PROGRAM & ABSTRACT BOOK

GreenSys 2023

International Symposium on New Technologies for Sustainable Greenhouse Systems

Joinly with IV International Symposium on Organic Greenhouse Horticulture

22–27 October, 2023

Cancún, México

greensys2023.org

Contents

Welcome message

Dear colleagues,

The GreenSys2023: International Symposium on New Technologies for Sustainable Greenhouse Systems jointly with the IV International Sympoisum on Organic Greenhouse Horticulture will be held in Cancún, México, from October 22th to 27th 2023. It is our pleasure to host this conference and invite you to attend.

This event is an opportunity to bring together scientists, researchers, technicians and other professionals to present their scientific and technological innovations in greenhouse horticulture and other controlled environment horticultural systems, to share their ideas and knowledge and discuss the state-of-the-art and future perspectives for the controlled environment horticulture sector with emphasis in the sustainability issues.

Cancún is an international touristic destination located at the Caribbean Sea to the east of the Yucatan Peninsula of México. It has 23 km of paradisiac beaches. Close to the Mayan Riviera which has about 140 km of shores and beaches of the Caribbean Sea. Visiting Cancún is a great opportunity to get acquainted with the Mayan' ancient culture by exploring the archeological sites around the Yucatan Peninsula such as Chichén Itzá an UNESCO World Heritage Site and others as Tulum, Calakmul and Uxmal. People who love nature, around Cancún will find several islands such as Cozumel, Isla Mujeres, Holbox Isla and aquatic attractions like Interactive Aquarium, Cenotes (2000 across Yucatan) and Bacalar Lagoon. You can also enjoy the natural rain forest ecosystem visiting Xcaret, Xelha, Kabah Park and Tulum.

We are convinced that you will enjoy your stay in Cancún, from the scientific sessions to the touristic and cultural programs that we will prepare for you. We look forward to seeing you all during the GreenSys2023 and the IV organic greenhouse horticulture symposia.

The Conveners,

Irineo Lorenzo López-Cruz and Efrén Fitz-Rodríguez / *Agricultural Engineering Graduate Program and Department of Mechanical Engineering, Universidad Autónoma Chapingo, Chapingo, Texcoco, México*

Martine Dorais / *Département de Phytologie Faculté des sciences de l'agriculture et de l'alimentation, Université Laval, Québec, Canada*

Conveners

Irineo Lorenzo López-Cruz
Agricultural Engineering Graduate Program and Department of Mechanical Engineering, Universidad Autónoma Chapingo, Chapingo, Texcoco, México

Efrén Fitz-Rodríguez
Agricultural Engineering Graduate Program and Department of Mechanical Engineering, Universidad Autónoma Chapingo, Chapingo, Texcoco, México

Martine Dorais
Département de Phytologie Faculté des sciences de l'agriculture et de l'alimentation, Université Laval, Québec, Canada

Organizing committee

Name	Institution	Country
Dr. Irineo Lorenzo López Cruz	Universidad Autónoma Chapingo (UACh)	
Dr. Efrén Fitz Rodríguez	Universidad Autónoma Chapingo (UACh)	
Dra. Raquel Salazar Moreno	Universidad Autónoma Chapingo (UACh)	
Dr. Abraham Rojano Aguilar	Universidad Autónoma Chapingo (UACh)	
Dr. José Armando Ramírez Arias	Universidad Autónoma Chapingo (UACh)	
Dr. Mauricio Carrillo García	Universidad Autónoma Chapingo (UACh)	
Dr. Joel Pineda Pineda	Universidad Autónoma Chapingo (UACh)	
Dr. Alejandro F. Barrientos Priego	Universidad Autónoma Chapingo (UACh)	
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Dr. Jorge Flores Velázquez	Colegio de Postgraduados (CP)	
Dr. Manuel Sandoval Villa	Colegio de Postgraduados (CP)	
Dr. Enrique Rico García	Universidad Autónoma de Querétaro (UAQ)	
Dr. Ramón Gerardo Guevara González	Universidad Autónoma de Querétaro (UAQ)	
Dr. Ernesto Olvera González	Tecnológico Nacional de México (TecNM)	

Scientific committee

Name	Institution	Country
Abdulaziz Al-Harbi	National Research and development center for sustainable Agriculture (Estidamah)	
Abraham Rojano-Aguilar	Universidad Autónoma Chapingo (UACh)	
Armando Ramirez-Arias	Universidad Autónoma Chapingo (UACh)	
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Ariane Grisey	CTIFL, Institute for Applied Research on Fruit and Vegetables	
Beatrix Alsanius	Swedish University of Agricultural Sciences	
Cecilia Stanghellini	Wageningen UR Greenhouse Horticulture	
Diego Valera-Martínez	University of Almeria	
Dietmar Schwarz	Leibniz Institute for Vegetable and Ornamental Crops	
Eddie Schrevens	K University of Leuven	
Eiji Goto	Graduate School of Horticulture, Chiba University	
Ep Heuvelink	Wageningen UR Greenhouse Horticulture	
Esteban Baeza	Wageningen UR Greenhouse Horticulture	
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Evelia Schettini	University of Bari	
Fatima Baptista	MED - Mediterranean Institute for Agriculture, Environment and Development University of Évora	
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Enrique Rico-García	University of Querétaro	
Fabio Tittarelli	CRA-RPS, Rome	
Francisco Domingo Molina-Aiz	University of Almeria	
Gene Giacomelli	University of Arizona	
Gerben Messelink	Wageningen UR, Greenhouse Horticulture	
Giacomo Scarascia-Mugnozza	University of Bari	
Giuliano Vox	University of Bari	
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Hicham Fatnassi	INRAE - French National Institute for Agriculture, Food, and Environment	
Ido Seginer	TECHNION. Israel Institute of Technology	

Name	Institution	Country
In-Bok Lee	Seoul National University	
Irineo López Cruz	Universidad Autónoma Chapingo (UACh)	
Jean-Claude Roy	Université de Bourgogne franche-Comté, Institut FEMTO-ST	
Jérôme Lambion	GRAB	
Joelle Herforth-Rahmé	FiBL, Switzerland	
Jose Tanny	Institute of Soil, Water and Environmental Sciences, Agricultural Research Organization. Volcani Center	
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Jorge Flores-Velázquez	Colegio de Postgraduados	
Jung-Eek Son	Seoul National University	
Kamel Mesmoudi	University of Batna	
Kurt Möller	Universität Hohenheim	
Leen Janmaat	Louis Bolk Institute	
Leo Marcelis	Wageningen UR – Horticulture and Product Physiology	
Manuel Sandoval-Villa	Colegio de Postgraduados	
Meir Teitel	Agricultural Research Organization. Volcani Center	
Michael Raviv	Newe Ya'ar Research Center, ARO	
Michel Verheul	Bioforks, Norway	
Ming Li	National Engineering Research Center for Information Technology in Agriculture (NERCITA)	
Murat Kacira	University of Arizona	
Nadia Bertin	INRAE - French National Institute for Agriculture, Food, and Environment	
Nazim Gruda	University of Bonn	
Nikolaos Katsoulas	University of Thessaly	
Pierre-Emmanuel Bournet	Agrocampus Ouest	
Pilar Lorenzo	IFAPA Almeria	
Pradeep Kumar	ICAR-Central Arid Zone Research Institute	
Ramón Guevara-González	University of Querétaro	
Raquel Salazar-Moreno	Universidad Autónoma Chapingo (UACh)	
Rodney Thomson	University of Almeria	

Name	Institution	Country
Sasan Aliniaeifard	University of Tehran	
Silke	Wageningen UR Greenhouse Horticulture	
Stefania De PASCALE	University of Naples Federico II	
Stephanie Burnett	University of Maine	
Takehiko Hoshi	Kindai University	
Tao Li	Institute of Environment and Sustainable Development in Agriculture, CAAS	
Thierry Boulard	INRAE - French National Institute for Agriculture, Food, and Environment	
Thomas Bartzanas	Agricultural University of Athens	
Toyoki Kozai	Japan Plant Factory Association	
Ulrich Schmutz	Coventry University, UK	
Uwe Schmidt	Humboldt-Universität zu Berlin	
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Martine Dorais	Université Laval	
Sase Sadanori	Nihon University	
Yousse Rouphael	University of Naples, Federico II	
Yuksel Tuzel	Ege University	
Mathala Juliet Gupta	ICAR-Central Coastal Agricultural Research Institute	
Oliver Körner	Leibniz Institute of Vegetable and Ornamental Crops (IGZ)	

Keynote speakers

Prof. Dr. Stefania De Pascale

Professor of Horticulture, Department of Agriculture, University of Naples Federico II, Italy

Keynote speech: Greenhouse Horticulture in the Context of Circular Economy

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Prof. Dr. Ir. Eldert J. van Henten

Professor of Biosystems Engineering, Farm Technology Group, Wageningen University & Research, The Netherlands

Keynote speech: Greenhouse robotics: current status, challenges and opportunities

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Prof. Dr. Uwe Schmidt

Professor of Biosystems Engineering, Biosystems Engineering Department, Humboldt University of Berlin, Germany

Keynote speech: Speaking Plant Approach in the Artificial Intelligence (AI) Century: Outdated Concept or Future Structure for Intelligent Greenhouse Process Automation

Invited speakers

Prof. Dr. Leo Marcelis

Horticulture and Product Physiology group, Wageningen University, The Netherlands

Keynote speech: Vertical farming: beyond the hype

Prof Dr. Leo Marcelis is head of the chair group Horticulture and Product Physiology at Wageningen University, The Netherlands. This group holds a strong position in research and education on greenhouse horticulture, vertical farming and post-harvest quality.

His research focuses on sustainable production of high quality products in vertical farms and greenhouses; Leo has a strong background in plant physiology, crop monitoring, computational modelling and experimentation. He has extensively studied the physiology, growth and development of plants in order to improve sustainability and quality of crop production in greenhouses and vertical farms. In particular fluxes of assimilates, water and nutrients in the plant, sink/source interactions and partition-

ing among plant organs in response to abiotic constraints are subject of study. LED lighting is a major theme in his research. At the moment he is leading large multidisciplinary research programmes on vertical farming and greenhouse crop production in which universities and private companies cooperate.

His publications can be found here: Leo F.M. Marcelis - Google Scholar
More info: https://www.wageningenur.nl/en/Persons/Leo-Marcelis.htm

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Dr. José Ernesto Olvera González

President of Technological Institute of Pabellón of Arteaga, Aguascalientes, México

Keynote speech: LED Light Technology in Mexican Agriculture

PhD. José Ernesto Olvera González is a professor-researcher and current President of Technological Institute of Pabellón of Arteaga in Aguascalientes, México. He earned a doctorate in engineering sciences at the Autonomous University of Zacatecas and is the founder of the Artificial Lighting Laboratory (LIA) in 2016, the only laboratory in México focused on the use of artificial light with LED technology applied for the production of crops for human consumption and other applications in the agro-industrial sector such as food disinfection with UV-LED Light. Dr. Olvera has more than 21 published international scientific research and technological innovation.

Prof. Dr. In-Bok Lee

Aero-Environmental & Energy Engineering Laboratory (A3EL), Department of Rural Systems Engineering, College of Agriculture & Life Sciences, Seoul National University

Keynote speech: Diversifying the application of CFD technology on Greenhouse R&D

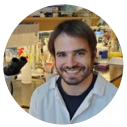
He received a PhD degree in 1998 in aerodynamics and energy in agriculture at Ohio State University, USA. The major research field of I.B. Lee is Aero-Environmental and Energy Engineering in Agriculture while his researches combine experimentation and simulation. He conducts studies on greenhouse structural design with wind loads, natural and mechanical ventilation design of greenhouses, energy saving and renewable energy of greenhouse, information and communication technology and smart farm greenhouses, virtual reality of greenhouse for education, etc. His research team, Aero-Environmental and Energy Engineering Laboratory (A3EL) is very strong for aerodynamic approaches such as Computational Fluid Dynamics, large-sized wind tunnel, particle image velocimetry, and actively develops various advanced experimental tools for field experiments. In-Bok Lee has published over 120 peer review papers and over 200 papers in professional journals.

Prof. Dr. Beatrix Alsanius

Swedish University of Agricultural Sciences, Sweden

Keynote speech: The riddle of soil biological assessments in organic greenhouse horticulture

Beatrix Waechter Alsanius is an internationally leading researcher on sustainable food production in horticultural cropping systems, emphasizing on the use of microorganisms for environmentally-sound cropping systems, threats of human and plant pathogens in horticultural production chains and food safety of vegetables and fruit. She has a Ph.D. from Bonn university (1991), Germany and combined her assistant professorship at SLU (1992-1998) with different postdoctorate leaves at INRA, France and USDA-ARS/ Washington State University, Pullman, WA, US. She was habilitated in horticulture in 1999 and in plant protection ecology in 2006 at the Swedish University of Agricultural Sciences. Since 2009 her current position is chair professor in horticulture at the Swedish University of Agricultural Sciences (SLU), Alnarp, Sweden. During 2010 to 2013 she acted also as an adjunct professor in phytology at Université Laval, Québec, Canada and headed from 2009-2014 the international postgraduate school "Microbial Horticulture (μHORT)", funded by the Swedish research council Formas. Within her position at SLU Alnarp she leads the research activities at the Microbial Horticulture Unit. Beatrix Alsanius was vice-chair of the EU-COST action "Biogreenhouses" during 2012-2016. Within the Core Organic project "GreenResilient" she lead the workpackage dealing with soil health and functional biodiversity. Beatrix Alsanius was awarded membership in the Royal Swedish Physiographic Society and the Royal Swedish Academy of Agriculture and Forestry.



Dr. Adam Barrada

Aix Marseille University, Canada

Keynote speech: Organic fertilizers: as priming agents for enhanced plant defences against pathogens?

Dr. Adam Barrada, an Agronomy engineer from the University of Lorraine (France), completed his plant biology PhD at Aix-Marseille University (France) in 2018. His research focused on the Target of Rapamycin (TOR) pathway, which regulates the balance between plant growth and stress adaptation. During his doctoral studies, Dr. Barrada made a significant discovery by identifying Yet Another Kinase 1 (YAK1) as a novel TOR target in plants, responsible for controlling cell proliferation in root meristems. Following his PhD, Dr. Barrada pursued a two-year postdoctoral position at Prof. Dominique Michaud's Laboratory at the Plant Research and Innovation Center (CRIV, Laval University). There, he collaborated with Medicago Inc. to engineer an agrobacterial strain capable of producing cytokinins. His research demonstrated the strain's ability to impact plant defense responses and increase recombinant protein yields in *Nicotiana benthamiana*. This project introduced him to the field of plant-microbe interactions, leading to his second postdoctoral position in Prof. Martine Dorais's laboratory at CRIV.

Since 2020, under Professor Dorais's guidance, Dr. Barrada has been investigating how organic farming practices affect plant physiology and stress responses. His recent focus has been on understanding how organic fertilizers can alter the rhizosphere microbiome, influencing plant defense metabolism and biotic stress resilience. Dr. Barrada employs various molecular tools in his research and is always eager to collaborate and share his expertise.

Thematic areas Greensys 2023

- Alternative energy in controlled environments
- Circular bioeconomy in controlled environments
- Climate control and modelling
- Computational Fluid Dynamics (CFD) in controlled environment horticulture
- Controlled environment horticulture to improve human nutrition
- Covering materials
- Energy in controlled environment agriculture systems
- Environmental impacts of controlled environment horticulture
- Fertigation, water management
- Greenhouse systems and design
- Greenhouse crops modelling and management
- Growing media, hydroponics, aquaponics
- Labor in greenhouses
- Lighting technology
- Plant production, protection, and quality
- Sustainable greenhouse systems and environmentally friendly technologies
- Sensors, automation, and robotics in greenhouses
- Semi-protected cultivation systems (high tunnels, shade, and screen houses)
- Vertical farming, Plant factory with artificial lighting (PFAL)
- Vulnerability and resilience of horticultural production systems

Thematic areas IV International Symposium on Organic Greenhouse Horticulture

- Biostimulants, soil, and plant microbiome
- Breeding, robust planting material and regulation
- Contentious inputs of organic farming
- Crop health – disease and pest management of organic crops
- Crop management of organic farming
- Economics, social and regulation of organic farming
- Environmental performance of organic greenhouse farming systems
- Innovative and diversified cropping farming systems
- Organic waste management
- Product quality, allergens, and contaminants
- Sustainable growing media and compost
- Sustainable irrigation management of organic cultivation
- Soil fertility and sustainable fertilization strategies
- Urban organic farming and food security

Workshops

Workshop on Computational Fluid Dynamics (CFD) in Greenhouses: Cultivating a Sustainable Future!

Modality: Presentation and discussion of practical cases and implementations
Duration: 1.5 hours
Date: October 24th, 2023
Presenter: Dr. Francisco Domingo Molina-Aiz, University of Almería, Spain

We welcome you to the Workshop on Computational Fluid Dynamics (CFD) in Greenhouses, where we will explore the possibilities of application of CFD simulations in greenhouses. The objective of this workshop is to involve a diverse audience of researchers, engineers, farmers and all attendant interested in using CFD simulations to model the interaction between crops and the microclimate inside greenhouses, visualizing the distribution of the different parameters in space and time.

The constant evolution of the world climate because of global warming has made it necessary to search for new solutions to design greenhouses and climate control systems that allow improving environmental conditions inside greenhouses. On the other hand, the increase in the prices of the inputs, the need to reduce the use of pesticides, the scarcity of water and the limitation of the use of energy make it necessary to optimize its use in greenhouses. The CFD has been shown to be a very useful tool to analyse the exchanges of matter and energy inside greenhouses and their effect on crops.

During this workshop we will analyse the immense capabilities of the CFD for the evaluation of climate control systems in greenhouses. We will also address its limitations and the need for robust model validations in order to guaranty the accuracy of its predictions.

Workshop on Machine Learning and IoT for Greenhouses: Cultivating a Sustainable Future!

Modality: Presentation and discussion of practical cases and implementations
Duration: 1.5 hours
Date: October 24th, 2023
Presenter: Dr. Alvaro Fuentes, Jeonbuk National University, South Korea

We welcome you to the Workshop on Machine Learning and IoT for Greenhouses, where we will delve into the powerful fusion of agriculture and artificial intelligence. This workshop aims to engage a diverse audience of practitioners, researchers, farmers, and all enthusiasts interested in harnessing cutting-edge AI-based technology to monitor and optimize plant growth within controlled greenhouse environments.

As the world faces pressing challenges such as climate change, resource limitations, and a growing global population, it is crucial to explore innovative and sustainable practices in agriculture. Greenhouse

farming has emerged as a beacon of hope in meeting these challenges, offering controlled environments that allow us to grow crops more efficiently, with minimal water usage and reduced reliance on pesticides. However, to truly unlock the full potential of greenhouse farming, we must harness the power of artificial intelligence.

During this workshop, we will embark on a journey to discover the immense possibilities that machine learning offers while addressing the challenges of transforming greenhouse practices. From automating monitoring and data collection processes to enabling predictive analytics for optimized crop yields, the applications of AI in agriculture are limitless.

Networking Session on Machine Learning and Data Science CIGR – Working Group 12

Modality: Dynamic Collaborative Circles
Duration: 1.5 hours
Date: October 24th, 2023
Moderation: Luis Miranda

The present workshop provides a structured platform for participants to meet and interact with multiple individuals in a short time. The focus is set on the facilitation of building professional networks of practitioners working on similar as well as complementary subjects.

The workshop underlines interaction and collaboration, combining fast networking with deeper, focused discussions in thematic groups and is organized in two phases as follows:

First phase: Speed Networking

The participants will be given the opportunity to briefly share their expertise and interests on a bilateral setting. The goal is to gain knowledge onthe common and complementary fields and interests and identify potential partners for deeper discussions.

Second phase:Unmoderated Thematic

Round Tables Thematic round tables will be freely available for joint discussions in groups. Participants are encouraged to use this setting to share their experiences, challenges, insights, and interests.

Topics: The following is a non-exhaustive list of topics of interest in the session:

- Phenotyping, 3D Models
- Energy harvesting, climate control, Irrigation
- Supply chains, logistics
- python, jupyter, R/RStudio, keras, CLI
- Image analysis, Multispectral sensors, Chlorophyll fluorescence
- openCV, Computer Vision

- Time Series Analysis and Forecasting
- Robotics, UAV
- Random Forests, Bayesian methods, Non-linear regression
- t-SNE, MonteCarlo, Evolutionary algorithms
- Deep learning, transformers
- Edge computing, Parallel computing, Scientific computing, GPUs
- IoT, Smart Sensors
- Decision Support Systems, Bots

FAO Workshop within the Framework of the of the GreenSys 2023: International Symposium on New Technologies for Sustainable Greenhouse Systems

"Sustainable Vegetable Production in Small-scale Farmer Greenhouses in Developing Countries"

Date: October 24th, 2023
Modality: Presentations and discussion of field experiences from FAO staff and international experts representing different regions
Duration: 1.5 hours
Moderator: Nazim Gruda and Melvin Medina

This workshop aims to present different field cases and engage the audience in active discussion on sustainable approaches for technological adaptation to increase the efficiency and resilience of horticultural systems for small-scale farmers. For example, how can limiting factors such as decreasing crop yields and incomes due to extreme climate events, water scarcity, land degradation, pests and diseases, limited access to technical assistance, appropriate inputs, financial resources, and lack of infrastructure and markets be overcome more affordably, closer to the economic reach of smallholders?

The workshop is of interest to a diverse audience of practitioners such as farmers and extension agents, researchers and horticulturalists, NGOs and opinion leaders, funding agencies and policymakers, to develop and implement projects, programmes, and initiatives and to create an enabling environment for the adoption of context-specific and cost-effective technologies adapted to small-scale farmers. Field experiences and innovative approaches will be openly discussed to understand how adaptation has been achieved and what challenges were overcome to ensure sustainability: income generation, environmental protection, and social equity.

Panellists representing different geographic regions, climatic conditions, and cropping systems will share experiences and knowledge on producing vegetable crops in protected cultivation. The primary objective is to improve the livelihoods of communities through sustainable agricultural practices. Moreover, the panellists will discuss scaling approaches to achieve the SDGs for better production, nutrition, livelihoods, and a healthier environment, all while minimising investments and running costs. An open discussion with the participants will follow the presentations to explore these topics further and exchange ideas.

The workshop will provide an opportunity to highlight the necessity of making research more practical, effective, inclusive, and participatory, also targeting small-scale farmers developing technologies and practices that are efficient and affordable to overcome limiting factors and achieve food security.

