35 μmol·m−2·s−1 of blue fluorescence was included to give the same final PPF. This combination of red plus blue was sufficient to give yields comparable to those found under CWF at the same PPF. However, blue light requirements for traits such as stem elongation seem to be genotype-specific, at least in potato (Yorio et al., 1998). Although the potato work was not carried out with LEDs, it has implications for the use of narrow-waveband LEDs in horticultural crop production. It is possible that certain cultivars might grow well with less costly and more efficient single-wavelength LED lighting systems.

Goins et al. (1998) examined the growth and seed yield of Arabidopsis plants grown from seed to seed under LED lights. Plants were grown either under 175 μmol·m−2·s−1 CWF or the same total PPF from red LEDs including 0%, 1%, or 10% BF. Like with wheat, Arabidopsis plants grown under red alone could produce seeds. However, the time to bolting increased with decreasing blue light level with plants under red alone taking twice as long to flower and set seed as those under CWF. Also, plants grown with 10% BF had half the seeds of those grown under CWF, whereas those with 0% or 1% BF had one-tenth the seeds of the CWF plants. Leaf morphology was abnormal for plants grown under red alone with downward curling of leaf margins and spiral growth of the rosette, but inclusion of blue light at any level restored normal leaf morphology. Seeds germinated at a high percentage under all light types tested, irrespective of the light environment in which they were produced (Goins et al., 1998).

Yorio et al. (2001) grew lettuce, radish, and spinach plants under red LEDs with or without 10% BF (≈30 μmol·m−2·s−1) and compared growth with that of plants grown under CWF at the same PPF. Spinach and radish plants grown under CWF had significantly higher dry weights than plants grown under LEDs. Their results indicated that adding blue to the red LED light produced growth of lettuce nearly equal to that under CWF, but this was not sufficient for spinach and radish plants. Measurements of leaf photosynthetic rates and g S showed no clear differences, although those rates tended to be lower for plants lighted solely with red LEDs (Yorio et al., 2001).

Studies with Far-Red and Infrared Leds

Schuerger et al. (1997) examined changes in leaf anatomy of pepper under different color combinations of light. They used red (660 nm) LEDs combined either with FR (735 nm) LEDs or BF lamps compared with MH controls, all at the same PPF. Their results indicated that leaf thickness and number of chloroplasts per cell depended much more on the level of blue light than the red:FR ratio. Treatments without added blue had the lowest leaf cross-sectional area, whereas red + 1% BF was intermediate in response, and MH controls (at 20% blue) had the greatest leaf thickness and most chloroplasts (Schuerger et al., 1997). Several other studies using FR LEDs are discussed by Kim et al. (2005) examining plant morphology, disease development, and nitrate accumulation. Until recently, it was difficult to obtain LED arrays with a wide light spectrum tunable at different emission peaks, but with the rapid, ongoing development of LED technology, such studies can now be conducted using multispectral arrays that generate a variety of colors or even white light.

Johnson et al. (1996) examined effects of infrared (IR) LEDs of 880 nm and 935 nm on etiolated oat seedlings. Spectroradiometric analysis of those long-wavelength sources showed that actual peak emission wavelengths averaged 916 nm and 958 nm, respectively. Compared with dark-grown controls, seedlings grown with 880 (916)-nm LEDs had shorter overall length but more advanced leaf emergence than either dark- or 935 (958)-nm-grown seedlings. Also, the proportion of mesocotyl tissue was significantly higher for seedlings grown with either IR source or dark grown, whereas the proportion of coleoptile tissue was significantly lower. An ancillary observation was that the IR LED radiation made seedlings significantly straighter and trained them to the gravity vector. The authors proposed the activation of a "gravitropism photon-sensing system" with potential involvement of phytochrome (Johnson et al., 1996).