Program at glance

DATE	OCT 22	OCT 23					OCT 24					OCT 25					OCT 26	OCT 27
HOUR	SUNDAY	MONDAY					TUESDAY					WEDNESDAY					THURSDAY	FRIDAY
8:00		Registration 8:00-18:00					Registration 8:00-18:00					Registration 8:00-18:00					TECHNICAL TOUR	POST-CONFERENCE TOURS
8:30		Opening ceremony					(Caribe 1-6) **Keynote Speaker**					(Caribe 1-6) **Keynote Speaker**						
9:00		(Caribe 1-6) **Keynote Speaker**																
9:30							Symposium Photo / Coffee break					Coffee break						
10:00		Coffee break					(Miramar 1) **OS-9** Lighting Technology II	(Miramar 2) **OS-10** Fertigation, water and growing medium I	(Miramar 3) **OS-11** Sensors, automation, and robotics in greenhouses I	(Caribe 7-8) **OS-12** Organic Greenhouse Horticulture: Soil health and biological assessments		(Miramar 1) **OS-17** CFD Modelling	(Miramar 2) **OS-18** Fertigation, water, and growing media III	(Miramar 3) **OS-19** Plant production, protection, and quality	(Caribe 7-8) **OS-20** Organic Greenhouse Horticulture: Soil fertility and plant health		
10:20		(Miramar 1) **OS-1** Climate control and modelling I	(Miramar 2) **OS-2** Greenhouse crops modelling and management I	(Miramar 3) **OS-3** Lighting technology I	(Caribe 7-8) **OS-4** Plant factory/ Vertical farming I													
10:40																		
11:00																		
11:20																		
11:40		Coffee break					Coffee break					Coffee break						
12:00		(Miramar 1) **OS-1** Climate control and modelling I	(Miramar 2) **OS-2** Greenhouse crops modelling and management I	(Miramar 3) **OS-3** Lighting technology I	(Caribe 7-8) **OS-4** Plant factory/ Vertical farming I		(Miramar 1) **OS-9** Lighting Technology II	(Miramar 2) **OS-10** Fertigation, water and growing medium I	(Miramar 3) **OS-11** Sensors, automation, and robotics in greenhouses I	(Caribe 7-8) **OS-12** Organic Greenhouse Horticulture: Soil health and biological assessments		(Miramar 1) **OS-17** CFD Modelling	(Miramar 2) **OS-18** Fertigation, water, and growing media III	(Miramar 3) **OS-19** Plant production, protection, and quality	(Caribe 7-8) **OS-20** Organic Greenhouse Horticulture: Soil fertility and plant health		
12:20																		
12:40																		
13:00																		
13:20		Lunch					Lunch					Lunch						
15:00	REGISTRATION	(Miramar 1) **OS-5** Climate control and modelling II	(Miramar 2) **OS-6** Greenhouse crops modeling and management II	(Miramar 3) **OS-7** Covering materials	(Caribe 7-8) **OS-8** Plant factory/ Vertical farming II		(Miramar 1) **OS-13** Greenhouse systems and design	(Miramar 2) **OS-14** Fertigation, water and growing medium II	(Miramar 3) **OS-15** Sensors, automation, and robotics in greenhouses II	(Caribe 7-8) **OS-16** Organic Greenhouse Horticulture: Crop systems and management		(Miramar 1) **OS-21** Energy in greenhouses	(Miramar 2) **OS-22** Environmental impact and sustainable production	(Miramar 3) **OS-23** Lighting technology III	(Caribe 7-8) **OS-24** Greenhouse crops management		
15:20																		
15:40																		
16:00																		
16:20																		
16:40																		
17:00		Poster sesion / Coffee break					Poster sesion / Coffee break					Poster sesion / Coffee break						
18:00	Welcome reception	ISHS Business Meeting					Workshop 1	Workshop 2	Workshop 3	Workshop 4		Closing ceremony						
19:00																		
20:00												Banquet Dinner						
21:00																		
22:00																		
24:00																		

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General Information

Language: The official language for the symposium is English.

Registration, Secrétariat, Information & Tour Desk :

All participants are required to check in at the registration desk. Registered participants will receive a name badge and the symposium package, including the Scientific Program and the Book of Abstracts.

Location: Convention Center Iberostar. Iberostar Selection Cancún Hotel (México).
Address: Boulevard Kukulcán km. 17, C.P. 77500, Cancún, Qroo., México.

Registration Hours:

22 October (Sunday): 15:00–18:00
23–25 October (Monday–Wednesday): 8:00–18:00

Registration fee covers:

	General participant	Student	Attendant/ Accompanying Person
Admission to all oral and poster sessions	X	x	x
Admission to workshops	X	x	x
Welcome reception event	X	x	x
Coffee/refreshments breaks and lunch	X	x	x
Symposium package	X	x	
Online access to the electronic version of the Acta Horticulturae symposium proceedings	X		

Identification Badge:

For security purposes, participants are reminded to wear their ID badges while attending symposia and social events. Entrance into sessions will be limited to badge holders only.

Internet:

Free Internet will be available in the Convention Center, Iberostar Selection Cancún Hotel. WiFi code will be announced near the registration desk.

Certificate of participation:

All the participants requiring a certificate of participation should ask for it at the registration desk or by e-mail to greensys2023@chapingo.mx or greensys2023@gmail.com before November 30. A digital certificate (PDF) will be sent to you by email.

Presentation guidelines

Oral presentations

Authors should prepare their presentation using Microsoft PowerPoint (2016 or latest version) or Portable Document Format (PDF). The organization is not responsible for problems caused by incompatible issues with the software.

The total time allotted to each oral presentation is 20 min: 15 minutes for presentation and 5 minutes for questions. Please strictly comply with this time schedule.

Please bring your presentation file on a USB Memory stick to the preview room at least 12 hours before your scheduled presentation time. Name your presentation using your full name and put it in the folder with the same name as your session name (e.g. OS12-03). Only one file by folder.

Location: preview room is Mezanine Convention Center Iberostar Peninsula.

Open Hours: 22 October (Sunday): 15:00-19:00
23 October (Monday): 8:00-18:00
24 October (Tuesday): 8:00-18:00
25 October (Wednesday): 8:00-15:00

Please ensure you reach your session room at least 15 minutes before the start of oral presentations to check if anything changes and discuss it with the session chair. We also recommend you bring your presentation file with you on a USB memory stick or save a copy of your presentation electronically on an accessible internet site.

Note: If you do not check your presentation into the preview room, you will be responsible for time lost to upload your presentation onto the computer in the session room.

Posters presentations

The following guidelines are provided to prepare posters:

a) Poster dimensions should be less than 91.4 cm (36 inches) in width and 121.9 cm (48 inches) in height.
b) In the upper part must be placed the Symposium logo, the title of the communication, author's names, and affiliation.
c) All text and characters should have a size that allows reading from a distance not exceeding 2 meters.
d) The Organizing Committee will provide placards to display the posters that will be affixed to the panels using poster glue available on the poster exhibition area.
e) Posters should be installed in the morning (from 8:00, or on Sunday afternoon for the Monday session) of the presentation and retrieved in the evening of the same day (before 18:30).

Posters will be displayed all day long. During the time schedule dedicated to poster presentations (see hereafter), authors are encouraged to stay next to their poster to answer questions.

Poster presentations (Isla room)

23 October (Monday), 17:00–18:00 (PS01)
24 October (Tuesday), 17:00–18:00 (PS02)
25 October (Wednesday), 17:00–18:00 (PS03)

Official/Social program

Welcome Reception:

All registered participants and accompanying persons are invited to attend the Welcome Reception. Food and drinks will be served.

Location: Miramar Garden at Iberostar Convention Center. Iberostar Selection Cancún Hotel.
Date & Time: 22 October (Sunday) 18:00–21:00

Opening Ceremony:

All registered participants are invited to attend the Opening Ceremony.

Location: Caribe Hall room 1-6 at Iberostar Convention Center. Iberostar Selection Cancún Hotel.
Date & Time: 23 October (Monday) 8:30–9:00

Closing Ceremony:

All registered participants are invited to attend the Closing Ceremony.

Location: Miramar Hall room at Iberostar Convention Center. Iberostar Selection Cancún Hotel.
Date & Time: 25 October (Wednesday) 18:00–18:30

Banquet Dinner:

Location: Caribe Hall room 1-6 at Iberostar Convention Center. Iberostar Selection Cancún Hotel.
Date & Time: 25 October (Wednesday) 20:00–24:00

Lunches:

Lunch will be provided for three days.

Location: Caribe Hall room 1-6 at Iberostar Convention Center. Iberostar Selection Cancún Hotel.
Date & Time: 23, 24 & 25 October 13:20–15:00

Coffee Breaks:

Coffee and tea will be served to all participants.

Location: Foyer Caribe & Foyer Miramar
Date & Time: 23 October (Monday) 10:00–12:20, 11:40–12:00, 17:00–18:00 with poster presentation.
24 October (Tuesday) 9:30–10:00 with group photo, 11:40–12:00, 17:00–18:00 with poster presentation.
25 October (Wednesday) 9:30–10:00, 11:40–12:00, 17:00–18:00 with poster presentation.

Group Photo:

A commemorative group photo will take place.

Location: Miramar Garden at Iberostar Convention Center. Iberostar Selection Cancún Hotel.
Date & Time: 24 October (Tuesday) 9:30–10:00

Technical Tour

The participants who wish to join the technical tour should confirm their attendance at the registration desk before midday on 23rd October. For late registration, please note that it will be subject to availability. Upon confirming your attendance at the desk, you will get detailed information about the tour.

Date & Time: 26 October 7:30–20:00

We draw the attention of participants to the fact that due to the busy time schedule and possible traffic jams, the return to the Cancún Hotel Area may be delayed. Also, because of time-zone differences, the arrival time at the Cáncun Hotel Zone will be around 21:00 pm.

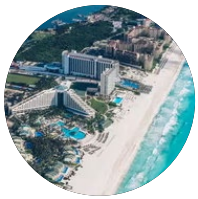
Tour fee: 120 USD.

Conditions: All admission fees, transportation, and lunch are included.

Itinerary:

7:30 Departure from the Iberostar Selection Cancún Hotel.
9:30–11:30 Visit to PAMASUR Company located at Temozon, Yucatán.
12:00 –14:00 Visit to Cenote Hubiku (including lunch).
14:00 Departure to Chichén Itzá Archeological site.
15:00–17:00 Visit to Chichén Itzá Archeological site.
17:00 Travel to Cancún Hotel zone.

Location



Convention Center Iberostar.
Iberostar Selection Cancún Hotel (México).

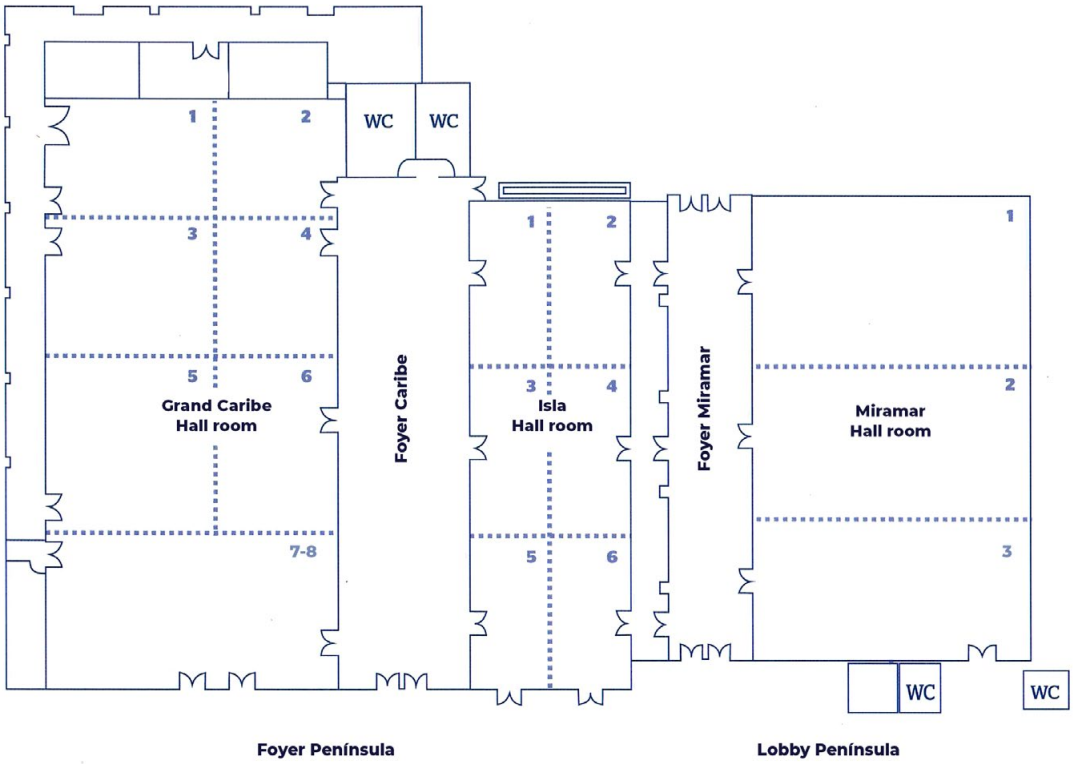
Address: Boulevard Kukulcán km. 17, C.P. 77500, Cancún, Qroo., México.

Google Maps location: https://maps.app.goo.gl/MKZGtSYL3CNwubQWA

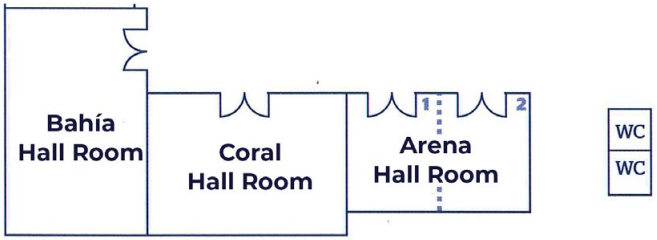
General Map / Iberostar Selection Cancún Hotel (México)

- Recepción / Front desk
- Star Market Tienda (Nivel 1) / Star Market Shop (Level 1)
- 1 Palapa de Aerobics y Ping Pong / Aerobics & Ping Pong Palapa
- 2 Kids Club
- 3 Teenie Club Star Friends
- 1 Restaurante Steakhouse "La Parrilla" / (Nivel de Mezzanini / Level Mezzanini)
- 2 Restaurante Japonés "Naga Hibachi" / (Nivel de Mezzanini / Level Mezzanini)
- 3 Restaurante Gourmet "La Horma" / (Nivel 1 / Level 1)
- 4 Restaurante "El Antiguo Laguito" / (Nivel 1 / Level 1)
- 5 Restaurante de Playa y Mexicano "Maguey" / Beach & Mexican Restaurant "Maguey"
- Canchas de deporte / Sports Courts
- 1 Lobby Bar "Las Palmas" (Nivel 1 / Level 1)
- 2 Sports Bar "Vértigo" / (Nivel Mezzanini / Mezzanini Level)
- 3 Bar Piscina "Carey" / Pool Bar "Carey"
- 4 Aqua Bar "La Perla"
- 5 Bar de Playa "Las Olas" / Beach Bar "Las Olas"
- Gimnasio (Nivel Mezzanini) / Fitness Center (Level Mezzanini)
- Centro de Negocios (Nivel 1) / Bussines Center (Level 1)
- Internet
- 1 Star Friends Club House
- 2 Star Friends Club House Toallas / Towels
- Centro de Convenciones / Convention Center
- 1 Salón "Miramar" (Planta Baja) / (Ground Floor)
- 2 Salón "Isla" (Planta Baja) / (Ground Floor)
- 3 Gran "Caribe" (Planta Baja) / (Ground Floor)
- 4 Jardín "Miramar" (Planta Baja) / (Ground Floor)
- 5 Salón de Reunión (Nivel Mezzanini) / (Bahía / Coral / Arena) (Level Mezzanini)
- 6 Playa de Grupos / Group's Beach
- 7 Lobby Centro de Convenciones Lobby Convention Center
- Jacuzzi
- Parque Acuático / Aquatic Park
- Gazebo de Bodas / Wedding Gazebo
- Cancha de Football / Soccer Field
- Teatro & Bar "El Telón" / Theatre & Bar "El Telón"
- Cohiba Atmosphere Bar de Fumadores (Nivel 1) / Cigar Bar (Level 1)
- Golf Club House
- 1 SPA Sensations / (Sótano / Basement)
- 2 Palapas de Masajes / Massage Palapa
- 3 Palapas de Masajes / Massage Palapa

Floor plan / Convention Center Iberostar



Mezanine Level



GreenSys 2023

International Symposium on New Technologies for Sustainable Greenhouse Systems

Scientific program

Monday October 23, 2023

8:00	Registration 8:00-18:00			
8:30	Opening ceremony 8:30-9:00			
9:00	Keynote speaker 9:00-10:00 Speaker: U. Schmidt Chair: I. L. Lopez-Cruz			
10:00	Coffee break 10:00-10:20			
10:20	Oral session 10:20-11.40			
	OS-1	**OS-2**	**OS-3**	**OS-4**
	Climate control and modelling I Chair: G. Giacomelli OS01-01: H. Choi OS01-02: S. van Mourik OS01-03: D. Kim OS01-04: P. de Heer	**Greenhouse crops modelling and management I** Chair: L. Miranda-Trujillo OS02-01: D. Savvas OS02-02: M. Verheul OS02-03: K. Jinhyun OS02-04: T. Ishii	**Lighting technology I** Chair: X. Hao OS03-01: B. Alsanius OS03-02: S. Chen OS03-03: J. Yu OS03-04: J. Yun	**Plant factory/Vertical farming I** Chair: F. Orsini OS04-01: L. Marcelis (Invited) OS04-02: E. Goto OS04-03: J. Hu
11:40	Coffee break 11:40-12:00			
12:00	Oral session 12:00-13:20			
	OS-1	**OS-2**	**OS-3**	**OS-4**
	OS01-05: E. Chantoiseau OS01-06: F. de Zwart OS01-07: H. Suh OS01-08: E. Fitz-Rodríguez	OS02-05: N. Fujiuchi OS02-06: Y. Iwasaki OS02-07: S. Yoon OS02-08: N. Vilfan	OS03-05: M. Han OS03-06: S. Nam OS03-07: T. Joilek OS03-08: M. Hellström	OS04-04: J. Kim OS04-05: F. Wang OS04-06: T. Jishi OS04-07: Y. Tong
13:20	Lunch (13:20-15:00)			
15:00	Oral session 15:00-17:00			
	OS-5	**OS-6**	**OS-7**	**OS-8**
	Climate control and modelling II Chair: H. Fatnassi OS05-01: E. Janssen OS05-02: J. Valencia-Islas OS05-03: R. Vanbeylen OS05-04: N. Katsoulas OS05-05: K. Weerheim OS05-06: J. Wang	**Greenhouse crops modeling and management II** Chair: A. Ramirez-Arias OS06-01: M. Gallardo OS06-02: H. Suh OS06-03: Y. Zheng OS06-04: F. Molina Aiz OS06-05: C. Collado OS06-06: S. Lee	**Covering materials** Chair: J. Flores-Velázquez OS07-01: P. E. Bournet OS07-02: M. Bergren OS07-03: H. Vitoshkin OS07-04: P. Persons OS07-05: J. Sánchez-Molina OS07-06: H. Seo	**Plant factory/Vertical farming II** Chair: E. Goto OS08-01: Ch. Vatistas OS08-02: G. Pennisi OS08-03: D. Nunez OS08-04: D. Tran OS08-05: C. Carpineti OS08-06: Y. Ji OS08-07: I. Righini
17:00	Poster session with coffee break 17:00-18:00			
18:00	ISHS Business meeting			

Oral presentations: Monday October 23, 2023

9:00–10:00 KEYNOTE LECTURE 1
Chair: I.L. López-Cruz

Speaking Plant Approach in the Artificial Intelligence (AI) Century: Outdated Concept or Future Structure for Intelligent Greenhouse Process Automation

U. Schmidt
Humboldt University Berlin, Germany

10:20–11:40 ORAL SESSION 1 / Climate control and modelling I
Chair: G. Giacomelli

OS01-01

Exploring NeRF for Automated 3D Phenotyping in Greenhouse: A Promising Direction in Shape Measurement and Analysis

HongBeom Choi, HyeIn Lee, HyukJae Lee, Dr. Soo Hyun Park, Dr. Taek-Sung Lee
Korea Institute of Science and Technology, Korea (Republic of)

OS01-02

Plant Performance in Precision Horticulture: Visualizing optimal control strategy under stochastic uncertainty

S. van Mourik[1], M. Vellekoop[2]
[1]Farm Technology group, Wageningen University & Research, Netherlands
[2]University of Amsterdam, Netherlands

OS01-03

Time series forecasting for air temperature inside a naturally ventilated greenhouse with optimal sensor location based on LSTM

Da In Kim, In-bok Lee, Jeong-hwa Cho, Young-bae Choi, Hyo-hyeog Jeong, Sol-moe Kang, Seo-ha Park
Seoul National University, Korea (Republic of)

OS01-04

Predicting greenhouse design performance and suggested improvements using massive cloud-simulation and machine learning

Paolo de Heer, Anouk Beelen, Athanasios Sapounas, Richard Dekker
TNO, Netherlands

12:00–13:20 ORAL SESSION 1 / Climate control and modelling I

OS01-05

Computing radiative heat transfers in greenhouses: a methodology coupling analytical and numerical approaches for view factors assessment

Samuel Sourisseau[2], Etienne Chantoiseau[1], Cyril Toublanc[1], Michel Havet[1]
[1]Institut Agro Rennes-Angers, France
[2]Oniris, Nantes Université, France

OS01-06

An on-line benchmark tool for greenhouse technology towards fossil-free greenhouses

Feije De Zwart, Gert-Jan Swinkels, Luuk Graamans, Silke Hemming, David Katzin, Kshiti Mishra
Wageningen UR Greenhouse Horticulture, Netherlands

OS01-07

Assessing Tree-Based Boosting Algorithms for Crop Growth Forecasting in Greenhouse Cultivation

Hyun Kwon Suh[1], Ju Yeon Ahn[1], Hyeonji Park[1], Soo Hyun Park[2], Joon Yong Kim[3]
[1]Sejong University, Korea (Republic of)
[2]Smart farm research center, Korea Institute of Science and Technology, Korea (Republic of)
[3]Dept. of Biosystems and Biomaterials eng., Research Institute of Agriculture, Seoul National University, Korea (Republic of)