Green Light

Many previous studies indicate that even with blue light added to red LEDs, plant growth is still better under white light. Certainly to humans, plants grown under red plus blue light appear purplish gray, and disease and disorder become difficult to diagnose (Fig. 1). One possible solution is using a small amount of green light. To test this hypothesis, Kim et al. (2004a) grew lettuce plants under red and blue LEDs with and without 5% (6 μmol·m−2·s−1) green from LEDs with both treatments at the same total PPF (136 μmol·m−2·s−1). They observed no impact on lettuce growth with all measurable characteristics such as photosynthesis rate, shoot weight, leaf area, and leaf number being the same with and without green. They followed this work with another lettuce study to determine the effects of higher levels of green light under a total PPF of 150 μmol·m−2·s−1 and an 18-h photoperiod (Kim et al., 2004b). They used red and blue LEDs with and without green fluorescence (GF) (24% green for RGB or 0% green for RB), GF alone (86% green), and CWF (51% green) and demonstrated that lettuce plants grown with RGB had higher fresh and dry weights and greater leaf area than those grown with CWF or RB alone. Plants grown under GF had the least biomass of all treatments. Further work with the same system (Kim et al., 2004c) examined g S. Although lettuce grown under CWF showed greater maximal g S than under RB, RGB, or GF, dry mass accumulation was highest in the RGB treatment, indicating that g S did not limit carbon assimilation under the growth conditions provided. Additionally, the authors demonstrated that g S could be changed reversibly in response to narrow waveband light, even for plants grown under CWF (Kim et al., 2004c). Kim et al. (2006) summarized the experiments with green supplementation of red and blue LED light and concluded that light sources consisting of more than 50% green cause reductions in plant growth, whereas combinations including up to 24% green enhance growth for some species. For more information on plant responses to green light, see Folta and Maruhnich (2007).

Fig. 1. Chard and lettuce plants growing under red plus blue (A) or red plus blue plus green (B) light-emitting diodes (LEDs). Plants grow equally well under both combinations but leaves appear purplish under the red plus blue, making visual assessment of plant condition difficult. Addition of green LED light resolves this problem for human visual perception.

Lamp Placement to Increase Lighting Efficiency

In addition to light quality, the position of light sources relative to the photosynthetic surfaces of plants has a large effect on crop productivity. Because the radiation energy intercepted by a surface from a point source is related to the inverse square of the distance between them (Bickford and Dunn, 1972), reducing that distance will have a large impact on the incident light level. Compared with scorching hot, high-intensity discharge emitters, cooler LED emitters can be brought much closer to plant tissues. LEDs, therefore, can be operated at much lower energy levels to give the same incident PPF at the photosynthetic surface.

Collaboration between Purdue University and the Orbital Technologies Corporation (Madison, WI) has led to the development of a reconfigurable LED lighting array to reduce electrical input for crop lighting. Massa et al. (2005a, 2005b) described a lighting array consisting of 16 "lightsicles," each of which contains 20 1-inch2 "light engines" with numerous printed-circuit LEDs. Each square light engine has columns of red and blue LEDs that are independently current-controlled to allow continuous dimming and color blending capability. The lightsicles can be arranged in a separate, vertical, intracanopy configuration whereby a crop stand of planophile plants such as beans or tomatoes can grow up around and surround the vertical light strips. The LED light engines are energized individually from the bottom up to keep pace with the top of the growing crop canopy. Preliminary crop growth studies were performed with cowpea (Vigna unguiculata L. Walp. breeding line IT87D-941-1), a dry-bean crop. When compared with stands grown under horizontal, overhead LEDs, either using the same system reconfigured (successive testing) or from a second system that became available later (simultaneous experimentation), intracanopy-grown cowpea produced a greater amount of biomass, converted a higher percentage of light energy into biomass, and had a greater retention rate of inner-canopy leaves. Figure 2 compares intracanopy versus overhead lighting for cowpea. Lower leaf senescence and abscission resulting from mutual shading from overhead lighting was virtually eliminated in the intracanopy-lighted stands. The biomass produced per kilowatt hour of energy consumed was more efficient for cowpea grown with intracanopy lighting than for stands grown with overhead lighting but all other conditions equivalent (Massa et al., 2006). The two growth systems produced comparable evapotranspiration rates (Russell et al., 2006). When the percentage of blue light was maintained less than 10% to 15% of total irradiation, cowpea plants developed abnormal intumescence or edema on older leaves (Fig. 3A). This tumor-like growth did not form under higher blue light levels. 'Triton' pepper plants grown with either intracanopy or overhead R + B LED lighting also developed severe occurrence of foliar edema. Although fruit set occurred, the extensive edema on both leaves and flower buds (Fig. 3B) strongly inhibited photosynthetic productivity (data not presented). The pepper symptoms were not mitigated by using higher percentages of blue light as occurred for cowpea. Preliminary analysis using additional ultraviolet A (365 nm) "black lights" was inconclusive, most likely as a result of the low energy flux from those lamps and unequal distances from the ultraviolet A source to the photosynthetic surfaces within a stand. 'Persimmon' tomato plants grown under the same LED lamps displayed normal growth without edema, indicating that even within solanaceous species, different susceptibilities to this physiological disorder occur. Further investigation of specific light requirements for normal growth and development of different plant species and cultivars will be required as LED lighting systems develop further.