OS01-08

High-pressure fogging system for VPDc control in low-tech greenhouse crops

Efrén Fitz-Rodríguez, José Orbelin Gutierrez-Hernández, José Armando Ramírez-rias, Irineo L. López-Cruz, Agustín Ruíz-García
Universidad Autónoma Chapingo, México

10:20–11:40 ORAL SESSION 2 / Greenhouse crops modelling and management I

Chair: L. Miranda-Trujillo

OS02-01

Model-based optimization of nutrient supply in a lettuce crop grown in recirculating nutrient solution using the Decision Support System NUTRISENSE

Dimitrios Savvas, Evangelos Giannothanasis, Lena Voulgari, Georgia Ntatsi
Agricultural University of Athens, Greece

OS02-02

Optimisation of tomato production in a closed greenhouse system in Norway

Michel Verheul
Norwegian Institute of Bioeconomy Research, Norway

OS02-03

Paprika Growth Modeling Using Cropbox

Kim Jinhyun, Min ju Shin, Ji Woong Bang, Ho Jeong Jeong, Seung Ri Yoon
National Institute of Horticultural and Herbal Science, Korea

OS02-04

Maintaining the quality of strawberry fruit in long-term storage by keeping the environment at low temperature and high humidity

Takashi Ishii, Tomohiro Jishi, Kazuhiro Shoji
Central Research Institute of Electric, Power, Graduate School of Horticulture, Japan

12:00–13:20 ORAL SESSION 2 / Greenhouse crops modeling and management modelling I

OS02-05

Process-based crop model to evaluate stress on tomato plants and predict the fruit yield and quality

Naomichi Fujiuchi[1], Hiroko Yamaura[2], Risa Suenaga[2], Naho Takebuchi[2], Misa Kikuchi[3], Hiroaki Saito[3], Garima Singh[3], Yuta Takahashi[3], Hiroshi Ezura[2], Naoya Fukuda[2]
[1]Ehime University, Japan
[2]University of Tsukuba, Japan
[3]Toyo Holdings, Co., Ltd, Japan

OS02-06

The "N-C balance model" for optimizing nitrogen supply and temperature management in greenhouse fruit vegetable production

Yasunaga Iwasaki
Meiji University, Faculty of Agriculture, Japan

OS02-07

Utilizing Decision Tree Algorithm for Melon Fruit Weight Prediction

Seungri Yoon[1], Taewon Moon[2], Jin Hyun Kim[1], Minju Shin[1], Ji Wong Bang[1], Ho Jeong Jeong[1], Tae In Ahn[2]
[1]National Institute of Horticultural and Herbal Science
[2]Seoul National University

OS02-08

Virtual Tomato Crops: a digital twin of a tomato crop

Nastassia Vilfan, Katarina Smolenova, Pieter De Visser, Jochem Evers
Wageningen University and Research, Netherlands

10:20–11:40 ORAL SESSION 3 / Lighting technology I

Chair: X. Hao

OS03-01

Integrated production in new light: light quality in greenhouse horticulture and its impact on the phyllosphere microbiome

Beatrix Waechter Alsanius, Maria Hellström, Karl-Johan Bergstrand, Anna Karin Rosberg, Maria Karlsson
Dept. of Biosystems and Technology, SLU, Microbial Horticulture Unit, Sweden

OS03-02

Effect of supplementary far-red light on plant growth, fruit set, yield and fruit quality of sweet pepper

Sijia Chen[1], Leo Marcelis[1], Remko Offringa[2], Theoharis Ouzounis[3], Ep Heuvelink[1]
[1]Wageningen University and Research, Netherlands
[2]Plant Developmental Genetics, University Leiden, Netherlands
[3]Fluence, Netherlands

OS03-03

Effect of Different Supplemental Lighting Sources on Cucumber (*Cucumis sativus* L.) Growth

Jin Yu, Eun Won Park, Ji Hye Yun, Hyeong Eun Choi, So Yeong Hwang, Jeong Hun Hwang, Hee Sung Hwang, Seung Jae Hwang
Gyeongsang National University, Korea (Republic of)

OS03-04

Intumescence Incidence of 'Sinhong' Hot Pepper Seedlings under Different Light Qualities

Ji Hye Yun, Jin Yu, So Yeong Hwang, Eun Won Park, Jeong Hun Hwang, Hyeong Eun Choi, Hee Sung Hwang, Seung Jae Hwang
Gyeongsang National University, Korea (Republic of)

12:00–13:20 ORAL SESSION 3 / Lighting technology I

OS03-05

Growth, morphology, and light acclimation of cucumber seedlings grown under different light spectral qualities

Minhee Han, Jiwoong Bang, Jungseop Lee, Chul Geon Ahn, Jaehan Lee, Jin Hyun Kim, Dongpil Kim
Protected Horticulture Research Institute, Korea (Republic of)

OS03-06

A chlorophyll fluorescence-based biofeedback system to optimize LED lighting: from seedling to harvest stage

Suyun Nam, Marc W. van Iersel, Rhuanito S. Ferrarezi
University of Georgia, United States of America

OS03-07

Growth comparison of corn salad and frill lettuce under the same environmental conditions with artificial light

Teeranuch Joilek[1], Maitree Munyanont[1], Thanit Ruangsangaram[2], Dannisa Fathiya Rachma[1], Tomoka Endo[1], Na Lu[1], Michiko Takagaki[1]
[1]Chiba university, Japan
[2]Kasetsart University, Thailand

OS03-08

Utilizing light exposure to its fullest: how light quality can aid biocontrol introduction in greenhouse horticulture

Maria Hellström, Maria Karlsson, Ramesh Raju Vetukuri, Paul G. Becher, Beatrix W. Alsanius
Swedish University of Agricultural Sciences, Sweden

10:20–11:40 ORAL SESSION 4 / Plant factory and vertical farming I

Chair: F. Orsini

OS04-01

Vertical farming: beyond the hype

Leo Marcelis
Horticulture and Product Physiology group, Wageningen University, The Netherlands

OS04-02

Development of a novel crop cultivation system with environmental and crop monitoring functions for a lunar-base plant factory

Eiji Goto, Hideo Yoshida, Kota Saito, Moe Sekiya, Taishi Okabe, Xinglin Ke, Shoko Hikosaka
Chiba University, Japan

OS04-03

Research and application of plant factory technology on precise control of selenium in vegetables

Jiangtao Hu[1], Zheng Wang[1], Li Zhang[1], Jie Peng[1], Tao Huang[1], Xiao Yang[1], Byoung Ryong Jeong[2], Qichang Yang[1]
[1]The Graduate School of Chinese Academy of Agricultural Sciences, China
[2]Gyeongsang National University GNU, Korea (Republic of)

12:00–13:20 ORAL SESSION 4 / Plant factory and vertical farming I

OS04-04

Analysis on the air-conditioning system to enhance the uniformity in a multi-layer vertical farm under tropical climate condition

Jaehyun Kim, Sang Min Lee, Eunjung Choi
Korea Institute of Machinery Materials, Korea (Republic of)

OS04-05

Effects of LED Red and Blue Light Component on Growth and Photosynthetic Characteristics of Coriander in Plant Factory

Fang Wang[1], Qi Gao, Qiuhong Liao[1], Qingming Li[1], Jianming Li[2], Qichang Yang[1]
[1]The Graduate School of Chinese Academy of Agricultural Sciences, China
[2]Northwest A&F University, China

OS04-06

Adjustment of equipment operation in a plant factory under solar power generation

Tomohiro Jishi[1], Kazuhiro Shoji[1], Takashi Ishii[1], Shigeru Bando[1], Norihiko Itoh[1], Fumiyuki Goto[2], Naoto Higa[3], Syougo Kinjyou[4]
[1] Central Research Institute of Electric Power Industry, Japan
[2] Saga University, Japan
[3]Nextems Co., Ltd. Nextems, Japan
[4]Okinawa Electric Power Company, Japan

OS04-07

Lettuce plant morphology and nutrient solution physiochemical properties in response to the recycled nutrient solution in a plant factory with artificial light

Yuxin Tong
Chinese Academy of Agricultural Science, China

15:00–17:00 ORAL SESSION 5 / Climate control and modeling II

Chair: H. Fatnassi

OS05-01

Dimensioning the reverse osmosis desalination system for a tomato greenhouse using the SIOM simulation software

Egon Janssen, Athanasios Sapounas, Richard Dekker, Robert Bezemer
TNO, Netherlands

OS05-02

Towards a modeling and control approach based on the drying product in greenhouses

Jose Olaf Valencia Islas[1], Murat Kacira[1], Irineo Lorenzo López Cruz[2], Gene Giacomelli[1], Agustín Ruiz García[2], Peiwen Li[1]
[1]The University of Arizona, United States of America
[2]Universidad Autónoma Chapingo, México

OS05-03

Combining plant sensor measurements and decision tree analysis to better understand the 'plant stress-reducing ventilation' strategy in greenhouses

Rune Vanbeylen[1], Fjo De Ridder[2], Herman Marien[2], Griet Janssen[2], Kathy Steppe[1]
[1]Ghent University, Belgium
[2]Thomas More is the largest University of Applied Sciences, Belgium

OS05-04

Effect of shading in evaporatively cooled greenhouses in the Mediterranean region

Nikolaos Katsoulas[1], Sofia Faliagka[1], Athanasios Sapounas[2]
[1]University of Thessaly, Greece
[2]TNO, Netherlands

OS05-05

Light fluctuations affect morphological and physiological processes and biomass in tomato

Anja Dieleman
Wageningen University & Research, Netherlands

OS05-06

Application of solar water circulation heating system in Chinese solar greenhouse

Jian Wang, Mei Qu, Shumei Zhao, Jieyu Cheng, Pingzhi Wang, Chengwei Ma
China Agricultural University, China

15:00–17:00 ORAL SESSION 6 / Greenhouse crops modeling and management modelling II

Chair: A. Ramirez-Arias

OS06-01

Evaluation of the VegSyst-DSS for the management of nutrients in fertigation of a soil-grown tomato crop in Mediterranean greenhouses

Marisa Gallardo, Maria Teresa Peña-Fleitas, Francisco Manue Padilla, Rodney B. Thompson
Universidad de Almería, Spain

OS06-02

Exploring the Potential of YOLOv8 for Real-time Strawberry Flower Detection in Greenhouses

Hyun Kwon Suh, Hyeonji Park, Ju Yeon Ahn, Doyeon Kim, Yoel Kim
Sejong University, Korea (Republic of)

OS06-03

Controlled Environment Cannabis Cultivation: Current Status, Challenges and Future Trends

Youbin Zheng
University of Guelph-SES, Canada

OS06-04

Use of marble gravel mulching for tomato production inside a Mediterranean naturally ventilated solar greenhouse

Francisco Domingo Molina Aiz, M.N. Honoré, P. Marin-Membrive, D.L. Valera
University of Almería, Spain

OS06-05

Effects of Rooting Hormone, Light, and Carbone Dioxide Enrichment on the Rooting of Cannabis sativa Cuttings

Cristian Collado, Ricardo Hernandez
North Carolina State University, United States of America

OS06-06

Fine dust reduction system in agricultural facilities for worker's respiratory safety

Seong-won Lee, Il-Hwan Seo, Hyo-Jae Seo
Jeonbuk National University, Korea (Republic of)

15:00–17:00 ORAL SESSION 7 / Covering materials

Chair: J. Flores-Velázquez

OS07-01

Impact of Insect Proof Nets on the Microclimate and on the Risks of Fungal Development inside a Greenhouse Crop

Rania Missaoui[1], Pierre-Emmanuel Bournet[1], Etienne Chantoiseau[1], David Vuillermet[2]
[1]Institut Agro Rennes Angers, France
[2]RATHO, ASTREDHOR, France

OS207-02

Solar spectrum modification by luminescent agriculture films for enhanced light use efficiency in greenhouse plant trials

Matthew Bergren[1], Morgan Mattingly[2], Charles Parrish[1], Michael Blum[2], Damon Hebert[1], Gene Giacomelli[2]
[1]UbiQD, United States of America
[2]University of Arizona, United States of America

OS07-03

Implementing of Semi-transparent Organic Photovoltaic Modules in a Tomato Greenhouse

Helena Vitoshkin[1], Meir Teitel[1], Roei Grimberg[1], Shay Ozer[1], Ibrahim Yehia[2], Esther Magadley[2], Avi Levy[3], Asher Levi[1], Shelly Gantz[4], Roni Amir[4], Farhad Geoola[1]
[1]ARO, Volcani Center, Israel
[2]Triangle Research and Development Center, Israel
[3]Department of Mechanical Engineering, Ben-Gurion University of the Negev, Israel
[4]Agricultural Extension Service, MOA, Israel

OS07-04

Lettuce Photosynthesis and Light Response Curves under Semi-transparent Solar Cells

Parker Persons, Rhuanito Ferrarezi, Marc van Lersel
University of Georgia, United States of America

OS07-05

Economic analysis of a photovoltaic field on a greenhouse roof

Jorge Antonio Sánchez Molina, Jerónimo Ramos, Francisco García Mañas, Manuel Berenguel, Jorge Antonio Molina
University of Almería Almería, Spain

OS07-06

Analysis on Insulation Effects of Wind Environment and Cover Materials for Greenhouse Energy Design in Reclaimed Land

Hyo Jae Seo, Il-Hwan Seo, Hak-Sung Le
Jeonbuk National University, Korea (Republic of)

15:00–17:00 ORAL SESSION 8 / Plant factory and vertical farming II

Chair: E. Goto

OS08-01

Effect of different lighting under various wavelengths on seed germination inside a vertical farming system

Christos Vatistas, Dr. Dafni Avgoustaki, Thomas Bartzanas
Agricultural University of Athens, Greece

OS08-02

Water Use Efficiency in a Vertical Farm with Artificial Lighting: first results from AlmaVFarm

Laura Carotti, Ilaria Zauli, Alessandro Pistillo, Giuseppina Pennisi, Giorgio Gianquinto, Francesco Orsini
University of Bologna, Italy

OS08-03

Lettuce growth and light use efficiency under non conventional diel cycles and noctoperiods

Diego Nunez, Tessa Haanskorf, Leo Marcelis, Ep Heuvelink
Wageningen University and Research, Netherlands

OS08-04

Agronomical comparison of hydroponically grown sweet basil cultivars for vertical farming

Daniel Tran, Gil Caron, Marilou Maret, Robert Farinet, Bastien Christ, Cédric Camps
Agroscope Research Centre, Switzerland

OS08-05

The added value of indoor products: the strawberry case

Caterina Carpineti[1], Lucia Vanacore[2], Esther Meinen[1], Jan Janse[1], Eva Ketel[1], Ada Leman[1], Tommaso Barbagli[1], Mark van Hoogdalem[1]
[1]Wageningen University and Research, Netherlands
[2]The University of Naples Federico II, Italy

OS08-06

Faster than fast: accelerating flowering for the speed breeding of lettuce (*Lactuca sativa*) with far-red radiation

Yongran Ji, Ilse Biemond, Kai Cao, Ep Heuvelink, Leo F. M. Marcelis
Wageningen University and Research, Netherlands

OS08-07

Performances of fruit-bearing crops in indoor farming: the case of dwarf tomato

Isabella Righini, Cecilia Stanghellini, Silke Hemming, Luuk Graamans, Leo Marcelis
Wageningen University Research, Netherlands

PS01: Poster presentations: Monday October 23, 2023

PS01-01 [Lighting technology]

Indoor growing of tomato with LED lamps and FR bulbs

Marco A. Bustamante[1], Alejandro Jose Bustamante Davila[2]
[1]Universidad Autonoma Agraria Antonio Narro, México
[2] Wageningen University & Research, Netherlands

PS01-02 [Greenhouse crops modelling and management]

Estimation of a thermal time in individual cucumber (*Cucumis sativus* L.) fruit under Japanese greenhouse production

Kazuya Maeda, Dong-Hyuk Ahn
National Agriculture and Food Research Organization, Japan

PS01-03 [Lighting technology]

Growth and Flowering Characteristics of Strawberry Affected by Application of Various Light Quality

Seung Jae Hwang, Jin Yu, Ji Hye Yun, So Yeong Hwang, Eun Won Park, Jeong Hun Hwang, Hyeong Eun Choi, Hee Sung Hwang
Gyeongsang National University, Korea (Republic of)

PS01-04 [Climate control and modelling]

Air quality monitoring system in agricultural areas to identify the generation characteristics

Byungwook Oh, Il-Hwan Seo, Jin-Ho Kim
Jeonbuk National University, Korea (Republic of)
National Academy of Agricultural Science, Korea (Republic of)

PS01-05 [Plant factory with artificial lighting]

Searching for environmental conditions that increase vindoline and catharanthine concentrations in *Catharanthus roseus* leaves during early nutritional growth

Shun Ishizu[1], Ryouhei Shimizu, Keiko Ohashi-Kaneko, Masahito Takeyama[2], Shunsuke Sakaguchi, Kosuke Yamada
[1]Tamagawa Academy & University, Japan
[2] Plantx Corp., Japan

PS01-06 [Lighting technology]

Growth and flower characteristics of calendula under different light spectra in a controlled environment

Maitree Munyanont, Na Lu, Teeranuch Joilek, Dannisa Fathiya Rachma, Michiko Takagaki
Chiba University, Japan

PS01-07 [Plant factory with artificial lighting]

Optimal Irrigation Prediction Model for Advanced Wild Ginseng in Smart Farm for Sustainability based on Deep Learning Technology with Xgboost

Solhee Kim, Kyo Suh, Taegon Kim
Seoul National University, Korea (Republic of)

PS01-08 [Plant factory with artificial lighting]

Effect of plant density and light intensity on growth and yield of green perilla in plant factory with artificial lighting

Thanit Ruangsangaram[1], Maitree Munyanont[2], Jose Gabriel Corno[3], Teeranuch Joilek[2], Tomoka Endoh[2], Dannisa Fathiya Rachma[2], Na Lu[2], Michiko Takagaki[2]
[1] Kasetsart University, Thailand
[2] Chiba University, Japan
[3] Technological University of Panama, Panama

PS01-09 [Plant factory with artificial lighting]

Effect of light quality environment on nutrient uptake in several plant species grown in plant factories with artificial lighting

Keiko Ohashi, Kazuki Serizawa
Tamagawa University, Japan

PS01-10 [Plant factory with artificial lighting]

Yield and quality of cherry tomato at different harvest timing determined by cumulative temperature in plant factory

Dannisa Fathia Rachma, Na Lu, Maitree Munyanont, Teeranuch Joilek, Tomoka Endoh, Thanit Ruangsangaram, Michiko Takagaki
Chiba University, Japan

PS01-11 [Plant factory with artificial lighting]

A new technique of LED light irradiation for green leek production in plant factory

Yukiko Tomari[1], Gauri Maharjan[2], Hiroyuki Watanabe[1]
[1]Tamagawa Academy & University, Japan
[2]Signify, Japan

PS01-12 [Lighting technology]

Agronomically & Economically profitability of a shifted-tomato-cultivation in greenhouse under a Semi-Continental with Meridional Influence Climate

Dunkel Theresa, Robert Farinet, Cédric Camps, Daniel Tran
Agroscope Research Centre, Switzerland

PS01-13 [Vertical farming]

The impact of sequential harvesting and irradiation methods on tuber yield in long-day conditions using temporary light interruption treatment in potato

Ryuji Hayashi, Hiroyuki Watanabe,
Tamagawa Academy & University, Japan

PS01-14 [Plant factory with artificial lighting]

The cultivation technology for high quality spinach by controlling light environment in plant factory

Ryuji Hayashi, Hiroyuki Watanabe
Tamagawa Academy & University, Japan

PS01–15 [Greenhouse crops modelling and management]

Predicting Stomatal Conductance in Controlled Environment Through Non-Parametric Machine Learning

Darren Drewry, Srishti Gaur
The Ohio State University, United States of America

PS01–16 [Greenhouse crops modelling and management]

Dynamic analysis of leaf and air temperatures in a greenhouse canopy: which measurement to use for greenhouse climate control?

Vincent Stauffer[1], David Vuillermet[2], Etienne Chantoiseau[3], Claire Ducourouble[4], Pierre-Emmanuel Bournet[3]
[1]SAVOIE TECHNOLAC, France;
[2] RATHO, ASTREDHOR, France;
[3]L'Institut Agro, France
[4] SERAIL, France

PS01–17 [Vertical farming]

Conditions and Directions to Distribute the Rooftop Greenhouse in Korea

Eunseok Lee, Sunjoon Kim, Kyounghun Min, Jisoo Ahn, Seokhwan Ji
Architecture Urban Research Institute, Korea (Republic of)

PS01–18 [Greenhouse crops modelling and management]

Deep learning-based phenotyping data fusion approach for effective detection of drought stress responses in basil

Yu Jin Jeon[1], Ye Jin Kim[1], Taek Sung Lee[2], Hyoung Seok Kim[2], Dae-Hyun Jung[1]
[1]Kyung Hee University, Korea (Republic of)
[2]KIST Korea Institute of Science and Technology, Korea (Republic of)

PS01–19 [Greenhouse crops modelling and management]

Profiling of individual desulfo-glucosinolates and sugar content among cabbage germplasm and selection of multi-functional genotypes for commercial breedin

Yu Kyeong Shin[1], Solly Kang[1], Young Eun Jeon[1], Chang Sun Choi[1], Seong-Hoon Kim[2], Hae Ju Kang[2], Jun Gu Lee[1]
[1]Jeonbuk National University, Korea (Republic of)
[2]National Institute of Agricultural Sciences, Korea (Republic of)

PS01–20 [Vertical farming]

Evaluation of energy and light use efficiency in Valerianella locusta growing in indoor vertical farms

Dafni Avgoustaki, Christos Vatistas, Thomas Bartzanas
Agricultural University of Athens, Greece

PS01-21 [Climate control and modelling]

Physiological Disorder Analysis of Strawberry Leaves using Hyperspectral Imaging and Deep Learning Algorithm

Myongkyoon Yang
Jeonbuk National University, Korea (Republic of)

PS01-22 [Vertical farming]

Changes in the growth and isoflavone content of soybean plants according to the R/FR ratio

Ye Lin Kim, Han-Sol Sim, Ki-Ho Son
Gyeongsang National University, Korea (Republic of)

PS01-23 [Vertical farming]

Enhancement of isoflavone contents in soybean plants by pre-harvest UV-B irradiation

Han-Sol Sim, Ye Lin Kim, Kye Man Cho, Ki-Ho Son
Gyeongsang National University, Korea (Republic of)

PS01-24 [Lighting technology]

Blue and UV-A light wavelengths positively affected the accumulation of healthy compound profiles in pakchoi

Yinjian Zheng, Pengpeng Mao, Yaliang Xu, Gaofeng Liu, Qingming Li
Chinese Academy of Agricultural Sciences (CAAS), China

PS01-25 [Greenhouse crops modelling and management]

Production of faba bean (*Vicia faba* L.) inside a Mediterranean naturally ventilated solar greenhouse

Francisco Domingo Molina Aiz, F.J. Palmero-Luque,
Universidad de Almería, Spain

PS01-26 [Lighting technology]

Effect of UV-B irradiation on the concentrations of rosmarinic acid in different leaf positions of red perilla

Hideo Yoshida, Ikumi Asaoka, Shoko Hikosaka, Eiji Goto
Chiba University, Japan

PS01-27 [Greenhouse crops modelling and management]

An organic fertilization system to sustain plastic-ho use soil health

Jinlong Dong
Institute of Soil Science, Chinese Academy of Sciences, China

PS01-28 [Greenhouse crops modelling and management]

Optimal leaf temperature for photosynthesis in melon plants predicted by stomatal conductance under soilless cultivation

Seungri Yoon[1], Jin Hyun Kim[1], Minju Shin[1], Ji Wong Bang[1], Ho Jeong Jeong[1], Tae In Ahn[2]

[1]National Institute of Horticultural and Herbal Science

[2]Seoul National University

PS01–29 [Vertical farming]

Total evapotranspiration estimation in multi-crop layers of indoor vertical farms for energy savings

Tundra Ramirez, Oliver Körner

Leibniz Institute of Vegetable and Ornamental Crops

PS01–30 [Lighting technology]

Blue Light, Higher Humidity, and Horticultural Substrate Promote the Adventitious Root Development of Hemp (*Cannabis sativa* L.) Cuttings

Seungyong Hahm, Yongjae Lee, Juhyung Shin, Jong Seok Park,

Chungnam National University, Korea (Republic of)

PS01–31 [Climate control and modelling]

Shading by solar panels influences growth and crop characteristics of kimchi cabbage in an agrivoltaic system

Dr. Wook Oh

Department of Horticultural Science, Jeju National University, Korea (Republic of)

PS01–32 [Climate control and modelling]

Reduction effect of fugitive dust by crop cultivation in reclaimed land

Jinwon Park, IlHwan Seo, Jae-Gwon Son

Jeonbuk National University, Korea (Republic of)

Tuesday October 24, 2023

8:00	Registration 8:00-18:00			
8:30	Keynote speaker 8:30-9:30 Speaker: E.J. van Henten Chair: E. Fitz-Rodriguez			
9:30	Symposia photo and Coffee break 9:30-10:00			
10:00	Oral session 10:00-11.40			
	OS-9	**OS-10**	**OS-11**	**OS-12**
	Lighting Technology II Chair: Y. Zheng OS09-01: E. Olvera (Invited) OS09-02: Y. Zhang OS09-03: Y. Zheng OS09-04: K. Weerheim	**Fertigation, water and growing medium I** Chair: R. Hernández OS10-01: S. Kim OS10-02: Ch. Kubota OS10-03: E. Kempen OS10-04: S. Craeye OS10-05: O. Jakobsen	**Sensors, automation, and robotics in greenhouses I** Chair: J. Sanchez-Molina OS11-01: P. de Heer OS11-02: K. Shimomoto OS11-03: S. Kang OS11-04: T. Dunkel OS11-05: S. Toda	**Organic Greenhouse Horticulture: Soil health and biological assessments** Chair: B. Alsanius OS12-01: B. Alsanius (Invited) OS12-02: O. Altuntas OS12-03: A. Rosberg OS12-04: J. Grossman
11:40	Coffee break 11:40-12:00			
12:00	Oral session 12:00-13:20			
	OS-9	**OS-10**	**OS-11**	**OS-12**
	OS09-05: G. Buss OS09-06: H. Vitoshkin OS09-07: R. Hernandez OS09-08: F. Orsini	OS10-06: Z. Ahmed OS10-07: M. Gang OS10-08: G. Hutchinson OS10-09: R. Ferrarezi	OS11-06: A.Fuentes OS11-07: K. Wacker OS11-08: D. Kim OS11-09: T. Moon	OS12-05: S. Pedersen OS12-06: F. Di Gioia OS12-07: H. Alvarado-Raya OS12-08: L. Ouyang
13:20	Lunch			
15:00	Oral session 15:00-17:00			
	OS-13	**OS-14**	**OS-15**	**OS-16**
	Greenhouse systems and design Chair: P. E. Bournet OS13-01: H. Fatnassi OS13-02: Y. Moon OS13-03: E. Darby OS13-04: K. Li OS13-05: J. Flores-Velázquez OS13-06: T. Fukuyama	**Fertigation, water and growing medium II** Chair: Ch. Kubota OS14-01: S. Craeye OS14-02: O. Jakobsen OS14-03: G. Hutchinson OS14-04: N. Katsoulas OS14-05: T. Ramirez OS14-06: F. Di Gioia	**Sensors, automation, and robotics in greenhouses II** Chair: E. Fitz-Rodríguez OS15-01: F. de Zwart OS15-02: R. Sakata OS15-03: M. Iradukunda OS15-04: K. Sparke OS15-05: J. Sánchez-Molina OS15-06: Ch. Paille	**Organic Greenhouse Horticulture: Crop systems and management** Chair: M. Dorais OS16-01: S. Persello OS16-02: G. Paquet OS16-03: D. Dannehl OS16-04: Y. Cho OS16-05: In-Bok Lee OS16-06: K. Ziane
17:00	Poster session with coffee break 17:00-18:00			
18:00	Workshops 18:00-19:30			
	Workshop 1	Workshop 2	Workshop 3	Workshop 4

Oral presentations: Tuesday October 24, 2023

8:30–9:30 KEYNOTE LECTURE 2
Chair: E. Fitz-Rodriguez

Speaker: E.J. van Henten
Wageningen University & Research

10:00–11:40 ORAL SESSION 9 / Lighting Technology II
Chair: Y. Zheng

OS09-01
LED Light Technology in Mexican Agriculture
José Ernesto Olvera González
Technological Institute of Pabellón of Arteaga in Aguascalientes, México

OS09-02
Acclimation to either daytime or nighttime supplementary UVB light increases leaf photosynthesis and photoprotection of young cucumbers
Yuqi Zhang[1], Jun Wang[2], Tao Li[1]
[1]IEDA, Chinese Academy of Agricultural Sciences, China
[2]Institute of Vegetables and Flowers, Chinese Academy of Agricultural Sciences, China

OS09-03
Effect of Light Intensity and Branch Origin Position on Cannabis sativa Inflorescence Density and THC Content
Youbin Zheng, Sebastian Dam
University of Guelph, Canada

OS09-04
Effects of LED light spectrum on light use efficiency, resilience and gene expression in a high-wire cucumber cultivation
Kees Weerheim, Kirsten Leiss, Puspa Khanal Joshi, Mark van Hoogdalem
Wageningen University & Research, Netherlands

12:00–13:20 ORAL SESSION 9 / Lighting Technology II

OS09-05

An assessment of lettuce growth performance using GREENBOX technology with different light concentrations and colors

George Buss[1], Mya Griffith[1], Paige Carroll[1], John L. Griffis[1], Ozlem Tuncay[2], Barry H. Rosen[1], Xiusheng Yang[3], Galen Papkov[1], Sarah Bauer[4], Kathryn Jackson[1], Ankit Singh[1]
[1]Florida Gulf Coast University, United States of America.
[2]EGE Universitesi, Turkey.
[3]University of Connecticut, , United States of America.
[4]Mercer University, Georgia, United States of America.

OS09-06

Light Distribution in a Two-level Unit with Supplemental LED Lighting in a Hydroponic Greenhouse

Helena Vitoshkin[1], Vitaly Haslavsky[2], Mollie Sacks[3], Eviathar Ziffer[1]
[1]Agricultural Research Organization of Israel, Israel
[2]Azrieli College of Engineering, Israel
[3]Ministry of Agriculture and Rural Development, Israel

OS09-07

Impacts of LED light intensity on the transient expression of GUS gene in soybean (*Glycine max*) with half-seed transformation method

Ricardo Hernandez, Xiaonan Shi
[1]North Carolina State University, United States of America

OS09-08

Do we light enough? Optimization of light use efficiency in a vertical farm by modulation of light intensity, photoperiod and far-red radiation

Giuseppina Pennisi, Laura Carotti, Alessandro Pistillo, Ilaria Zauli, Giorgio Gianquinto, Francesco Orsini
University of Bologna, Italy

10:00–11:40 ORAL SESSION 10 / Fertigation, water and growing medium I

Chair: J. Son

OS10-01

Ozone-nano Water can Promote the Growth and Secondary Metabolites of Horticultural Plants in Hydroponic Systems

SunWoo Kim[1], Gwonjeong Bok[1], Juhyung Shin[1], Jongseok Park[1], Jong-won Do[2]
[1] Chungnam National University, Korea (Republic of)
[2] Rural Research Institute, Korea Rural Community Corporation, Korea (Republic of)

OS10-02

Hydroponic crop production with low-pH nutrient solution for mitigating risks of root-rot diseases

Chieri Kubota, Jeffrey Bates, Daniel Gillespie, Gio Papio, Ian Rabinowitz, Sally Miller

[1]The Ohio State University, United States of America

OS10-03

Improving the sustainability of hydroponic systems through optimisation of the nutrient solution composition

Estelle Kempen

Stellenbosch University, South Africa

OS10-04

Hy4Dense, a newly developed hydroponics system for leafy vegetables sown at high density

Maarten Ameye[1], Simon Craeye, Elise Tardy[1], An Decombel[1], Lydia Smith[2], Matthijs Blind[3], Jasper Schermer[3], John Stamford[4], Bart Grimonprez[5], Tracy Lawson[4]

[1]INAGRO, Belgium

[2]NIAB Innovation Farm, United Kingdom

[3]Vertify, Netherlands

[4]University of Essex, United Kingdom

[5]Howest University of Applied Sciences (Belgium), Belgium

OS10-05

Monitoring and control of nitrate in closed-loop hydroponics

Oyvind M. Jakobsen, Kai Arne Kristiansen, Mona Schiefloe, Ann-Iren Kittang Jost

NTNU Social Research, Norway

12:00-13:20 ORAL SESSION 10 / Fertigation, water and growing medium I

OS10-06

A sustainable eco-friendly approach for vegetable production in hydroponics

Zienab Ahmed[1], Khuloud Alneyadi[1], Shamma aldhaheri[1], Eida Almansoori[1], Aysha haji Alka haji Alkaabi[1], Mariam AL Hebsi[1], Fatima Hassan[1], Francisco Di Gioia[2], Nikolaos Tzortzakis[3]

[1]College of Agriculture and Veterinary Medic, United Arab Emirates University, United Arab Emirates

[2]College of Agricultural Science, Pennsylvania State University, United States of America

[3]Biotechnology and Food Science, Cyprus University of Technology, Cyprus

OS10-07

Development of an Ion Selective Electrode-based Nutrient Management System to Maintain Ionic Balance in Closed Hydroponic Solutions

Min-Seok Gang[1], Hak-Jin Kim[1], Woo-Jae Cho[2], Tae In Ahn[1], Joo-Shin Kim[1], Ju Young Lee[3], Ji-Eun Hwang[4], Jae Wook Jang[5]
[1]Seoul National University, Korea (Republic of)
[2]Gyeongsang National University, Korea (Republic of)
[3]Korea Institute of Science Technology, Korea (Republic of)
[4]Gyeonggi-do Ag. Research Extension Service, Korea (Republic of)
[5]SHINHAN A-TEC Co., Ltd., Korea (Republic of)

OS10-08

To leach or not to leach: water management strategies for hydroponic strawberry production

George Hutchinson, Rhuanito Ferrarezi
University of Georgia, United States of America

OS10-09

Alternative substrates for arugula and lettuce production in greenhouses

Rhuanito Ferrarezi, Lan Nguyen, Samuel Poole, Matthew Housley, Kuan Qin
University of Georgia, United States of America

10:00–11:40 ORAL SESSION 11 / Sensors, automation, and robotics in greenhouses I

Chair: J. Sanchez-Molina

OS11-01

Semantic Explanation and Navigation System for Greenhouse Robotics Systems

Paolo de Heer, Jack Verhoosel
TNO, Netherlands

OS11-02

Development of Double-Camera AI System for Efficient Monitoring of Paprika Fruits

Kota Shimomoto[1], Mitsuyoshi Shimazu[1], Takafumi Matsuo[2], Syuji Kato[2], Hiroki Naito[1], Tokihiro Fukatsu[1]
[1]National Agriculture and Food Research Organization (NARO), Japan
[2]Takahiko Agro-business co., ltd., Japan

OS11-03

Decision of Optimal Sensor Location for predicting the Internal Environment of Greenhouse using Machine Learning Model

Sol-moe Kang, In-bok Lee, Hyo-hyeog Jeong, Jeong-hwa Cho, Young-bae Choi, Da-in Kim, Seo-ha Park
Seoul National University, Korea (Republic of)

OS11-04

Novel fruit growers advisory system using connected fruit dendrometer, micro-climate data and machine learning algorithms

Theresa Dunkel[1], Elena Najdenovska[1], Fabien Dutoit[1], Laura Elena Raileanu[1], Robert Whittaker[2], Cédric Camps[1]
[1]Agroscope, Switzerland
[2]JDC Electronic SA, Switzerland

OS11-05

Imaging of strawberry's vegetation indexes by hand-held smartphone

Seitaro Toda[1], Yuya Imai[1], Takeru Kanoh[2], Naomichi Fujiuchi[2], Kotaro Takayama[1]
[1]Toyohashi University of Technology, Japan
[2]Faculty of Agriculture / Graduate School of Agriculture, Japan

12:00-13:20 ORAL SESSION 11 / Sensors, automation, and robotics in greenhouses I

OS11-06

Crop growth monitoring with time series data based on deep learning techniques

Alvaro Fuentes[1], Jiuqing Dong[1], Jaehwan Lee[1], Taehyun Kim[2], Sook Yoon[3], Dong Sun Park[1]
[1]Jeonbuk National University, Korea (Republic of)
[2]National Institute of Agricultural Science, Korea (Republic of)
[3]Mokpo National University, Korea (Republic of)

OS11-07

Multispectral imaging for pH induced micronutrient deficiency detection

Kahlin Wacker, Marc van Iersel
University of Georgia, United States of America

OS11-08

Detecting Rice Blast using Hyperspectral Imagery

Daeyoung Kim, Seongmin Park, Suk-Ju Hong, Sang-Yeong Kim, Eungchan Kim, Chang-Hyup Lee, NanditaIrsaulul Nurhisna, Sungjay Kim, Yangjae-daero, Songpa-gu
Seoul National University, Korea (Republic of)

OS11-09

Automated Feature Extraction of Lettuce Grown in Vertical Farms with Image Processing and Deep Neural Networks

Taewon Moon[1], Da-Seul Choi[2], Tae In Ahn[1], Myung-Min Oh[2]
[1]Seoul National University, Korea (Republic of)
[2]Chungbuk National University, Korea (Republic of)

10:00–11:40 ORAL SESSION 12 / Organic Greenhouse Horticulture: Soil health and biological assessments

Chair: B. Alsanius

OS12-01

The riddle of soil biological assessments in organic greenhouse horticulture

Beatrix Alsanius, Anna Karin Rosberg
SLU Alnarp Microbial Horticulture Unit, Sweden

OS12-02

The Effect of Using Biofertilizers on Yield and Quality in Endive Lettuce (*Cichorium endivia* L.) Cultivated in Soilless Culture

Ozlem Altuntas, Sena Nur Gur
Malatya Turgut Ozal University, Turkey

OS12-03

Short crop rotations in organic greenhouse production: consequences for soil health

Anna Rosberg, Beatrix Alsanius
SLU Alnarp Microbial Horticulture Unit, Sweden

OS12-04

Legume cover crop nitrogen contributions in organic high tunnels in the United States

Julie Grossman[1], Miriam Gieske[1], Ada Fitz Axen[2], Harywilliam Gonzales[3], Hannah Walsh[1]
[1]University Of Minnesota, United States of America
[2]Colorado State University, United States of America
[3]University of Puerto Rico at Utuado, Puerto Rico

12:00–13:20 ORAL SESSION 12 / Organic Greenhouse Horticulture: Soil health and biological assessments,.

OS12-05

Soil health and local recirculation ensuring organic cucumber cultivation in Norway

Susanne Friis Pedersen[1], Kaia Slaagedal[2], Michel Verheul[2]
[1]Norwegian Centre for Organic Agriculture, Norway
[2]University College for Agriculture, Norway

OS12-06

Leveraging By-Products of the Agri-Food Industry for the Application of Anaerobic Soil Disinfestation in Organic High Tunnel Vegetable Production

Francesco Di Gioia[1], Joe Ono-Raphel[1], Kathleen Arrington[1], Raymond Balaguer[1], Francisco Dini-Andreote[1], Jason Kaye[1], Erin Rosskopf[2]
[1]University Park, United States of America
[2]Horticultural Research Laboratory, United States of America

OS12-07

Reusing organic substrates and plants increases irrigation water use efficiency without affecting plant yield in a day neutral strawberry pot production system

Horacio E. Alvarado-Raya[1], J. Armando Ramirez-Arias[1], Roberto Rivera-del-Rio[1], Maria Eugenia Estrada-Chavira[2], Pablo Emilio Escamilla-Garcia[3], Guillermo Calderon-Zavala[4]
[1]Universidad Autónoma Chapingo, México
[2]Tecnológico Nacional de México, México
[3]Instituto Politécnico Nacional, México
[4]Colegio de Posgraduados, México

OS12-08

The feasibility of growing media originated from greenhouse waste for plant seedling and growing

Lin Ouyang[1], Rui Yang[2], Dongdong Zhang[2]
[1]Chengdu National Agricultural Science and, Technology Center, China
[2]Chinese Academy of Agricultural Sciences, China

15:00–17:00 ORAL SESSION 13 / Greenhouse systems and design
Chair: T. Bartzanas

OS13-01
Transforming Agriculture for a Changing Climate: Harnessing Precision Technologies and Controlled Environments to Enhance Food Security in Arid and Semi-arid zones
Hicham Fatnassi[1], Rashyd Zaaboul[1], Ali El Battay[2], Jeetendra Prakash Aryal[1], Nazim Gruda[3]
[1]International Center for Biosaline Agriculture, United Arab Emirates
[2]Center for Remote Sensing Applications, CRSA Mohammed VI Polytechnic University, Morocco
[3]University of Bonn, INRES, Division of horticulture, Germany

OS13-02
Development, Correction, and Testing of a Semi-Open Chamber System for Gas Exchanges Measurement of Cucumber Seedlings
Yu Hyun Moon, Ui Jeong Woo, Ha Seon Sim, Tae Yeon Lee, Ha Rang Shin, Jung Su Jo, Sung Kyeom Kim
Kyungpook National University, Korea (Republic of)

OS13-03
Cultivar selection of mizuna for optimal space station performance
Ethan Darby, Sarah Parker, Kellie Walters
University of Tennessee, United States of America

OS13-04
Modeling and Optimization of Ultraviolet LED Nutrient Solution Sterilization Module
Kun Li, Ruifeng Cheng, Haochun Ke
Chinese Academy of Agricultural Sciences, China

OS13-05
Comprehensive CFD model to analyze potential Mexican greenhouse horticulture zones
Jorge Flores[1], C. Ernesto Aguilar[2], Edwin Villagran[3], Abraham Rojano[4]
[1]Colegio de Potgraduados, México
[2]Instituto Tecnológico de los Reyes, México

[3]AGROSAVIA, Colombia
[4]Universidad Autónoma Chapingo, MéxicoOS13-06
Vinblastine production of Catharanthus roseus in the plant factory using artificial lighting
Taro Fukuyama, Tatsuki Hanyu, Shun Ishizu, Rio Saito, Keiko Ohashi-Kaneko
Tamagawa Academy & University, Japan

15:00–17:00 ORAL SESSION 14/ Fertigation, water and growing medium II

Chair: Ch. Kubota

OS14-01

Agrotopia, a platform to test alternative water sources for urban horticulture

Maarten Ameye, Simon Craeye
Inagro, Belgium

OS14-02

Consumption of and preference for NH4+ versus NO3- of hydroponically cultivated lettuce in different NH4+/NO3- ratios

Oyvind M. Jakobsen[1], Mona Schiefloe[1], Armida Gjindali[2], Irene Karoliussen[1], Ann-Iren Kittang Jost[1]
[1]CIRiS, NTNU Social Research, Norway
[2]University of Manchester, United Kingdom

OS14-03

Can they dig it? Hydroponic system comparison for greenhouse strawberry production

George Hutchinson, Rhuanito Ferrarezi
University of Georgia, United States of America

OS14-04

Drainage management in a cascade hydroponic system: Combination of cucumber and melon crops

Nikolaos Katsoulas, Ioannis Naounoulis, Sofia Faliagka
University of Thessaly, Dept. of Agriculture, Rural Development and Environment, Greece

OS14-05

Transpiration rates for suitable crop combinations of Cascade hydroponics systems

Tundra Ramirez[1], Nikolaous Katsoulas[2], Oliver Körner[1]
[1]IGZ-Leibniz Institute of Vegetable and Ornamental Crops e.V., Germany
[2]University of Thessaly, Greece

OS14-06

Spent Mushroom Compost as an Alternative to Peat-based Soilless Media for Greenhouse Potted Basil Production

Trevor Johnson, Francesco Di Gioia
Pennsylvania State University, United States of America

15:00–17:00 ORAL SESSION 15/ Sensors, automation, and robotics in greenhouses II
Chair: E. Fitz-Rodríguez

OS15-01
Autonomous greenhouse and crop control in cucumber
Anja Dieleman, Anna Petropoulou, Ilias Tsafaras, Monique Bijlaard, Anne Elings, Feije De Zwart, Bart van Marrewijk, Guido Jansen, Selwin Hageraats, Georgios Ntakos
Wageningen University & Research, Netherlands

OS15-02
Utility-Purpose Small Robots for Farmers: A Case Study on Harvesting Apples
Ryota Sakata, Takayuki Tsukamoto, Keita Yoshinaga
Institute of Agricultural Machinery, NARO, Japan