Fig. 2. Intracanopy light-emitting diode (LED) lighting (A) compared with overhead LED lighting (B) of a cowpea crop. Arrow in B shows leaf drop resulting from canopy closure and mutual shading in the overhead-lighted canopy.

Fig. 3. Abaxial edema in a fully expanded cowpea leaf grown under less than 10% blue light-emitting diode (LED) light (A) and terminal edema in 'Triton' pepper with intumescent growths forming on the shoot apex as well as other growths occurring on flower sepals and mature and immature leaves grown at 15% blue LED light (B).

Importance of LEDs for Horticulture

Light quality plays a major role in the appearance and productivity of ornamental and food specialty crop species. Far-red light, for example, is important for stimulating flowering of long-day plants (Deitzer et al., 1979; Downs, 1956) as well as for promoting internode elongation (Morgan and Smith, 1979). Blue light is important for phototropism (Blaauw and Blaauw-Jansen, 1970), for stomatal opening (Schwartz and Zeiger, 1984), and for inhibiting seedling growth on emergence of seedlings from a growth medium (Thomas and Dickinson, 1979). The blue light photoreceptor class of cryptochromes has been found to work in conjunction with the red/FR phytochrome photoreceptor class to control factors such as circadian rhythms and de-etiolation in plants (Devlin et al., 2007). The interactions are complex and continue to be unraveled at the molecular level (Devlin et al., 2007), but much of our understanding of these responses comes from studies with narrow-waveband lighting sources, in which LEDs provide obvious advantages. Similar studies have been performed with materials that modify intercepted light quality such as colored films, mulches, or ColorNets crop netting (Polysack Plastics Industries, Israel) (Shahak et al., 2004). Thus, one potential role of LEDs in horticulture could be to enhance desired characteristics for specific crops.

In addition to changes in appearance and productivity, plant responses to narrow-bandwidth light sources or to supplemental LED lighting range from decreased viral resistance in pepper to increased suppression of pathogens in tomato and cucumber to increased nitrate accumulation in spinach (Kim et al., 2005 and references therein). These studies are just the tip of an as yet unmapped iceberg of crop responses to narrow-spectrum lighting. Future needs for controlled environment crop management also will involve interactions of lighting parameters with still other environmental factors. Crop breeders could, for example, select phenotypes with desirable traits expressed in response to unique lighting conditions.

New questions arise when considering LEDs for horticultural lighting in view of studies reported previously. First, what levels/proportions of red, green, and blue light will be required for particular crops? Will these optima change over the life cycle of the crop, and how should waveband ratios be modified for optimal production, whether it be yield or appearance? Data for the few species already tested already show tolerance diversity for narrow-band radiation. Better productivity generally is seen with additional wavelengths and broadening of the spectrum. This begs the question of whether we are just rediscovering the importance of white light. White LEDs do exist, but typically are blue LEDs with phosphor coatings and by their nature are less efficient than the single-wave-peak LEDs. Plant studies with these light sources remain to be performed. Perhaps LEDs used as supplements to sunlight or other types of lighting in greenhouses or growth chambers could modify crop growth or development in a desired direction without depriving crops of necessary wavelengths. The trick will be to find the right spectral and intensity combinations for each crop given that differences in light response are likely to exist even at the cultivar level.