OS15-03
Seedling Vigor and Germination Rate of Lettuce Cultivars Quantified Using a Simple and Automated Imaging Technique
Mark Iradukunda, Marc van Iersel†, Rhuanito S. Ferrarezi
University of Georgia, United States of America

OS15-04
The impact of automation and digitalization on management and labor in greenhouse operations in German horticulture – a mixed methods investigation
Kai Sparke, Mira Lehberger, Sam Schröder
Geisenheim University, Germany

OS15-05
Navigation of a Differential Robot for Transporting Tasks in Mediterranean Greenhouses
Jorge Antonio Sánchez Molina, Ángel López-Gázquez, Francisco José Mañas-Alvarez, José Carlos Moreno Úbeda, Fernando Cañadas
Universidad de Almería, Spain

OS15-06
Food production in future human space exploration: when and how to envisage a crop production system
Christel Paille, Brigitte Lamaze
European Space Research and Technology Centre (ESTEC), Netherlands

15:00–17:00 ORAL SESSION 16 / Organic Greenhouse Horticulture: Crop systems and management

Chair: M. Dorais

OS16-01

Assessing the Benefits and Limitations of a Dynamic Agrivoltaic Greenhouse for Crop Protection and Yield Optimization in a Changing Climate

Séverine Persello[1], Gerardo Lopez[1], Jérôme Chopard[1], Perrine Juillion[1], Vincent Hitte[1], Yassin Elamri[1], Romain Grizou[2], Fanny Thiery[2], Damien Fumey[1]
[1]Sun'Agri, France
[2]Invenio & Chambre d'agriculture, France

OS16-02

A new rotating vertical growing system for the production of organic lettuce

Guillaume Paquet, Annie Bregard, Thi Thuy An Nguyen, Martine Dorais
Université Laval, Canada

OS16-03

Development of a hybrid aeroponic-water-buffer system for intensive tomato production

Dennis Dannehl[1], Raquel Salazar[2], Efrén Fitz-Rodriguez[2], Irineo Lopez-Cruz[2], Abraham Rojano-Aguilar[2], Christian Ulrichs[1], Uwe Schmidt[1]
[1]Humboldt – Universität zu Berlin, Germany
[2]Universidad Autónoma Chapingo, México

OS16-04

Development of a Seasonal Leafy Vegetable Crop Model for Rooftop Greenhouse Energy Model

Jeong-hwa Cho, In-bok Lee, Yun-woo Cho, Young-bae Choi, Hyo-hyeok Jeong, Sol-moe Kang, Da-in Kim
[1]Seoul National University, Korea (Republic of)

OS16-05

Energy Saving Design and Control Strategy for Sustainable Rooftop Greenhouse with Passive and Active Heat Transfer Methods

Jeong-hwa Cho, In-bok Lee, Young-bae Choi, Hyo-Hyeog Jeong, Sol-moe Kang, Da-In Kim, and Youn-woo Cho
[1]Seoul National University, Korea (Republic of)

OS16-06

Testing the Interaction of Strawberry Cultivars with organic and conventional cropping systems in Morocco

Kawtar Ziane, Lamiae Ghaouti, Mustapha Arbaoui
Institut Agronomique et Vétérinaires Hassan II, Morocco

PS02: Poster presentations: Tuesday October 24, 2023

PS02-01 [Growing media, water management and hydroponics]

Dynamic irrigation control under evapotranspiration uncertainty

Francisco D. Mondaca Duarte, Daniel Reyes Lastiri, Jan-David Wacker, Simon van Mourik, Eldert van Henten
Wageningen University & Research, Netherlands

PS02-02 [Greenhouse crops modelling and management]

Seed priming improves yield attributes of tomato under salt stress in greenhouse conditions

Nasratullah Habibi
Tokyo University of Agriculture NODAI, Japan

PS02-03 [Sensors, automation, and robotics in greenhouses]

Development of a system using acceleration sensor for automatic collection of work records in a greenhouse

Mitsuyoshi Shimazu, Kota Shimomoto, Tokihiro Fukatsu
National Institute of Animal Health (NARO), Japan

PS02-04 [Sensors, automation, and robotics in greenhouses]

A main stem-based operation method for a cultivation management robot system in greenhouse horticulture

Tokihiro Fukatsu, Masakazu Kashino, Natsuki Nakayama, Hideto Kurosaki
National Institute of Animal Health (NARO), Japan

PS02-05 [Sensors, automation, and robotics in greenhouses]

Detection of tomato main-stem skeleton using point cloud segmentation

Masakazu Kashino, Tokihiro Fukatsu, Hideto Kurosaki, Natsuki Nakayama
National Institute of Animal Health (NARO), Japan

PS02-06 [Sensors, automation, and robotics in greenhouses]

Design of Intelligent Tomato Disease Image Classification System Based on Complex Environmental Information

Taehyun Kim, Jeonghyun Baek, Donghyoek Im
Rural Development Administration, Korea (Republic of)

PS02-07 [Greenhouse systems and design]

Urban smart farms: architectural approach and system design

Nahyang Byun, Donghwa Shon
Chungbuk National University, Korea (Republic of)

PS02-08 [Sensors, automation, and robotics in greenhouses]

Counting the number of cherry tomato fruits by using a hanging-type imaging robot: the relationship between the width of image analysis and the fruit number per plant

Kaede Tauchi[1], Naomichi Fujiuchi[1], Takeru Kanoh[2], Seitaro Toda[3], Kotaro Takayama[3]
[1]Ehime University, Japan
[2]PLANT DATA Co., Ltd., Japan
[3]Toyohashi University of Technology, Japan

PS02-09 [Growing media, water management and hydroponics]

Influence of the growing media on phytochemical composition of six salad rocket (*Eruca sativa*) accessions

Juan A. Fernandez[1], Catalina Egea-Gilabert[1], Jesús Ochoa[1], Fabio Amoruso[1], Angelo Signore[1], Víctor Gallegos-Cedillo[1], Raúl Domínguez-Perles[2]
[1]Universidad Politécnica de Cartagena, Spain
[2]CEBAS-CSIC, University Campus, Spain

PS02-10 [Growing media, water management and hydroponics]

Design and implementation of Wireless sensor and control network for Deep Flow Technique (DFT) in Hydroponic Systems

Rodrigo Morfin Magaña, Cruz Ernesto Aguilar Rodríguez, Jesus Andany Zepeda García
TecNM Campus Los Reyes, México

PS02-11 [Growing media, water management and hydroponics]

Load cell-based automated irrigation system for efficient irrigation management of plug production

Jongyun Kim[1], Seong Kwang An[2], Sunghyun Oh[1]
[1]Korea University, Korea (Republic of)
[2]Pusan National University, Korea (Republic of)

PS02-12 [Sensors, automation, and robotics in greenhouses]

Development of a high-precision, non-destructive technique for estimating individual and plug tray unit plant height and leaf area in red pepper seedlings using Plant Image Measurement System (PIMS)

Solly Kang[1], Young Eun Jeon[1], Yu Kyeong Shin[1], Seung Wook Song[2], Han Ryul Seo[2], Jun Gu Lee[1]

[1]Jeonbuk National University, Korea (Republic of)

[2]Podo INC., Korea (Republic of)

PS02-13 [Greenhouse systems and design]

AstroPlant: a novel IT infrastructure and network of plant growth chambers

Stefania De Pascale[1], Antonio Pannico[1], Thieme Hennis[2], Luigi Gennaro Izzo[1], Giovanna Aronne[1], Christel Paillé[3]

[1]University of Naples Federico II, Italy

[2]Delft University of Technology, Netherlands

[3]European Space Agency, ESA-ESTEC, Netherlands

PS02-14 [Growing media, water management and hydroponics]

Substrate comparison for tomato propagation under different irrigation protocols

Uttara Samarakoon[1], Alexa Espinoza[2], James Altland[2], Leslie Taylor[1], Teng Yang[1]

[1]Ohio State University ATI, United States of America

USDA-ARS, United States of America

PS02-15 [Greenhouse systems and design]

Novel Greenhouse Cooling Technology Using Natural Cold Energy in Winter

Youngjik Youn, Jaejoon Choi, Sae Byul Kang, Hyun Hee Le

Korea Institute of Energy Research, Korea (Republic of)

PS02-16 [Greenhouse systems and design]

Use of 'double roof' with photoconversion films to improve yield and photosynthetic activity in Mediterranean greenhouses

Diego L. Valera[1], María Ángeles Moreno-Teruel[2], Francisco D. Molina-Aiz[1], Kristof Proost[3], Frederic Peilleron[3], Alejandro López-Martínez[1]

[1]Universidad de Almería, Spain

[2]Universidade de Évora, Portugal

[3]Centre dffaires Emergence, France

PS02-17 [Growing media, water management and hydroponics]

Evaluation of Decision Tree-based Ion-Specific Dosing Algorithm for Closed Hydroponics

Yeong-Hyeon Shin[1], Woo-Jae Cho[1], Min-Seok Gang[2], Hak-Jin Kim[2], Young-Kyun Jang[3]

[1]College of Agriculture and Life Sciences, Korea (Republic of)

[2]Seoul National University, Korea (Republic of)

[3]GreenCS, Damyang-gun, Korea (Republic of)

PS02-18

Assessment of nutritional properties of Valerianella locusta plants growing in indoor vertical farms under different lighting conditions

Niki Mougiou[1], Spyros Didos[1], Ioanna Bouzouka[1], Dafni Despoina Avgoustaki[2], Anagnostis Argiriou[3]

[1]Institute of Applied Biosciences, Centre for Research and Technology Hellas, Greece

[2]Agricultural University of Athens, Grece

[3]University of the Aegean, Greece

PS02-19 [Growing media, water management and hydroponics]

Optimization of nutrient solution concentration improves plant growth and secondary metabolites of Cannabis sativa L in hydroponics

Juhyung Shin, Seungyong Ham, Jongseok Park

Chungnam National University, Korea (Republic of)

PS02-20 [Vertical farming & plant factory]

Calibration and evaluation of a simplified dynamic model for lettuce grown in a mini plant factory

Agustin Ruiz-Garcia[1], Joshua Esaú Patiño-Espejel[1], Irineo L. López-Cruz[1], Joel Pineda-Pineda[1], Ernesto Olvera-González[2]

[1]Universidad Autónoma Chapingo

[2]Instituto Tecnológico Pabellón de Arteaga, México

PS02-21 [Growing media, water management and hydroponics]

Change in physicochemical properties of coconut coir during five cultivation cycles of blueberry (*Vaccinium* spp.) cv biloxi

Joel Pineda Pineda, Andrea B. Jacobo-Hernández, Mateo Vargas-Hernández, J. Armando Ramírez-Arias

Universidad Autónoma Chapingo, México

PS02-22 [Greenhouse crops modelling and management]

Dynamic lettuce growth model for temporal spectral changes

Eunjeong Lim[1], Myung-Min Oh[2], Tae In Ahn[1]
[1]Seoul National University, Korea (Republic of)
[2]Chungbuk National University, Cheongju, Korea (Republic of)

PS02-23 [Greenhouse crops modelling and management]

Simplified greenhouse climate and crop model predicts yield using Bayesian inference

Juan Daniel Molina Muñoz[1], Antonio Capella Kort[2], Aarón I. Vélez-Ramírez[3], J. Andrés Christen[4]
[1]Centro de Investigación en Matemáticas, Colombia
[2]Instituto de Matemáticas, Universidad Nacional Autónoma de México, México
[3]Universidad Nacional Autónoma de México, México
[4] Centro de Investigación en Matemáticas, CIMAT, México

PS02-24 [Growing media, water management and hydroponics]

Growth evaluation of the tomato root system cultivated in two hydroponic systems

Armando Ramirez Arias, Joel Pineda-Pineda, Horacio Alvarado-Raya, Ximena Lopez-Zamora
Universidad Autónoma Chapingo, México

PS02-25 [Sensors, automation, and robotics in greenhouses]

Machine Learning image classifier: autonomous fertilization management of indoor-grown lettuce for baby leaf production

Matteo Landolfo, Giuseppina Pennisi, Francesco Orsini
University of Bologna, Italy

PS02-26 [Growing media, water management and hydroponics]

Rosa 'Bonica 82' cuttings in aeroponic system: optimization of light spectrum for adventitious root formation

Alessandro Pistillo, Andrea D'Aprile, Maria Eva Giorgioni, Francesco Orsini, Giuseppina Pennisi, Giorgio Gianquinto
University of Bologna, Italy

PS02-27 [Vertical farming & plant factory]

Architectural design based on light performance of urban rooftop smart farm

Donghwa Shon, Nahyang Byun, jisu hur, Eunteak Lim
Chungbuk National University, Cheongju, Korea (Republic of)

PS02-28 [Organic greenhouse horticulture]

Conditions and Directions to Distribute the Rooftop Greenhouse in Korea

Eunseok Lee, Sunjoon Kim,Kyounghun Min, Jisoo Ahn, Seokhwan Ji
Architecture Urban Research Institute, Korea (Republic of)

PS02-29 [Growing media, water management and hydroponics]

Technology transfer from aquaculture to horticulture: rectangular sedimentation filter does not meet efficacy thresholds set for closed horticultural cropping systems

Beatrix Waechter Alsanius[1], Thomas Brand[2]
[1]Swedish University of Agricultural Sciences, Sweden
[2]Chamber of Agriculture in Lower Saxony, Germany

PS02-30 [Organic greenhouse horticulture]

How can high tunnel coverings and an insect-proof barrier improve productivity and pest management in berry crops?

Martine Dorais, Andréane Couture, Annie Brégard
Université Laval, Canada

PS02-31 [Organic greenhouse horticulture]

The spread of *Botrytis cinerea* in green leaf lettuce *in vitro*

Viktorija Vastakaite-Kairiene, Alma Valiuskaite, Kristina Buneviciene, Neringa Rasiukeviciute
Lithuanian Research Centre for Agriculture and Forestry, Lithuania

PS02-32 [Organic greenhouse horticulture]

Determination of weight on index indicating seedling quality using AHP (Analytic Hierarchy Process) in tomato

Hye-jin Lee, Ki Bum Kweon, Hee-Ju Lee, Seung-Hwan Wi, Jin-Hyoung Lee
Vegetable Research Division, NIHHS, RDA, Korea (Republic of)

PS02-33 [Vertical farming & plant factory]

Comparison of various crop models in greenhouse CFD model design: Porous medium model and 3-dimensional crop structure model

Sol-moe Kang, Sang-yeon Lee, Jun-gyu Kim, Dae-heon Park, Se-han Kim, In-bok Lee
Seoul National University, Korea (Republic of)

Wednesday October 25, 2023

8:00	Registration 8:00-18:00			
8:30	Keynote speaker 8:30-9:30 Speaker: S. De Pascale Chair: R. Salazar-Moreno			
9.30	Coffee break 9:30-10:00			
10:00	Oral session 10:00-11.40			
	OS-17	**OS-18**	**OS-19**	**OS-20**
	CFD Modelling Chair: M. Kacira OS17-01: In-Bok Lee (Invited) OS17-02: I. Tsafaras OS17-03: In-Bok Lee OS17-04: A. Kintu	**Fertigation, water, and growing media III** Chair: J. Pineda-Pineda OS18-01: D. Zhang OS18-02: A. Poleatewich OS18-03: R. Salazar-Moreno OS18-04: J. Quijia Pillajo OS18-05: E. Romantchik	**Plant production, protection, and quality** Chair: E. Schrevens OS19-01: A. Mayorga-Gomez OS19-02: E. Hernández OS19-03: Z. Wang OS19-04: E. Schrevens OS19-05: I. Parola-Contreras	**Organic Greenhouse Horticulture: Soil fertility and plant health** Chair: Y. Zheng OS20-01: A. Barrada (Invited) OS20-02: R. Mahmoudi OS20-03: U. Samarakoon OS20-04: O. Altuntas
11:40	Coffee break 11:40-12:00			
12:00	Oral session 12:00-13:20			
	OS-17	**OS-18**	**OS-19**	**OS-20**
	OS17-05: H. Jeong OS17-06: J. Valencia-Islas OS17-07: W. Plas OS17-08: D. D. Avgostaki	OS18-06: T. Jayalath	OS19-06: G. Samouliene OS19-07: D. Zhang OS19-08: W. Sae-Tang OS19-09: F. Di Gioia	OS20-05: T. Endoh OS20-06: E. Boudreau-Forgues OS20-07: E. Solis OS20-08: M. Belley
13:20	Lunch			
15:00	Oral session 15:00-17:00			
	OS-21	**OS-22**	**OS-23**	**OS-24**
	Energy in greenhouses Chair: R. Salazar-Moreno OS21-01: S. Hemming OS21-02: I. Tsafaras OS21-03: Y. Zhang OS21-04: M. Ishii OS21-05: R. Errais OS21-06: S. Hemming	**Environmental impact and sustainable production** Chair: N. Gruda OS22-01: Ch. Ulrichs OS22-02: E. Schrevens OS22-03: N. Katsoulas OS22-04: D. Kim OS22-05: C. Probst	**Lighting technology III** Chair: E. Olvera OS23-01: L. Marcelis OS23-02: M. Holweg OS23-03: J. Shin OS23-04: J. Lanoue OS23-05: Ch. Kubota OS23-06: F. Wang OS23-07: X. Hao	**Greenhouse crops management** Chair: I. L. López-Cruz OS24-01: R. Hernandez OS24-02: Y. Cao OS24-03: X. Yang OS24-04: N. García Victoria OS24-05: T. Li OS24-06: E. Rios-Urban
17:00	Poster session with coffee break 17:00-18:00			
18:00	Closing ceremony 18:00-18:30			
20:00	Banquet dinner 20:00-24:00			

Oral presentations: Wednesday October 25, 2023

8:30–9:30 KEYNOTE LECTURE 3
Chair: R. Salazar-Moreno

Speaker: S. De Pascale
University of Naples Federico II, Italy

10:00–11:40 ORAL SESSION 17 / CFD Modelling
Chair: M. Kacira

OS17-01
Diversifying the application of CFD technology on Greenhouse R&D
In-bok Lee
Seoul National University, Rep. of Korea, Seoul, Korea (Republic of)

OS17-02
Evaluating possibilities to create homogeneous greenhouse climate at night time through 3D climate simulations
Ilias Tsafaras, Silke Hemming
Wageningen University & Research, Wageningen, Netherlands

OS17-03
Snow Load Computation of Greenhouse using CFD-DEM Method
Young-Bae Choi, In-bok Lee, Jeong-hwa Cho, Hyo-Hyeog Jeong, Sol-moe Kang, Da-In Kim, Youn-woo Cho
Seoul National University, Seoul, Korea (Republic of)

OS17-04
CFD model design optimization and verification in large-scale Venlo greenhouse complex for tomato cultivation
Anthony Kintu, IlHwan Seo
Jeonbuk National University, Korea (Republic of)

12:00–13:20 ORAL SESSION 17 / CFD Modelling

OS17-05
Ventilation Rate Prediction for Naturally Ventilated Greenhouses using CFD-Driven Machine Learning Model
Hyo-Hyeog Jeong, In-bok Lee, Jeong-hwa Cho, Young-bae Choi, Sol-moe Kang, Da-In Kim
Seoul National University, Rep. of Korea, Seoul, Korea (Republic of)

OS17-06

Recirculating the air from the attic as a pre-renovation control strategy in a greenhouse-type solar dryer

Jose Olaf Valencia Islas[1], Murat Kacira[1], Irineo Lorenzo López Cruz[2], Gene Giacomelli[1], Agustín Ruiz García[2], Peiwen Li[1]
[1]University of Arizona, United States of America
[2]Universidad Autónoma Chapingo

OS17-07

Analysing the Local Climate in a Plant Factory in CFD by Simulating the Heat and Mass Transfer of the Plants using a Realistic Plant Model

Wito Plas, Michel De Paepe, Toon Demeester
Ghent University, Belgium

OS17-08

Numerical evaluation of organic photovoltaics on greenhouse microclimate spatial distribution

Konstantinos Karamanos[1], Dafni D. Avgostaki[1], Nikolaos Katsoulas[2], Thomas Bartzanas[1]
[1]Agricultural University of Athens, Greece
[2]University of Thessaly, Greece

10:00–11:40 ORAL SESSION 18 / Fertigation, water, and growing media III

Chair: J. Pineda-Pineda

OS18-01

Customizing a slightly carbonized biochar as peat alternative in growing media

Dongdong Zhang, Lin Ouyang, Rui Yang
Chinese Academy of Agricultural Sciences, China

OS18-02

The effect of peat moss amended with three engineered wood substrate components on suppression of crown and root rot in floriculture crops

Anissa Poleatewich[1], Martina Florian[1], Brian Jackson[2], Liza DeGenring[1]
[1]University of New Hampshire, United States of America
[2]North Carolina State University, United States of America

OS18-03
Sizing lettuce growing surface in aquaponic systems based on evapotranspiration and fish feed
Raquel Salazar Moreno, Ana Cristina Sánchez Martínez, Joel Pineda Pineda, Irineo López-Cruz
Universidad Autónoma Chapingo, México

OS18-04
Developing a screening pipeline for the identification of phosphorus-solubilizing bacteria
Juan Quijia Pillajo, Sachin Naik, Michelle Jones
The Ohio State University, United States of America

OS18-05
Evaluation of automatic irrigation control systems and shade mesh position for strawberry crop growth (*Fragaria* sp.)
Eugenio Romantchik, Gilberto López Cañtens, Diego Flores
Universidad Autónoma Chapingo, México

12:00–13:20 ORAL SESSION 18 / Fertigation, water, and growing media III

OS18-06
Providing more nitrogen with high light levels can accelerate hydroponic lettuce production
Theekshana Jayalath, Marc van Iersel
University of Georgia, United States of America

10:00–11:40 ORAL SESSION 19 / Plant production, protection, and quality
Chair: E. Schrevens

OS19-01
Photosynthesis, transpiration and water use efficiency of lettuce (*Lactuca sativa*) under varying light intensities
Andres Mayorga-Gomez, Marc van Lersel
University of Georgia, United States of America

OS19-02

Starwars: The use of lasers for indoor pest control

Kirsten Leiss[1], Estuardo Hernandez Olesinski[1], Jesica Perez Rodriguez[1], Joseph Peller[1], Systsma Menno[1], Ilias Tsafaras[1], Edwin Kroon[2]
[1]Wageningen University & Research, Netherlands
[2]Lion Laser Systems, Netherlands

OS19-03

Comparing efficacy of different biostimulants for hydroponically-grown lettuce (*Lactuca sativa* L.)

Zheng Wang, Rui Yang, Zheng Wang, Jiangtao Hu, Li Zhang, Qichang Yang
Chinese Academy of Agricultural Sciences, China

OS19-04

Eddie Schrevens[1], Jérémie Haumont[2], Peter Lootens[2], Jan Diels[1], Tim De Cuypere[3], Onno Bes[4], Jonas Bodyn[5], Wouter Saeys[1]
[1]Katholieke Universiteit Leuven, Belgium
[2]ILVO, Belgium
[3]INAGRO, Belgium
[4]Proefstation voor de Groenteteelt (PSKW), Belgium
[5]Provinciaal Proefcentrum voor de Groenteteelt Oost-Vlaanderen (PCG), Belgium

OS19-05

Comparison of Phenolic Compounds and Antioxidant Activity in three Black Cherry Tomato Varieties Grown Under Greenhouse Conditions

Ixchel Parola-Contreras[1], Josue Daniel Hernández-Vega[2], Erik Gustavo Tovar-Pérez[2], Rosalía Reynoso-Camacho[2], Ramón Gerardo Guevara-González[2]
Claudia Gutiérrez-Antonio[2], Ana Angélica Feregrino-Pérez[2], Rosario Guzmán-Cruz[2]
[1]Tecnológico de Estudios Superiores de Chimalhuacán, México
[2]Universidad Autónoma de Querétaro, México

12:00–13:20 ORAL SESSION 19 / Plant production, protection, and quality

OS19-06

Diverse plant species in relation to improve human nutrition

Giedre Samuoliene, Kristina Lauzike, Leva Gudzinskaite, Gediminas Kudirka, Audrius Pukalskas, Akvile Virsile
Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry, Lithuania

OS19-07

The feasibility of growing media originated from greenhouse

Dongdong Zhang
Chinese Academy of Agricultural Sciences, China

OS19-08

Flower induction and development under extended photoperiod in medicinal cannabis

Wannida Sae-Tang[1], Jesus Marin Gomez[1], Carlos Contrera Aviles[1], Donis Bernal Cortes[1], Wouter Mooij[1], Hein Groen[1], Céline C.S. Nicole[2], Sabrina Carvalho[2], Iris F. Kappers, Ep Heuvelink[1], Leo Marcelis[1]
[1]Wageningen University and Research, Netherlands
[2]Signify Research, Netherlands

OS19-09

Evaluation of Alternative Soilless Growing Systems for Resource Use Efficiency, Yield and Quality Performance of Multi-leaf Lettuce

Pradip Poudel, Francesco Di Gioia
The Pennsylvania State University, United States of America

10:00-11:40 ORAL SESSION 20 / Organic Greenhouse Horticulture:
Soil fertility and plant health
Chair: Y. Zheng

OS20-01

Organic fertilizers: as priming agents for enhanced plant defences against pathogens?

Adam Barrada[1], Robab Mahmoudi[2], Noémie Rochon[2], Thy Thui An Nguyen[2], Martine Dorais[2]
[1]Aix Marseille University, Canada
[2]Laval University, Canada

OS20-02

Black soldier fly frass: a new organic fertilizer or biostimulant?

Robab Mahmoudi, Adam Barrada, Thi Thuy An Nguyen, Grant Vandenberg, Martine Dorais
Laval University, Canada

OS20-03

Analysis of Nutrient Composition of Organic Liquid Fertilizer for Optimizing Fertilizer Dosing for Hydroponic Crop Production

Uttara Samarakoon[1], Milon Chowdhury[1], James Altland[2], Hunter Myers[1], Leslie Taylor[1]
[1]Ohio State University, United States of America
[2]USDA, United States of America

OS20-04

The effect of organic liquid fertilizer treatment on growth and yield of Bean (*Phaseolus vulgaris*) grown in soilless culture in greenhouse

Ozlem Altuntas, Rabia Kucuk
Malatya Turgut Ozal University, Turkey

12:00–13:20 ORAL SESSION 20 / Organic Greenhouse Horticulture: Soil fertility and plant health

OS20-05

Feasibility study on application of organic liquid fertilizer in hydroponic water spinach (*Ipomoea aquatics* Forssk.)

Tomoka Endoh[1], Takumi Shimada[2], Jiaxun Hu[2], Na Lu[1], Michiko Takagaki[1]
[1]Chiba University, Japan
[2]Planet Co. Ltd., Japan

OS20-06

Evaluating the influence of organic fertilizers on container-grown highbush blueberries in high tunnels

Ève-Marie Boudreau-Forgues, Linda Gaudreau, Annie Brégard, André Gosselin, Laura Thériault
Laval University, Canada

OS20-07

Lettuce (*Lactuca sativa* L. var. Lalique) Production Using Organic Nutrient Solution Under Hydroponics System

Erecson Solis
Camiguin Polytechnic State College, Philippines

OS20-08

Valorization of greenhouse crop residues using anaerobic digestion

Marianne Belley, Martine Dorais
Laval University, Canada

15:00–17:00 ORAL SESSION 21 / Energy in greenhouses
Chair: R. Salazar-Moreno

OS21-01
Quantifying energy saving by screens – the role of humidity transport
Silke Hemming, Feije de Zwart, Vida Mohammadkhani, Marcel Raaphorst
Wageningen University & Research, Netherlands

OS21-02
The trade-off between yield and electricity use for sweet pepper production in closed greenhouses in arid environments
Ilias Tsafaras[1], Jouke Campen[1], Feije de Zwart[1], Wim Voogt[1], Hessel van der Heide[1], Muien Qaryouti[2], Mohamed Ewis Abdelaziz[2]
[1]Wageningen University & Research, Netherlands
[2]The National Research and Development Center for Sustainable Agriculture (Estidamah), Saudi Arabia

OS21-03
Analysis of greenhouse energy consumption in northern China
Yi Zhang, Chao Wang
IEDA, China

OS21-04
Development and demonstration of a net zero energy greenhouse (ZEG) for contributes to the decarbonization of horticulture
Masahisa Ishii[1], Soma Sugano[2], Yuta Ohashi[1], Ryota Tsuchiya[1], Takashi Miki[1], Keita Yoshinaga[3], Takayuki Tsukamoto[3], Hisao Okumura[4], Tomoko Shimizu[4], Yasumasa Hayashi[5], Kuninori Suzuki[6], Hiroyuki Watanabe[7], Makoto Nakaune[8], Eiji Goto[9], Hiroaki Nishi[10], Shin-ichi Tanabe[2]
[1]Institute for Rural Engineering, National Agriculture and Food Research Organization, Japan
[2]Waseda University, Japan
[3]Institute of Agricultural Machinery, National Agriculture and Food Research Organization, Japan
[4]Toyobo Co., Ltd., Japan
[5]The Holt Group LLC, Japan
[6]Inochio Group, Japan
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OS21-05

Assessment of the solar radiation and microclimate distribution inside a prototypal dynamic photovoltaic greenhouse equipped with solar tracker: An experimental and CFD assisted study

Reda Errais[1], Younes El Fellah[1], Allal Senhaji[2], Wissal Bozalmat[1]
[1]Institut Agronomique et Vétérinaire Hassan II, Morocco
[2]l'Ecole Nationale Superieure d'Arts et Metiers ENSAM-MEKNES, Morocco

OS21-06

Energy savings in greenhouses by the use of low emissivity materials in screens

David Katzin, Cecilia Stanghellini, Vida Mohammadkhani, Silke Hemming
Wageningen University & Research, Netherlands

15:00–17:00 ORAL SESSION 22 / Environmental impact and sustainable production

Chair: N. Gruda

OS22-01

Circular economy – transferring biological control principles into intensive production systems – the zero waste approach

Christian Ulrichs, Dennis Dannehl, Uwe Schmidt, Zoltan Ferenczi, Sophia Tadesse, Inga Mewis
Humboldt University Berlin, Germany

OS22-02

Model-based optimization of N-fertilization strategies, balancing production and nitrate leaching in horticultural crops

Eddie Schrevens[1], Jérémie Haumont[2], Jan Diels[1], Peter Lootens[2], Tim De Cuypere[3], Onno Bes[4], Jonas Bodyn[5], Wouter Saeys[1]
[1]Katholieke Universiteit Leuven, Belgium
[2]ILVO, Belgium
[3]INAGRO, Belgium
[4]Proefstation voor de Groenteteelt (PSKW), Belgium
[5]Provinciaal Proefcentrum voor de Groenteteelt Oost-Vlaanderen (PCG), Belgium

OS22-03

Implementation of the circular economy concept in greenhouse production systems: microalgae and biofertiliser production using soilless crops' drainage nutrient solution

Nikolaos Katsoulas[1], Sofia Faliagka[1], George Kountrias[1], Eleftheria Pechlivani[2]
[1]University of Thessaly, Greece
[2]Centre for Research and Technology Hellas, Information Technologies Institute, Greece

OS22-04
Electric fields influence lettuce plant growth and mineral uptake
Dahae Kim, Tae In Ahn
Seoul National University, Korea (Republic of)

OS22-05
AI-Based Detection of Plant Stress: A Case Study on Fir Trees Under Bark Beetle Attack
Claudia Probst, Georg Schneider
University of Applied Science Upper Austria, School of Engineering, Austria

15:00–17:00 ORAL SESSION 23 / Lighting technology III
Chair: E. Olvera

OS23-01
Intra-canopy lighting in tomato and cucumber crops
Leo F. M. Marcelis, Tijmen Kerstens, Britt Besemer, Ep Heuvelink
Wageningen University & Research, Netherlands

OS23-02
Effect of light intensity and air temperature on morphology, specialized metabolism, and photosynthesis of medical cannabis (*Cannabis sativa* L.)
Mexximiliaan Holweg, Aurora Cravino, Thomas J. Curren, Ep Heuvelink, Leo F.M. Marcelis
Wageningen University and Research, Netherlands

OS23-03
Interactions between photon spectra and temperature in lettuce and basil grown under sole-source lighting
Jiyong Shin, Erik Runkle
Michigan State University, United States of America

OS23-04
The effect of photoperiod and light spectra on greenhouse eggplant production
Jason Lanoue[1], Daniel Terlizzese[2], Celeste Little[1], Sarah St. Louis[1], Youbin Zheng[2], Xiuming Hao[1]
[1]Harrow Research and Development Centre, Canada
[2]University of Guelph, Canada

OS23-05

Evaluations of Dim Nighttime Blue Lighting and Downward Airflow to Manage Tipburn in Indoor Farm Lettuce

John Ertle, Chieri Kubota
The Ohio State University, United States of America

OS23-06

Effects of different supplemental lighting directions and intensities on leaf photosynthetic characteristics and fruit yield of strawberry (*Fragaria×ananassa*)

Fang Wang, Qiuhong Liao, Qingming Li, Qichang Yang
The Graduate School of Chinese Academy of Agricultural Sciences, China

OS23-07

Response of greenhouse tomato to continuous LED lighting varies with lighting placement

Xiuming Hao, Jason Lanoue, Celeste Little, Sarah St. Louis
Harrow Research and Development Centre, Canada

15:00–17:00 ORAL SESSION 24 / Greenhouse crops management

Chair: I. L. López-Cruz

OS24-01

Effects of vertical air velocity on growth, morphology, and acclimatization of tomato seedlings

Ricardo Hernandez[1], Brandon Huber[2]
[1]North Carolina State University, United States of America
[2]South Carolina State University, United States of America

OS24-02

Study on the mechanism of different soil-rotation irrigation with brackish and fresh water coordinately regulate cucumber development

Yune Cao, Yanfeng Wei, Wenhui Li
Ningxia University, Helan Mountain, China

OS24-03

Pre-harvest Nitrogen Limitation and Continuous Lighting Improve the Quality and Flavor of Lettuce (*Lactuca sativa* L.) under Hydroponic Conditions in Greenhouse

Xiao Yang, Jiangtao Hu, Zheng Wang, Tao Huang, Li Zhang, Jie Peng, Bo Song, Yuejian Li, Qichang Yang
Chinese Academy of Agricultural Sciences (CAAS), China

OS24-04

Can extreme light diffusion still increase crop growth in greenhouses?

Nieves Garcia Victoria[1], Esteban Baeza Romero[2], Bram Van Breugel[1], Cecilia Stanghellini[1], Silke Hemming[1]
[1]Wageningen University & Research, Netherlands
[2]Future Farms Solutions, University of Almería Spain

OS24-05

UVA1 radiation induced a rapid "leaf-blade flattening" response and promoted growth of tomato plants

Tao Li, Yating Zhang
Chinese Academy of Agricultural Sciences, China

OS24-06

Implementation of wind-solar hybrid systems in solar dryers through a mathematical model and the analysis of the ventilation rate

Eduardo Ríos Urbán, Elisa Sánchez Cruces, Eugenio Romantchik Kriuchkova, Alexis U. Chavez Rivera
Universidad Autónoma Chapingo, México

PS3: Poster presentations: Wednesday October 25, 2023

PS03-01 [Computational Fluid Dynamics]

Performance of a home plants factory (easy) for indoor lettuce production using computational fluid dynamics

Jorge Flores-Velazquez[1], Ernesto Aguilar[2], Candido Mendoza[1], Francisco Garcia[1]
[1]Colegio de Postgraduados, México
[2]Tecnológico Nacional de México Campus Los Reyes, México

PS03-02 [Computational Fluid Dynamics]

Implementation of ventilation towers in a greenhouse at the end of a slope: Numerical approach to natural ventilation behavior

Cruz Ernesto Aguilar Rodríguez[1], Jorge Flores Velázquez[2], Gamaliel Valdivia Rojas[1], Oscar Eduardo Aguilar Rodriguez[1], Eligio Flores Rodríguez[1], Rodrigo Morfin Magaña[1]
[1]Tecnológico Nacional de México Campus Los Reyes, México
[2]Colegio de Postgraduados, México

PS03-03 [Energy & environment]

Cross-laminated timber wall design and energy consumption analysis

Hyun Mi Cho, Dae-Hee Jang, KiUhn Ahn, Yo-Sun Yun, Taeh-Young Kim, Chaeyoung Bae, Chang U Chae
Korea Institute of Civil Engineering and Building Technology, Korea (Republic of)

PS03-04 [Energy & environment]

Proposal of revitalization plan through analysis of building greening technology trend and policy status in Korea

Dae-Hee Jang, Yo-Sun Yun, Hyun Mi Cho, Chang U Chae, KiUhn Ahn, Taeh-Young Kim
Korea Institute of Civil Engineering and Building Technology, Korea

PS03-05 [Computational Fluid Dynamics]

Thermal behavior and leaf temperature in high pressure sodium lamp supplemented greenhouse

Seungri Yoon[1], Jin Hyun Kim[1], Minju Shin[1], Dongpil Kim[1], Ho Jeong Jeong[1], Tae In Ahn[2]
[1] National Institute of Horticultural and Herbal Science, Korea (Republic of)
[2] Seoul National University, Korea (Republic of)

PS03-06 [Energy & environment]

Development of green building certification system for sustainable building-integrated greenhouse

Yosun Yun, Daehee Jang, Hyunmi Cho, Changu Chae
Korea Institute of Civil Engineering and Building Technology, Korea (Republic of)

PS03-07 [Covering materials]

The performance of semi-transparent photovoltaics in the field of greenhouse systems

Ioannis Lycoskoufis[1], Angeliki Kavga[2], Theororos Petrakis[2]
[1]Department of Agriculture, University of Peloponnese, Greece
[2]Department of Agricultural Science, University of Patras, Greece

PS03-08 [Energy & environment]

Analysis of Energy Load for Semi-closed Greenhouse with Hydrogen Fuel Cell Technology Based Trigeneration System using BES

Rack-woo Kim, Seung-hun Lee, Woo-ju kim, Jun-seop Mun, Chan-min Kim, Hee-woong Seok, Su-been Ahn, Sun-hyoung Lee, Jeong-hwan Park
Department of SmartFarm Engineering, Kongju National University, Korea (Republic of)

PS03-09 [Covering materials]

Optimized sunlight use in greenhouses with Agri-Photovoltaic

Daniel Tran, Sandra Anselmo, Robert Farinet, Cédric Camps
Agroscope, Switzerland

PS03-10 [Computational Fluid Dynamics]

Analysis of High-temperature Air Environment of Wide Span Type & Semi-closed Greenhouses

Rack-woo Kim, Seung-hun Lee, Woo-ju Kim, Jun-seop Mun, Chan-min Kim, Hee-woong Seok, Su-been Ahn, Sun-hyoung Lee, Jeong-hwan Park
Department of SmartFarm Engineering, Kongju National University, Korea (Republic of)

PS03-11 [Computational Fluid Dynamics]

CFD analysis of environmental uniformity in seedling factories

Mil Oh, IlHwan Seo
Jeonbuk National University, Korea (Republic of)

PS03-12 [Energy & environment]

Greenhouse vegetable production from the point of view of climate change

Nazim Gruda
University of Bonn, INRES Horticultural Sciences, Germany

PS03-13 [Computational Fluid Dynamics]

CFD analysis of the effect of external obstructions on the natural ventilation of greenhouses

Cruz Ernesto Aguilar Rodríguez[1], Jorge Flores Velázquez[2], Juan Carlos Martínez Jiménez[3], Eduardo Pulido Toro[1]
[1]Tecnológico Nacional de México Campus Los Reyes, México
[2]Colegio de Postgraduados, México
[3]Universidad Juárez Autónoma de Tabasco, México

PS03-14 [Energy & environment]

Impact of a rooftop greenhouse on building cooling and heating energy of a commercial building using building energy simulation (BES) model

Eunjung Choi, Jaehyun Kim, Sang Min Lee
Korea Institute of Machinery & Materials, Korea (Republic of)

PS03-15 [Energy & environment]

Analysis of odor patterns in swine manure according to feed type

Woo Je Lee, Won Choi, Ki Youn Kim
Seoul National University of Science and Technology, Korea (Republic of)

PS03–16 [Energy & environment]

Evaluation of the effectiveness of disinfectants to reduce bacteria – focusing on meat processing

Doo young Kim, Ki Youn Kim, Woo Je Lee
Seoul National University of Science & Technology, Korea (Republic of)

PS03–17 [Growing media]

Effects of nutrient media and temperature on botrytis cinerea pers. Variability

Neringa Rasiukeviciute, Alma Valiuskaite, Kristina Buneviciene, Viktorija Vastakaite-Kairiene
Lithuanian Research Centre for Agriculture and Forestry, Lithuania

PS03–18 [Covering materials]

Effect of a high transmittance film cover on agronomic and microclimatic plant parameters in a greenhouse tomato crop

María Angeles Moreno-Teruel[1], Francisco D. Molina-Aiz[2], Diego L. Valera[2], Alejandro López-Martínez[2], Fatima Baptista[1]
[1]Universidade de Évora, Portugal
[2]Universidad de Almería, Spain

PS03–19 [Energy & environment]

The energy balance in a mezcal process by analyzing the cooking system of "Pinia"

Raquel Salazar Moreno[1], Abraham Rojano Aguilar[1], Luis Miranda Trujillo[2]
[1]Universidad Autónoma Chapingo, México
[2]Universidad Humboldt de Berlín, Berlin, Germany

PS03–20 [Crop Management]

Biostimulants and inductors for the control of some stress variables in tomato (*Solanum lycopersicum* Mill)

Domingo Montalvo-Hernández, Karina Bruno-Armengolt, Armando Ramírez-Arias, Joel Pineda-Pineda
Universidad Autónoma Chapingo, México

PS03–21 [Energy & environment]

A Sustainable Greenhouse Business Model – A Way to Transform the agricultural landscape of Central Europe

Sandra Mühlböck
International Summer Academy in Engineering for Women, Austria

PS03-22 [Organic greenhouse horticulture]

Influence of Silicon application on the agronomic and nutritional performance on container grown highbush blueberries

Martine Dorais, Ève-Marie Boudreau-Forgues, Linda Gaudreau, Annie Brégard, André Gosselin, Laura Thériault
Laval University, Canada

PS03-23 [Organic greenhouse horticulture]

Optimizing Nitrogen Availability for Organic Greenhouse Cultures: A Study on Various Organic Fertilizers and Growing Media

Martine Dorais, Philippe Vézina, Thi Thuy An Nguyen, Adam Barrada, Annie Brégard, Jacynthe Dessureault-Rompré
Laval University, Canada

PS03-24 [Organic greenhouse horticulture]

Optimizing electrical conductivity level improves plant growth and secondary metabolites of *Cannabis sativa* L.

Juhyung Shin, Seungyong Ham, Jongseok Park
Chungnam National University, Korea (Republic of)

PS03-25 [Organic greenhouse horticulture]

Nitrogen mineralization from organic fertilizers and water and oxygen content in growing media: How are they related?

Laura Thériault, Steeve Pepin, Martine Dorais
Laval University, Canada

PS03-26 [Organic greenhouse horticulture]

Assessment of two natural biostimulants for the production of organic vegetable seedlings in greenhouses

Dan Ioan Avasiloaiei, Silvica Ambarus, Petre Marian Brezeanu, Creola Brezeanu, Mariana Calara
Stațiunea De Cercetare-Dezvoltare Pentru Legumicultură Bacău, Rumania

PS03-27 [Organic greenhouse horticulture]

Effect of humic acids on the tomato production in soilless media

Marco A. Bustamante[1], Alejandro José Bustamante Dávila
[1]Universidad Autónoma Agraria Antonio Narro, México
[2]Wageningen University and Research, Netherlands

PS03-28 [Organic greenhouse horticulture]

Assessment of biofumigation with mustard or canola residues for controlling Rhizoctonia solani in greenhouse-grown cucumbers

An Thi Thuy Nguyen, Martine Dorais
Laval University, Canada

PS03-29 [Lighting technology]

Effects of light spectrum on inflorescence development and specialized metabolism, at different light intensities in medical cannabis

Mexximiliaan Holweg, Luc L.W. Rademakers, Beertje Douven, Leo F.M. Marcelis
Wageningen University & Research, Netherlands

PS03-30 [Crop Management]

Investigations of auxins transport in Petunia hybrida caused by thigmomorphogenesis

Agata Jedrzejuk[1], Margrethe Serek[2]
[1]Warsaw University of Life Science, Poland
[2]Leibniz University of Hannover, Germany

PS03-31 [Computational Fluid Dynamics]

Analysis of Thermal Energy Loads of a Building-integrated Rooftop Greenhouse (BiRTG) for Urban Agriculture

Uk-Hyeon Yeo[1], In-bok Lee[2]
[1]Gyeongsang National University, Korea (Republic of)
[2]Seoul National University, Korea (Republic of)

PS03-32 [Organic greenhouse horticulture]

Choosing light for a perfect date? Light spectra have different impacts on mating and developmental performances of the generalist beneficial Orius insidiosus (Say)

Morgane Canovas[1], Jean-François Cormier[2], Tigran Galstian[1], Paul Abram[3], Martine Dorais[1]
[1]Laval University, Canada
[2]Institut National d'Optique, Canada
[3]Agassiz Research and Development Centre, Agriculture and Agrifood, Canada.