Another issue in considering sole-source narrow-spectrum lighting with LEDs relates to visualization of plants and early detection of disease and disorder. Perhaps in species that have no absolute green light requirement, green could be used only when viewing crops for easier and clearer visualization with the human eye, and when not under observation, the energy could be redirected into other LED wavelengths.

What are some possible advantages of tailored light quality and application methods? From the data currently available, it seems likely that custom-designed lighting systems could significantly reduce insect, disease, or pathogen loads on certain crops. It is easy to imagine a lighting system enhanced or restricted in certain wavelengths that eliminates or minimizes the abilities of fungi to proliferate or insects to navigate to host species, reproduce, and so on. Although these advantages might be limited in a commercial production setting, they could be significant in growth facilities for disease-free germplasm production. Other easy-to-imagine scenarios include using select-waveband LEDs to stimulate early or uniform flowering in seasonal ornamentals or to generate specialty produce crops with enhanced levels of vitamins or minerals. Possibly treating crops with low dosages of narrow-band radiation at key points in the life cycle could initiate a cascade of responses in a cost-effective manner. Indeed, as LED technology continues to develop and the price of components drops, LEDs may fill many, if not all, niches of other more traditional horticultural light sources. Anticipating such eventualities now will allow horticulturists to keep pace with advances in this rapidly developing technology.

Another issue that LED technology raises for horticulture regards development of metrics for quantification of this light source. New techniques, software calibrations, and hardware must be developed to accurately quantify PPF for LEDs as well as light absorbed by crops, especially for nontraditional lighting scenarios such as three-dimensional intracanopy lighting. Additional metrics of radiation capture may need to be reported to take into account parameters such as canopy volume or total energy use/cost.

An important issue for LEDs in horticulture concerns their economic viability. Like with any developing technology, as demand increases and research results accumulate, the cost of LEDs for plant growth lighting will decrease over time. For more on the economics of LEDs for plant growth, see the articles by Bourget (2008) and Morrow (2008). With advancing technology developments, LEDs are poised to become the light source with the highest electrical energy conversion ratio. Even now, LED arrays and discrete emitters with selectable, multiple colors are commercially available and are relatively inexpensive. Although many LED products do not have the capacity to produce light levels sufficient for sole-source crop lighting, a few systems do, and this number will grow. Also, less intense sources might be used in greenhouses for supplemental lighting with selected wavelengths or for night breaks in off-season production of long-day crops. Calculations need to be performed to determine breakeven points for LED cost and energy efficiency for various types of crop lighting, including sole-source lighting for CEA. With rising transportation costs and developing capabilities for local energy generation from wastes (Mitchell, 2005), LED lighting may be the key for locally produced, sustainable CEA in the future. Indeed, several "plant factories" already exist in urban areas of Japan (Cosmo Plant Co., Ltd., Fukuroi, Japan), where LEDs are used to grow lettuce for the commercial market (Ono and Watanabe, 2006). Although the breakeven point for fresh produce differs for region, population, land area, climate, transportation costs, and so on, it seems likely that LEDs will soon approach and surpass traditional crop growth lighting as an option for controlled environment production.

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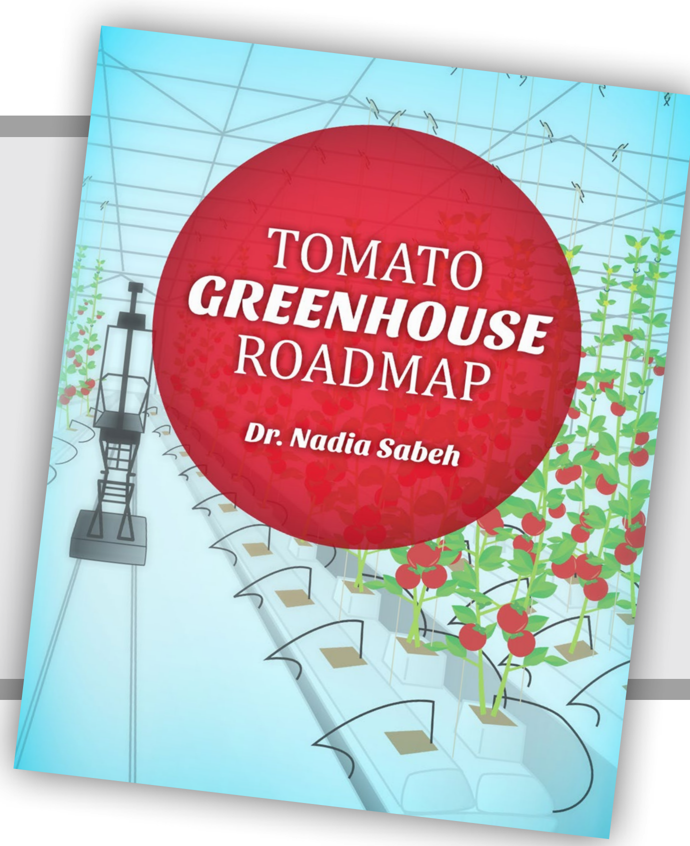

NASA LEADS THE WAY WITH LEDS

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Carl Wilhelm Siemens coined the term 'electro horticulture' in the 1980's to define this application of electric lamps and postulated that "the horticulturist will have the means of making himself practically independent of solar light for producing a high quality of fruit at all seasons of the year" (1881). A decade later, the great horticulturist Liberty Hyde Bailey wrote "There is every reason, therefore, to suppose that the electric light can be profitably used in the growing of plants" and concludes with "On the whole, I am inclined towards Seimens view that there is a future for electro-horticulture" (Bailey, 1891). Both these predictions have been realized, with supplemental lighting being routinely used in commercial greenhouse production worldwide to promote growth and extend daylength.

A century later, the National Aeronautics and Space Administration's (NASA) funded scientists grew a number species under low output red (~660 nm) LEDs as lighting sources: findings which resulted the first plants to be grown in space under LEDs in 1994. NASA has continued to incorporate LED's and is currently has VEGGIE onboard the International station for production of leafy greens.

In preparation for human colonization of space, NASA beginning integrating a food production system for production of continuously produced fresh vegetables to increase the quality of crew diets. This operational system is required to fit into an existing habitat, and not interfere of ongoing work, science and living operations. Various designs were incorporated in the NASA's Deep Space Habit and deployed at NASA Desert Research and Technology Studies (DRATS) test site. A design of automated watering, and LED lighting were incorporated into an atrium area between the laboratory and living modules and mizuna, lettuce, basil, radish and sweet potato grown, with eating the radishes and leafy greens.

Fig. 1. International Space Station crew member, Dr. Steve Swanson tending the Vegetable Production System (Veggie) on ISS during Expedition 40. Veggie is a plant growth system installed on ISS which uses a LED lighting system that is designed to produce salad-type crops to provide the crew with fresh food while on orbit. (Photo courtesy of NASA Public Affairs Office).

In addition to developing specialized lighting system for space flight, NASA funded research in both public and private sector have advanced the understanding of the narrow spectrum lighting on plant performance, and provided scientific and technical basis for commercial development of the technology. This has included requirements for blue light, beneficial effects of green light, and increasing concentration of bioactive compounds.

(Figure 4; Effect of light quality on anthocyanin in lettuce)

These early findings from NASA have since been demonstrated in a number of species, including lettuce, kale, broccoli, strawberry and tomato and specialized spectra are being developed to increase the antioxidant and nutritional content of horticultural. LED lighting is being shown to be a valuable management tools in production of ornamental species during tissue culture, vegetative and seed propagation as well as manage the morphology of seedlings, transplants, and grafted seedlings.

The publication of results from NASA funded research in 1989 signaled the beginning of an exponential increase research reports on use of LEDs horticulture. Figure 1 illustrates the exponential increase in research for the 25 year period from 1990 to 2015 using criteria {"Light emitting diodes" and 'Horticulture" on scholar.google.com accessed 14 July, 2014} returned 102 items (journals articles, patents, journal citations) in the five years (1990-1995) following the first reports of successful growth of plants under red LED's. A decade later (2001-2005) the same search criteria returned 1,130 results, a 10-fold increase, and it's on track to approach 10,000 articles, or over 2000/year, for the period from 2011 to 2015!