GreenSys 2023

International Symposium on New Technologies for Sustainable Greenhouse Systems

Oral presentations

Oral presentations

Oral presentations: Monday October 23, 2023

ORAL SESSION 1 / Climate control and modelling I

OS01-01

Exploring NeRF for Automated 3D Phenotyping in Greenhouse: A Promising Direction in Shape Measurement and Analysis

HongBeom Choi, HyeIn, HyukJae Lee, Dr. Soo Hyun Park, Dr. Taek-Sung Lee
Korea Institute of Science and Technology, Gangneung Institute of Natural Product, Korea (Republic of)

3D plant phenotyping is crucial for understanding plant growth and environmental responses. Traditional methods, like Structure from Motion (SfM) and Light Detection and Ranging (LiDAR), have limitations in resolution, noise sensitivity, and computational efficiency. We propose a novel, automated pipeline to plant phenotyping using Neural Radiance Fields (NeRF), a deep learning technique that models continuous volumetric scene representations. Incorporating a 6-DOF robotic manipulator, our method automates the data acquisition process, significantly reducing manual labor and human error. NeRF overcomes the limitations of SfM and LiDAR by offering better handling of computation time, better results in greenhouse environment, and robustness on sparse input data. Our work demonstrates the potential of NeRF as a valuable tool for plant phenotyping, advancing our understanding and quantification of plant morphology and growth. This preliminary exploration lays the groundwork for future research and development in plant phenotyping and shape analysis, potentially benefiting from advancements in other cutting-edge techniques such as neural implicit surfaces.

Keywords: 3D Phenotyping, Neural Radiance Field, Digital Twin, Greenhouse Automation, Deep Learning.

OS01-02

Plant Performance in Precision Horticulture: Visualizing optimal control strategy under stochastic uncertainty

S. van Mourik[1], M. Vellekoop[2]
[1]Farm Technology group, Wageningen University & Research, Netherlands
[2]University of Amsterdam, Netherlands

We present an optimal control algorithm for crop production with precise harvest weight requirements when state dynamics are uncertain due to stochastic noise. Our case study concerns a 50-day production round of lettuce in a greenhouse where the climate is controlled

by heating. The controller prescribes day and night indoor temperature as a function of crop weight and time based on optimal net revenue defined by harvesting revenues minus heating costs. The latter is calculated with the degree-hour method. The optimal control policy, subsequent crop growth dynamics, and expected revenues are visually linked to helping elucidate the rationale behind the optimal control policy.

We observed that the controller only prescribes heating in a small band around the optimal state trajectory. Outside this band, no investment in heating was made due to low payout expectancy. On sunny days the controller increased the indoor day temperature to accelerate crop growth rate when necessary, whereas the night temperature was increased to slow the growth rate down. On days with little sunlight, no heating was prescribed for any state at any time. Extra risk due to increased state noise was mitigated primarily by cancelling investments at the beginning of the growth cycle, where the payoff is most uncertain.

Keywords: Control, greenhouse, stochastic, lettuce.

OS01-03

Time series forecasting for air temperature inside a naturally ventilated greenhouse with optimal sensor location based on LSTM

Da In Kim, In-bok Lee, Jeong-hwa Cho, Young-bae Choi, Hyo-hyeog Jeong, Sol-moe Kang, Seo-ha Park

Seoul National University, Korea (Republic of)

Greenhouses can adjust the internal environment artificially, maintaining an appropriate growing environment for growing crops, which has the advantage of high annual productivity. Environmental factors such as air temperature, relative humidity, and CO_2 are not only greatly affected by the growth of crops but also by the quality of crops, so it is important to properly control the growth environment of crops for high greenhouse productivity. However, the internal environment of the greenhouse consists of complex environmental systems, including nonlinearity, time variation, and uncertainty. The purpose of this study is to predict the future air temperature of each of the nine locations in the greenhouse, considering the minimum sensor using the LSTM model. First, an LSTM model was developed to predict the air temperature of the sensor in advance by learning the environmental data and external environmental data measured from one of the sensors installed in the greenhouse. Furthermore, in order to minimize the number of sensors installed in the greenhouse, the future air temperature for nine locations in the greenhouse was predicted by learning environmental data and external environmental data measured at the optimal sensor location. For the development of the LSTM model, various environmental data, such as air temperature, relative humidity, and CO_2 inside the experimental greenhouse, were collected. The appropriate sequence length derived through the sequence length test was 30 min. The LSTM model developed in this study

showed high accuracy of $R^2 > 0.95$ and RMSE < 0.65 for air temperature prediction at most locations. In order to further minimize sensor installation, the LSTM model applied with the optimal sensor location in previous studies was developed and defined as the prediction of future air temperature using the optimal sensor machine learning model (PFTO-ML). PFTO-ML with only one optimal sensor location showed that the prediction accuracy was reduced in most locations, but the accuracy was improved when multiple optimal sensor locations were applied. Therefore, it was recommended to apply at least three optimal sensor locations for future air temperature prediction.

Keywords: Air temperature, Forecasting, Greenhouse, Natural ventilation, LSTM, Optimal sensor location.

OS01-04

Predicting greenhouse design performance and suggested improvements using massive cloud-simulation and machine learning

Paolo de Heer, Anouk Beelen, Athanasios Sapounas, Richard Dekker
TNO, Netherlands

Greenhouse design involves hundreds of choices, from location and orientation to material types, installed installations, and systems. Additionally, there is no 'best' greenhouse; instead, this depends on the crop type, local resource availability (including network effects like waste-heat from industry), and desired growing strategy. All these choices have to be made deliberately by the greenhouse builder. Software tools like SIOM are entering the playing field that can simulate entire growth years for a user-made greenhouse design to aid in this design process. To take this one step further, in this project, multiple key-performance indicators were defined that provide a way to compare the performance of the designs, from resource use for heating and lighting to photosynthesis per radiation and water use. Furthermore, a machine learning algorithm was trained on a large database of SIOM greenhouse designs that have been fully simulated in the cloud and for which the key performance indicators were calculated. With this AI model, the performance of new greenhouse designs can immediately be predicted (with an r-squared score of above 0.9) without having to simulate the entire cultivation year fully. Additionally, a tool was developed that automatically suggests changes to the original design based on the results of the performance indicators. Future work includes multi-objective optimization, improvements to the AI algorithms, and a more diverse corpus of greenhouse configurations to further push the predictive capabilities of the models.

Keywords: key performance indicators, KPI, machine learning, artificial intelligence, AI, simulation, climate, strategy, scenario analysis, resource use optimization, greenhouse design, automatization, greenhouse construction, system optimisation, decision support.

OS01-05

Computing radiative heat transfers in greenhouses: a methodology coupling analytical and numerical approaches for view factors assessment

Samuel Sourisseau[2], Etienne Chantoiseau[1], Cyril Toublanc[1], Michel Havet[1]
[1]Institut Agro Rennes-Angers, France
[2]Oniris, Nantes Université, France

Soilless cultivation under heated greenhouses is a common practice for Northwestern France tomato producers. However, it comes with important energy consumption that shall be more than ever addressed, especially because it still relies in a large proportion on fossil fuels. Modelling the greenhouse climate and its effects on crop growth and yield can help to evaluate existing and innovative heating systems in relation to the associated energy consumption. Radiative heat transfers, in particular, shall be studied because of their magnitude compared with convection in greenhouses. However, computing view factors, which characterize how surfaces "see" each other, is complex in greenhouse cases where the configuration does not correspond to simplified analytical cases, with obstacles and surface arrangement varying with time as the crop grows.

In this work, a methodology is presented to evaluate view factors in a 1000 m² soilless tomato experimental greenhouse fitted with three different heating pipe networks and air ducts below the gutters. The approach uses Free and Open Source Software in conjunction with analytical solutions whenever possible to reduce computation time. The following elements are considered: floor, ducts, gutters, heating pipes, horizontal screens, roof, and sidewalls. In order to evaluate view factors that depend on the crop growth, regression formulas are presented to take into account the crop rows height and Leaf Area Index (LAI) from low ones (where radiative energy losses with the roof and the walls might be important to assess for year-round energy consumption studies) to mature ones. The methodology itself can not only be applied to any other greenhouse arrangement but also, more generally, to any geometry where radiative transfers occur within a volume that includes obstacles.

Keywords: Radiative heat transfer, View factor, Energy efficiency, Greenhouse.

OS01-06

An on-line benchmark tool for greenhouse technology towards fossil-free greenhouses

Feije De Zwart, Gert-Jan Swinkels, Luuk Graamans, Silke Hemming, David Katzin, Kshiti Mishra
Wageningen UR Greenhouse Horticulture, Netherlands

The modern greenhouse industry is highly productive but also resource intensive. In higher latitudes, considerable amounts of heating and electricity are used. In arid regions, water consumption is a serious concern. The horticultural industry develops all kinds of new technologies to contribute to better resource efficiency, but due to the large variation in

local climatic conditions and market circumstances, it is very difficult to assess the impact on the sustainability and economic viability of such technologies. Especially when innovative techniques are used in combination with an intensified crop cultivation system, an improved resource use efficiency can get blurred by the higher amount of inputs needed.

In order to clearly show the interaction of crop cultivation and technical equipment, and to express the overall result in terms of resources per unit of produce, Wageningen University and Research Greenhouse Horticulture has developed an on-line simulation environment in close cooperation with key players in the horticultural supply industry. The tool is based on the validated dynamic greenhouse climate simulation model KASPRO, and is made publicly accessible in order to provide benchmark data that support the societal debate on the roadmap towards fossil-free production systems for high-value horticultural products. The simulation tool allows to set the greenhouse and crop properties on one side (crop type, covering material, screen installations, illumination, etc.) and the climate control equipment on the other side (e.g., heat pumps, geothermal heat, photovoltaics, cooling, and heating equipment). The output shows the performance of user-defined combinations of primary energy and electricity sources, water, CO_2 consumption, and resource use efficiency and therefore allows for objective comparisons of scenarios. When using the tool, all input and output are concisely described, and an accompanying website provides a number of examples where the inputs and outputs of the simulation tool are explained in detail.

Keywords: resource use efficiency, greenhouse climate, simulation model.

OS01-07

Assessing Tree-Based Boosting Algorithms for Crop Growth Forecasting in Greenhouse Cultivation

Hyun Kwon Suh[1], Ju Yeon Ahn[1], Hyeonji Park[1], Soo Hyun Park[2], Joon Yong Kim[3]

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[2]Smart farm research center, Korea Institute of Science and Technology, Korea (Republic of)

[3]Dept. of Biosystems and Biomaterials Eng., Research Institute of Agriculture, Seoul National University, Korea (Republic of)

Significant climate shifts and increasing global temperatures have a substantial impact on crop yield and quality, including those grown in greenhouse environments. As the climate crisis has increased the risk of crop failure, forecasting crop growth using environmental data has gained significant importance. This study assessed tree-based forecasting algorithms to estimate crop growth based on the 2nd AGIC dataset (Autonomous Greenhouses International Challenge) gathered from a cherry tomato greenhouse in the experimental greenhouses of Wageningen University & Research (Bleiswijk, the Netherlands). The AGIC dataset includes both environmental and crop growth data, collected from December 16, 2019, to May 30, 2020. Environmental data - including CO_2 concentration, drain EC, total PAR light, drain pH, water supply, outside temperature, solar radiation, radiation sum, and wind speed - was gathered from sensors every 5 minutes. In contrast,

crop growth data, such as the number of trusses and stem elongation, was measured manually on a weekly basis. Utilizing nine environmental variables and two crop growth measurements, this study examined tree-based boosting algorithms, LightGBM and XGBoost, known for their recent success in data science, to predict crop growth. Performance was assessed using RMSE and MAE metrics. In forecasting stem elongation, LightGBM achieved an RMSE of 0.0072 and an MAE of 0.0036, while XGBoost showed an RMSE of 0.0208 and an MAE of 0.0114. In forecasting the number of trusses, LightGBM achieved an RMSE of 0.0118 and an MAE of 0.0058, while XGBoost showed an RMSE of 0.0229 and an MAE of 0.0125. This study shows that tree-based boosting algorithms, LightGBM and XGBoost, can be utilized as a valuable tool for crop growth forecasting in greenhouse cultivation.

Keywords: time-series forecasting, crop growth forecasting, LightGBM, XGBoost, greenhouse cultivation.

OS01-08

High-pressure fogging system for VPDc control in low-tech greenhouse crops

E. Fitz-Rodríguez[1], J.O. Gutierrez-Hernández[1], J.A. Ramírez-Arias[1], I.L. López-Cruz[1], A. Ruiz-García[1]

[1]Postgrado IAUIA, Universidad Autónoma Chapingo, México

More than 90% of greenhouses in México are passive, with no heating or cooling systems. They rely on natural ventilation for climate management, limiting their potential for increased productivity and year-round production. The climate conditions in México are diverse, and the current study focuses on improving the daytime environment of low-tech greenhouses located in regions with low humidity. In combination with adequate ventilation, high-pressure fogging systems have been shown effective in enhancing the crop environment to optimum air temperature and humidity levels, thus maximizing photosynthesis and reducing transpiration. A crop-related vapor pressure deficit (*VPDc*) control was implemented in a 300 m^2 single-bay greenhouse with polyethylene covering and side and ridge vents. A tomato crop was grown in a hydroponic system in a coco coir substrate. Several *VPDc* levels (at 0.4, 0.7, 1.0, 1.3, 1.6, 1.9, and 2.4 kPa) were implemented during the daytime (from 10:00 to 15:00) to observe the physiological response of the plants by measuring stomatal conductance. The control system effectively achieved the *VPDc* levels, established as a setpoint, by activating the fogging pump when required. A *VPDc* of 1.0 kPa produced the best conditions for optimal photosynthesis levels with maximum values of stomatal conductance of g_s = 778 µmol·m^{-2}·s^{-1}, and optimal environmental conditions (*Ta* = 25.3 °C, *RH* = 59.8 %). On the other hand, with no *VPDc* control, the environment conditions were *Ta* = 29.3 °C, *RH* = 20.6 %, an average *VPDc* = 2.6 kPa, and g_s = 426 µmol·m^{-2}·s^{-1}.

Keywords: Greenhouse climate control, Humidity control, Stomatal conductance, Transpiration, Photosynthesis.

ORAL SESSION 2 / Greenhouse crops modelling and management I

OS02-01

Model-based optimization of nutrient supply in a lettuce crop grown in recirculating nutrient solution using the Decision Support System NUTRISENSE

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Year-round cultivation of lettuce in modern hydroponic systems with recirculating nutrient solutions under controlled-environment conditions using moving gutter systems can be a highly profitable system for commercial production. However, optimal nutrition of the plants in such systems is a prerequisite for maintaining high production and quality over time. In this production system, one of the most challenging requirements is the maintenance of optimal nutrient concentrations in the recirculating nutrient solution (NS). In the current study, the Decision Support System (DSS) NUTRISENSE (https://nutrisense.online/) was used in a commercial lettuce crop grown in recirculating NS to control the nutrient supply. The composition of the NS added to the recirculating NS to compensate for plant uptake (added solution: AS) was readjusted weekly through NUTRISENSE. The DSS NUTRISENSE uses an algorithm based on a mass balance model to calculate a readjusted composition of the AS whenever fed with the current composition of the recirculating NS. The frequent readjustment of the AS was aiming to match nutrient input to the variations of crop nutrient uptake, thus maintaining the nutrient concentrations within target ranges in the root zone. Overall, the experimental results showed that lettuce has a higher phosphorus and potassium demand than fruit vegetables, as indicated by the high mean uptake concentrations (nutrient/water uptake ratios) established for these nutrients. The use of NUTRISENSE allowed for maintenance of the nutrient concentrations in the recirculating nutrient solution close to standard recommended levels. Based on the obtained results, a standard AS composition for lettuce grown in recirculating NS corresponding to the anticipated mean uptake concentrations was established. Nevertheless, this composition should be considered as a standard basis used mainly as a starting point, but frequent readjustment using a suitable DSS like NUTRISENSE is essential to maintain the nutrient concentrations in the root zone within optimal target ranges.

Keywords: hydroponics, *Lactuca sativa*, nutrient uptake, NUTRISENSE, soilless culture.

OS02-02

Optimisation of tomato production in a closed greenhouse system in Norway

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Meeting the rising food demand of a growing global population requires new and sustainable production methods. In Norway, hydroponic greenhouse production systems using supplemental light result in predictable yield year-round. A closed greenhouse system using hydroelectric energy provides sustainable conditions for maximizing photosynthetic performance while reducing the loss of resources like CO_2, heat, and water. However, profitable closed greenhouse production requires high yields and quality.

In our research facilities at NIBIO Særheim, standard hydroponic round tomatoes were grown in two greenhouse compartments of each 225 m^2, both using High Pressure Sodium (HPS) supplemental top light (400 µmol $m^{-2}s^{-1}$) with or without LED inter-light (130 µmol $m^{-2}s^{-1}$). In the control compartment, greenhouse climate and ventilation were regulated by a standard horticultural computer. The other compartment used an Environmental Control System (ECS, GreenCap Solutions AS) to regulate greenhouse air temperature, humidity, and CO_2 concentration. The result was that the windows could be kept completely closed during the experiment that lasted from week 6 to week 39 (2020). CO_2 was provided by a system for Direct Air Capture (DAC).

In a production period of 26 weeks, a tomato yield of 65.3 kg m^{-2} was achieved in the control compartment and 85.3 kg m^{-2} in the closed greenhouse compartment. The increase in production could largely be explained by a difference in the average CO_2 concentration in the greenhouse compartments. The use of LED inter-light further increased the production in the closed greenhouse compartment to 95.0 kg m^{-2}. No such increase in production was observed in the control compartment. The closed greenhouse system reduced CO_2 emissions and improved the quality, size, and taste of the tomato fruits. The ECS collected plant transpiration vapor from the greenhouse air and controlled the growth environment in a way that we had no need for chemical plant protection.

Keywords: Sustainable food production; Environmental Control System (ECS); Supplemental light; Direct Air Capture (DAC), CO_2 emission.

OS02-03

Paprika Growth Modeling Using Cropbox

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Crop modeling is essential to develop sustainable and resilient agricultural technologies by improving the efficiency of energy, material, and human resources. To predict crop growth, development, and yield, it is necessary to accurately calculate income and outcome at the

plant level. Accurate model construction is possible only with accurate information on photosynthesis, respiration, and organ distribution. In this progress, many physiological reactions are involved, so modeling programs are widely used. The Cropbox is a process-based model consisting of four modules: Phenology (Seedling, Germination, senescence ...), Physiology (Carbon gain and allocation), Morphology (Leaf, Stem, Fruit growth ...), and Gas exchange. Cropbox can predict plant growth traits (number of leaves, leaf area, fresh weight ...) and simulate climate change scenarios (RCP 4.5, 8.5). Cropbox modeling is currently carried out on four crops: 1 Root crop(garlic) and 3 Fruit crops (cucumber, paprika, tomato). Especially fruit crops were constructed to be analyzed in the hydroponic environment.

Keywords: Growth modeling, Paprika, Cropbox, Julia.

OS02-04

Maintaining the quality of strawberry fruit in long-term storage by keeping the environment at low temperature and high humidity

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Strawberry fruit are soft, easily damaged, and prone to water loss, so their quality must be carefully maintained during fruit distribution and storage. In addition, the price of fresh strawberries varies widely depending on the time of the year, so maintaining quality by optimizing storage conditions and adjusting shipment times can add value. Studies have shown that controlling various aspects of the post-harvest environment, such as temperature, humidity, and packaging, is essential for maintaining fruit quality. However, few studies have explored storage methods at a high relative humidity (RH) because of the difficulty of maintaining and measuring high RH. In this study, we investigated strawberry fruit quality after storage under high RH (close to 100%) conditions created using two types of humidifiers and wet paper towels. The RH during storage was maintained at 89% using only an evaporative humidifier and at 92% using a combination of an evaporative humidifier and an ultrasonic humidifier. Even higher RH (99%) conditions were established by wrapping plastic packs filled with strawberry fruit in wet paper towels. Strawberry fruit quality after storage was evaluated by measuring relative weight (100% at harvest), sugar content (Brix), acidity, and the apparent modulus of elasticity. The fruit relative weight decreased in proportion to the number of storage days. After 42 days of storage, the fruit stored at 99% humidity decreased to 99% relative weight, and those stored at 92% humidity decreased to 89% relative weight. The fruit stored at 99% humidity retained their sugar content, acidity, and apparent modulus of elasticity for 42 days. The same fruits stored under different RH conditions were evaluated every 3 days, and the rate of weight loss was proportional to the vapor pressure deficit of the storage environment. However, the skin of strawberry fruit was discolored after 42 days of storage.

Keywords: semiconductor sensor, humidification, cold storage, fruit quality, postharvest.

OS02-05

Process-based crop model to evaluate stress on tomato plants and predict the fruit yield and quality

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Process-based tomato models are mainly used to predict yield in low-stress conditions. However, stress is applied to tomato plants to produce sweet tomato fruits. In this study, we added a parameter of stress intensity (SI) to a process-based tomato model. The SI, which ranges from 0 (no stress) to 1 (full stress), was used to reduce the potential expansion rates of leaves and fruits. We evaluated the SI and predicted fruit yield and quality of plants cultivated under stress conditions. We first predicted the sizes of individual leaves and fruits on each day under different SI from 0 to 1. Measured actual sizes of leaves and fruits of tomato plants cultivated under stress conditions were compared with the predicted ones. The actual SI was then determined as the SI that was used for the prediction of the closest sizes of leaves and fruits. We predicted tomato fruit yield by using the actual sizes and the determined SI as initial inputs of the process-based model. Both the actual yield and the predicted yield with the SI were lower than that obtained by the prediction without SI. The dry matter content (DMC) of tomato fruits was also predicted based on the predicted amount of assimilation pool in the process-based model. The predicted DMC was higher than the actual one. The SI determination and prediction with the SI performed well in predicting the reduced yield and increased DMC under stress conditions.