(Figure 5, publication of LED related research)

Concurrent with increase in research, increased access to the internet has arguably driven the proliferation of research reports, field observations, and user experiences with LEDs being distributed to scientists, hobbyists, commercial growers, lighting manufacturers and distributors. The amount of publically available information available is staggering. A search (www.google.com accessed 14 December, 2014) of "LED Lighting" resulting in an estimated 32,500,000 web pages!

The sheer volume of information indicates that research on LEDs and plant growth, both professional and amateur, is being widely-distributed and presumably informing decision makers on the selection and use of LEDs in horticultural production. The explosion in information also presents a unique challenge to end users to accept the risk that misinformation is being perpetuated and acknowledge their responsibility to critically review information retrieved from online sources.

NASA supported research use of LEDs to grow plant in space in the late 1980's laid the groundwork for the

Fig. 2. NASA's Deep Space Habitat Module on location for field testing in Arizona Desert. A food production system was integrated as an atrium between the living (upper) and working (lower) areas.

Fig. 3. Wide angle view of NASA's Habit Demonstration Unit work laboratory showing effect of red/blue LED's positioned in plant atrium.

industry-wide transition from gas-discharge lamps developed in the 19th century to LED lighting. Research, government policy and information technology has resulted in an exponential increase in research into the use and application of LED technology in horticulture over the past 25 years. This research has identified many opportunities for LED lighting to optimize light spectra to promote growth, regulate morphology, increase nutrient content, and reduce operating costs in commercial horticulture. NASA's support of LED-light technology is continues to enabling the development of innovative lighting systems for production of edible, ornamental and medicinal plants.

Fig. 4. Addition of blue light during results in higher concentration of anthocyanin in Lactuca sativa cv. Outredegous. Leaves were harvested 28 days after plants were grown at 280 μmol m-2 s-1 PAR under monochromatic 640 nm red LED (Red) or under red light with an additional of 20 μmol m-2 s-1 PAR 440 nm blue from day 21-28 (Red and Blue). (Adapted from Stutte et al., 2009).

Conclusion

The use of LEDs to support plant growth is a radical departure from traditional gas-discharge lamps developed in the mid-19th century and refined throughout the 20th century. The initial investments by NASA in solid state lighting research is enabling improved energy efficiency, reduced operating and management costs, and enhanced quality for traditional commercial crops, and are being widely adopted by emerging high value medicinal plant production and supporting the production of food in space. The adoption of this NASA technology holds great promise for the future of commercial horticulture as management tool for the production of high quality, high value products.

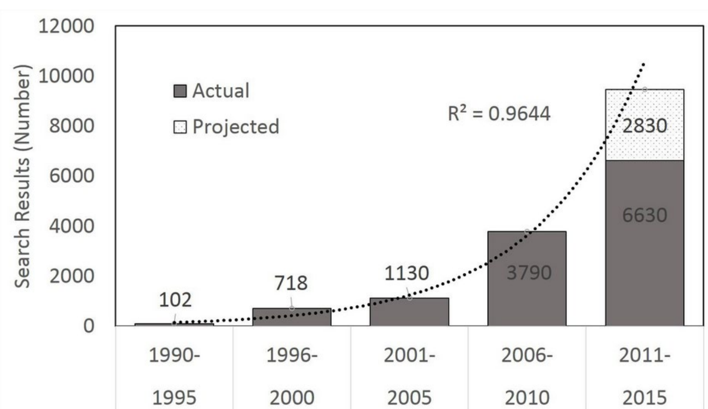

Fig. 5. Results from internet search of scholarly articles (scholar.google.com), using key words "Horticulture" and "Light Emitting Diodes". The search results include peer-reviewed papers, theses, books, abstracts and technical reports from a broad range of disciplines. The number of citations from 2015 was projected based on previous year's rate of increase. No categorization of results has been performed (Stutte, HortScience, 2015 (in press).

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