Keywords: dry matter content, environmental conditions, Japanese tomato cultivars, leaf and fruit expansion rate.

OS02-06

The "N-C balance model" for optimizing nitrogen supply and temperature management in greenhouse fruit vegetable production

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The "N-C balance model" developed by the authors is a growth model that describes the mechanisms by which solar radiation, temperature, and nitrogen supply determine the distribution of photosynthates (leaves, stems, fruits, and roots), flower bud differentiation, and flower number. We noted that the N content is almost constant for each organ, i.e., a constant N/C ratio relationship exists. Since crop growth, such as the increase in the number of leaves and fruit ripeness, is strongly influenced by temperature, many conventional models describe the sink strength of each organ as a function of temperature. The N-C

balance model is unique in that it assumes that the sink strength of an organ is determined by the amount of N distributed to that organ. The N demand of an organ is first expressed as a function of temperature for each organ. Then, the absorbed N is distributed in proportion to the demand. Then, C has distributed so the organ has a specific N content. The upper limit of the amount of N acceptable per period of time is larger in leaves, and stems and smaller in fruits. Thus, the excess N is distributed to the leaves and stems, then the amount of C distributed to them increases, resulting in a larger leaf area. The amount of N absorbed determines the C demand. Solar radiation determines the photosynthates (C supply). Sugar concentration in the plant can be estimated from the ratio of C supply to C demand. Sugar concentration has a great influence on flower bud differentiation and flower number. Therefore, the N-C balance model can predict the timing of flower bud differentiation and the number of flowers from the amount of N absorbed and solar radiation.

Keywords: distribution, photosynthesis, flower bud differentiation, nitrogen.

OS02-07

Utilizing Decision Tree Algorithm for Melon Fruit Weight Prediction

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The visual characteristics of a melon serve as a crucial gauge for assessing its growth and development, monitoring its irrigation requirements, and evaluating its market potential at different growth stages. The horticulture industry has extensively employed computer vision systems for the purpose of automatic external quality control of agricultural products. The objective of our research is to leverage computer vision and machine learning methodologies to precisely measure fruit dimensions, including length and width, while concurrently estimating their fresh weight. The plants were transplanted on January 9, 2023, to a Venlo-type glasshouse. After fruit set, the melons were weighed twice daily using a loadcell system capable of providing real-time measurement. Image segmentation was performed using the Segment Anything Model (SAM), and dimension detection was performed using OpenCV in Python. Fruit length, width, and fresh weight data were used as training data. To compare model performance, regression analysis, multilayer perceptron, and decision tree were employed. A total of 200 melon fruits were investigated by growth stages. Results indicated that the decision tree exhibited superior predictive power compared to the other models. By employing these cutting-edge techniques, we aim to develop a more accurate and reliable system for assessing the external quality of fruits, with the potential to enhance the efficiency and productivity of the horticultural industry.

Keywords: Machine learning, Decision Tree, Deep learning, Convolutional neural network, Fruit weight prediction.

OS02-08

Virtual Tomato Crops: a digital twin of a tomato crop

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Wageningen University & Research has built a proof-of-concept digital twin of a greenhouse tomato crop, the "Virtual Tomato Crop" (VTC), with the aim to help increase resource use efficiency of greenhouse tomato systems. At the core of this digital twin is a dynamic functional-structural plant (FSP) model, developed in the GroIMP platform (gitlab.com/grogra/groimp). The FPS model is linked to the greenhouse climate model Kaspro, which simulates indoor climate using outdoor climate data and greenhouse properties.

To collect data for model development, experiments were conducted in 2021 in the Netherlands Plant Eco-phenotyping Centre (www.npec.nl) facility with four tomato cultivars: 'Merlice', 'Brioso', 'Moneymaker', and 'Gardener's Delight'. A plant-to-sensor system was used to image all plants approximately every 3 days. Additional manual measurements were performed, including optical properties of leaves, leaf photosynthesis, as well as biomass and crop height over time. Based on these measurements, the VTC model was calibrated for different tomato cultivars.

The shade patterns created by greenhouse construction, the planting pattern and 3D plant architecture, as well as plant development and growth processes, are all taken into account by the VTC model. This complex feedback between crop light absorption and assimilate production can be used to predict crop response to environmental factors and management decisions, assess the minimal sensor requirements for a greenhouse tomato cultivation, and generate datasets for automation and prediction efforts. In this paper, we describe the model and discuss its benefits, limitations, and potential.

Keywords: tomato digital twin, FSMP, tomato model.

ORAL SESSION 3 / Lighting technology I

OS03-01

Integrated production in new light: light quality in greenhouse horticulture and its impact on the phyllosphere microbiome

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Horticultural crop production in greenhouses, polytunnels and plant factories uses artificial assimilation lighting to improve plant performance and the profitability as well as bioactive compound content. Using light emitting diodes (LED) as a light source, light quality can easily

be adopted for the crop's demands and specific crop management measures. Most horticultural literature related to artificial lighting focuses on the plant and its product. However, light quality also affects non-phototrophic microorganisms associated to the canopy microbiota (*phyllobiome*). In this contribution we highlight the impact of light quality on plant–microbe interactions, with special emphasis on non-phototrophic organisms. Bacterial and fungal pathogens, biocontrol agents, and the phyllobiome are considered. Relevant molecular mechanisms regulating light-quality-related processes in bacteria are described. We also highlight how microbial functions crucial for biocontrol activity are affected by light quality and nutritional preconditions and how this can be used in future BCA application.

Keywords: Abiotic and biotic interactions, Greenhouse applications, Light quality, Molecular mechanisms, Ornamental plants, Phyllosphere, Tomato.

OS03-02

Effect of supplementary far-red light on plant growth, fruit set, yield and fruit quality of sweet pepper

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Supplementary far-red (FR) lighting can trigger a wide range of photomorphogenic responses. In greenhouse tomato, supplementary FR increases fruit yield, mainly due to an increased fruit sink strength. In sweet pepper, it was also reported recently that supplementary FR can increase fruit yield especially in the early production. However, a detailed explanation is still lacking for the FR effect on the yield of sweet pepper.

Sweet pepper production frequently suffers from poor and irregular fruit set. Typically about two-thirds of all flowers abort, even in controlled environments. Weeks with good fruit set are alternated by weeks with poor fruit set, resulting in a flushing pattern in fruit set and yield. In our previous climate room experiments, we observed that FR stimulated flower and fruit abortion in young sweet pepper plants, which conflicts with FR's beneficial effect on yield in long-season production in greenhouses. The reason behind this conflict is still under investigation. Moreover, if supplementary FR indeed improves fruit yield of sweet pepper, it is not certain whether there is a trade-off between yield and fruit quality.

Therefore, we conducted a greenhouse experiment, with the following aims: 1) to determine the effect of FR on yield of sweet pepper in greenhouse conditions; 2) to explain this effect using a yield component analysis; 3) to examine the quality and post-harvest performance of fruits cultivated with or without supplementary FR. In this experiment, sweet pepper plants (*Capsicum annuum* L. cv. 'Gialte' and 'Margrethe') were grown in glasshouses in the

Netherlands, from October 2022 till February 2023. Plants were cultivated under natural sunlight plus 200 $\mu mol\,m^{-2}\,s^{-1}$ of supplementary white LED lights (80% red light), with 0, 50 or 100 $\mu mol\,m^{-2}\,s^{-1}$ of additional FR. Growth and developmental parameters were recorded for a yield component analysis. Additional parameters of interest include weekly fruit set to indicate flushing pattern; fruit quality such as sugar content and shelf life. The data is currently being analyzed.

Keywords: Capsicum, light quality, yield component analysis, fruit set, fruit quality.

OS03-03

Effect of Different Supplemental Lighting Sources on Cucumber (*Cucumis sativus* L.) Growth

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Low solar radiation condition in spring and winter in the Republic of Korea reduces the photosynthesis of cucumber. A continuous low light intensity condition can be a problem in greenhouse cultivation due to the reduced growth of crops and fruit yield. To solve this problem, supplemental lighting technology can be used. Supplemental lighting is a technique that adjusts the length and amount of light to complement insufficient sunlight. The effect of supplemental lighting is different by light sources, light intensity, light quality, and photoperiod. Therefore, this study investigated the effects of different supplemental lighting sources on the growth and fruit yield of cucumbers. Cucumber seedlings were transplanted on a hydroponic system in the Venlo-type greenhouse. The light sources used in the experiment were a high-pressure sodium lamp (HPS), white LED (W LED), and combined red and blue LED (RB LED, red:blue = 50:50). Non-treated (non-supplemental lighting) was set as the control. Supplemental lighting was conducted for 4 hours after sunrise with a photosynthetic photon flux density of 150 ± 10 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The results of this research can be used as the basic research data for improving the growth and yield of cucumbers in low solar radiation conditions.

This work was carried out with the support of "Cooperative Research Program for Agriculture Science and Technology Development (Project No. PJ01707201)" Rural Development Administration, Republic of Korea.

Keywords: combined red and blue LED, high-pressure sodium lamp, low light intensity, white LED.

OS03-04

Intumescence Incidence of 'Sinhong' Hot Pepper Seedlings under Different Light Qualities

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Intumescence is a physiological disorder in which epidermal cells of leaves and stems enlarge and occur mainly in solanaceous crops. Intumescence not only impairs the plant's physiological processes but also negatively affects the aesthetic quality of the crop. Intumescence research is mainly conducted on tomatoes; the disorder has been reported to be observed under a lacking blue or ultraviolet (UV) spectrum. In addition, far-red light has been reported to diminish the incidence of intumescence. But the intumescence inhibition effect of the light quality is different between crops. Hot pepper (*Capsicum annuum* L.) is a solanaceous crop like tomatoes. Seedlings of Korean hot pepper have been exported to various countries, such as Japan and China. Therefore, this study investigated the effects of different light qualities on the incidence of intumescence in hot pepper seedlings. Hot pepper seedlings are placed in a closed plant production system with light treatment set in R100, B100, G100, R5G5, R5B5, B5G5, R5G2B3, R4B4Fr2, and R5B5 + UV 0.4 $\mu W \cdot m^{-2}$. All treatments were provided 12 hours a day with a light intensity of 100 ± 10 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux density. The results of this study can be used as basic research data for inhibiting the intumescence incidence in hot pepper.

This work was supported by the National Research Foundation of Korea (NRF) grant funded by the Republic of Korea government (MSIT) (NRF-2022R1F1A1074218).

Keywords: epidermal cell, far-red, physiological disorder, solanaceous crop, ultraviolet.

OS03-05

Growth, morphology, and light acclimation of cucumber seedlings grown under different light spectral qualities

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This study evaluated the effect of red, blue, and far-red (R, B, FR) LEDs on the growth, morphology, and photosynthetic acclimation of cucumber (*Cucumis sativus* cv. Joeunbaekdadagi) seedlings grown in a plant factory and their subsequent growing shift in the greenhouse. Three combinations of light spectra were used: 50R 50B, 80R 20B, and 80R 10B 10FR, with a photon flux density of 400 $\mu mol\ m^{-2}\ s^{-1}$. After four weeks of seedling, plants were transplanted in an experimental glasshouse in Haman, Korea. Leaf photosynthesis and chlorophyll fluorescence were measured every three days after transplanting. 80R 10B 10FR showed the highest plant height, leaf area, fresh weight, and dry weight in the seedling stage. However, the SPAD value of 80R 10B 10FR seedling was significantly lower than the

other groups. Maximal leaf photosynthesis (P_{max}) was the highest for 50R 50B, and F_v/F_m was the lowest for 80R 20B seedlings. On the first day after transplanting, 80R 20B plant showed the highest P_{max}, and there was no difference in F_v/F_m among treatments. One week after transplanting, P_{max} did not differ between the treatments. F_v/F_m was the lowest for 80R 20B, while 50R 50B and 80R 10B 10FR showed no difference. The plant height and the number of flowers were highest in 80R 10B 10FR, two weeks after transplanting. The results suggest that the overall growth of the seedling stage might have a greater impact than light acclimation after transplanting.

Keywords: cucumber, seedling, LEDs, light quality, light acclimation, plant factory.

OS03-06

A chlorophyll fluorescence-based biofeedback system to optimize LED lighting: from seedling to harvest stage

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Artificial lighting needs to be controlled precisely and efficiently to minimize energy costs. For that, we have developed a chlorophyll fluorescence-based biofeedback (BFB) system that adjusts the LED light intensities based on the physiological responses of plants. The BFB system previously has been used within a single day, but not throughout a whole growth cycle. Therefore, the objective of this study is to test the performance of the BFB system for long-term use from seedling to harvest stage. The LED light intensities were adjusted based on three target electron transport rates (ETR) (55, 90, and 125 $\mu mol \cdot m^{-2} \cdot s^{-1}$), and each target ETR was maintained for 18 hours per day with four replicates. Lettuce (*Lactuca sativa*) 'Green Towers' plants were used and harvested two weeks after the start of the ETR treatments. The BFB system could maintain the three target ETRs accurately throughout the whole growth period and adjust LED light intensities automatically in real-time. To maintain ETRs of 55, 90, and 125 $\mu mol \cdot m^{-2} \cdot s^{-1}$, the LED light intensities were maintained as 184, 316, and 457 $\mu mol \cdot m^{-2} \cdot s^{-1}$ on average, respectively. During the growing period, plants under 125 $\mu mol \cdot m^{-2} \cdot s^{-1}$ ETR treatment acclimated physiologically and morphologically to the high light conditions. At the end of the experiment, plants from all ETR treatments had a fairly similar quantum yield of photosystem II (φPSII) (0.68 – 0.70), despite a wide range of light intensities (180 – 460 $\mu mol \cdot m^{-2} \cdot s^{-1}$). Additionally, the plants under 125 $\mu mol \cdot m^{-2} \cdot s^{-1}$ ETR treatment had thicker leaves, higher chlorophyll content, and lower light use efficiency (shoot dry weight / total incident light). This study suggests that the BFB system is an accurate, reliable, and efficient lighting control system to grow lettuce plants from seedling to harvest stage. This indicates the feasibility of the BFB system for long-term use in controlled environment agriculture.

Keywords: controlled environment agriculture, artificial lighting, chlorophyll fluorescence, biofeedback system, quantum yield of photosystem II, electron transport rate, light use efficiency.

OS03-07

Growth comparison of corn salad and frill lettuce under the same environmental conditions with artificial light

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Plant factory with artificial light (PFAL) is a plant production system that became popular for fresh-consuming vegetables. Lettuce (*Lactuca sativa* L) is commercially the most popular crop cultivated in the PFAL system. However, the market demand for a variety of vegetable categories is increasing. Corn salad (*Valerianella locusta* L. Laterr.) is a leafy green vegetable originally grown in Europe, contains three times higher vitamin C than lettuce, and is rich in beta-carotene, vitamin B6, iron, and potassium. Corn salad is considered one of the emerging vegetable categories for fresh consumption. In practice, corn salad is grown in open field or greenhouses, while its growth characteristics are unclear when it is cultivated in the PFAL. This study compared the growth characteristics, including relative growth rate (RGR), of corn salad and frill lettuce in a PFAL. Fresh and dry weights, leaf number, SPAD, leaf area, and RGR were measured and analyzed. The results show that the lettuce grew faster than corn salad under the same cultivation condition, and corn salad needs double time to obtain the same yield (such as 60g/plant). However, corn salad plants contained higher chlorophyll and less water than lettuce.

Keywords: plant factory, leafy greens, relative growth rate, yield, growth characteristics

OS03-08

Utilizing light exposure to its fullest: how light quality can aid biocontrol introduction in greenhouse horticulture

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The use of LED lighting in controlled environmental agriculture is a necessity for regions that require supplemental light for greenhouse-grown crops. In contrast to plants, the native and non-native microbiota's response to environmental light (wavelength, irradiation, day length) has not received much attention. Light energy has the capacity to modulate major aspects of the physiology of an organism, as it is a strong environmental factor. In an effort to enable a better establishment of biocontrol agents, an appropriate light-quality application could be the key to their success. This could change how they are applied and lead to a more integrated pest control measure. By tailoring the choice of light quality and an external carbon source, we studied the introduction of *Pseudomonas choloraphis* in the phyllosphere of greenhouse-grown tomatoes. A detached leaf assay was conducted using several carbon sources and wavelengths. The results indicate that for a successful biocontrol

agent (BCA) establishment on plant canopies, the light environment is an essential feature. Assisted by different carbon sources in combination with light, BCA efficacy may be enhanced.

Keywords: biocontrol agents, controlled environment agriculture, LED, pathogens, Pseudomonas chlororaphis, tomatoes.

ORAL SESSION 4 / Plant factory and vertical farming I

OS04-01

Vertical farming: beyond the hype

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OS04-02

Development of a novel crop cultivation system with environmental and crop monitoring functions for a lunar-base plant factory

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Crop production and resource recycling, in a lunar-base plant factory/vertical farm are the key components of a food supply system to support long-term human colonization on the moon. Eight candidate food crops, namely rice, soybean, potato, sweet potato, tomato, strawberry, cucumber, and lettuce are selected based on nutritional requirements. A closed-type crop production system equipped with a cultivation shelf is developed to evaluate the photosynthesis, transpiration, respiration, and nutrient ion absorption capacities of the crops, and monitor the electric energy consumption of the operation. The system comprises an elevated air-tight cultivation shelf, air conditioning unit, air current control device, LED lamps, hydroponic container, and crop data acquisition subsystem. The dimensions of the shelf are 260 cm (width) and 60 cm (depth). The height of the shelf types A (eight shelves) and B (four shelves) are 60 cm for short crops and 120 cm for tall crops, respectively. The space in the cultivation shelf is minimized to maintain a high space-utilization efficiency. The velocity of the air current flowing through the crop canopy is regulated at 0.1–0.8 m s^{-1} using the air current control device. The LED lamps provide a maximum PPFD of 800 $\mu mol \cdot m^{-2} \cdot s^{-1}$ at each crop cultivation panel. The crop data acquisition subsystem continuously measures the CO_2 and H_2O concentrations at the inlet and outlet of the shelves, and calculates the photosynthetic, respiration, and transpiration rates in the crop canopy at a given interval. It also calculates the energy consumption of the operation. The nutrient ion absorption capacity of the crops is estimated using offline ion

chromatography. Remote cameras are incorporated in the crop data acquisition subsystem for real-time monitoring and analysis of parameters such as the number of leaves and flowers and the leaf area of crops at 1-h intervals.

Keywords: Energy and material balances, photosynthetic rate, space agriculture, transpiration rate

OS04-03

Research and application of plant factory technology on precise control of selenium in vegetables

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Selenium (Se) is an essential trace element for human health. For adults (≥18 years), the recommended nutrient intake (RNI) of Se for both genders in Chinese populations is 60 μg per day. Dietary deficiency of Se in humans is associated with an increased risk of death, hypoimmunity, and cognitive decline, while excess Se supplementation may cause toxicity as Se is involved in the generation of reactive oxygen species and oxidation of thiol compounds, which can lead to oxidative damage in cells. Therefore, a suitable dietary source of Se supplementation containing appropriate levels of this element could be beneficial for human health. To ensure safe and effective intake of Se, several issues need to be addressed, including 1) how to improve the accumulation of seleno-amino acids (Se-AAs), and 2) how to control the total Se and Se-AAs contents in vegetables. The combined use of plant factories with artificial lighting (PFAL) and multiple analytical technologies may help to resolve these issues. Moreover, we propose a Precise Control of Selenium Content (PCSC) production system, which has the potential to produce vegetables with specified amounts of Se and high proportions of Se-AAs.

Keywords: plant factory, precise control, selenium metabolism, seleno-amino acids, vegetables and mushrooms.

OS04-04

Analysis on the air-conditioning system to enhance the uniformity in a multi-layer vertical farm under tropical climate condition

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Urban farming is a promising methodology for food production and can be a desirable solution for environmental issues such as population growth, urbanization, and food security. Furthermore, it is also expected to satisfy the need for high-value fresh food for

modern citizens. A multi-layer indoor vertical farm can be a reasonable solution for urban farming in terms of high productivity, efficient land usage, and consistent production throughout the year, regardless of outdoor climate conditions. Using the vertical farm, there has been an attempt in Indonesia to cultivate strawberries as a high value crop. However, it is not easy to cultivate low-temperature crops like strawberries in Indonesia's hot and humid climate. The cultivating conditions with high cooling loads can be achieved by using cooling systems with room air-conditioners and unit coolers. For securing the quality of products, environmental conditions, such as temperature, humidity, CO_2 concentration, and velocity around products, should be uniformly distributed under the reasonable range. In this study, we focused on the effect of global flow by air-conditioning system on the uniformity inside the vertical farm cultivating strawberries in Indonesia, which was aimed at understanding the thermodynamic characteristics of the system optimization. CFD model was developed for this research and validated by the experiments using a container farm which consists of the multi-layer production system, LEDs, fans, and air-conditioning system for cooling and heating with multiple sensors measuring the internal temperature, CO_2 concentrations, humidity, and velocity. Based on the validated model, the parametric study has been conducted with variations of air-conditioning flow design, such as the area and the positions of the inlets and outlets of the air-conditioning system. Through the understanding, the optimized air-conditioning flow design can be developed on the multi-variable space using the response surface method in order to optimally improve flow uniformity under several constraints on temperature, humidity, and velocity. It is expected that efficient cultivation of low-temperature crops under tropical climate conditions can be achieved with the improved uniformity inside the vertical farm through this study.

Keywords: Vertical farm, tropical climate condition, air-conditioning, uniformity

OS04-05

Effects of LED Red and Blue Light Component on Growth and Photosynthetic Characteristics of Coriander in Plant Factory

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Coriander is a whole-plant edible micro vegetable frequently used in the food industry. Its fresh eating features give it a flavor that is both tasty and refreshing, as well as potentially dangerous due to the bacteria (e.g., *Shigella sonnei*) it may contain. Artificial light-based plant factories are becoming increasingly popular due to the development of light-emitting diodes (i.e., LEDs). These plant factories employ artificial light to recreate the ideal lighting conditions for photosynthesis, ensuring plant yield and safety. Red (R) light and blue (B) light are essential for crop development and photosynthesis because R light and B light correspond to the wavelength absorption peaks of chlorophyll. However, the sensitivity of various crops to the light of varying wavelengths varies. Here, we determined the ideal R to

B light ratio for cultivating coriander in plant factories by evaluating the photosynthetic characteristics of coriander ('Sumai') under different red–blue ratios. Specifically, we used monochrome red (R) and blue (B) light as controls and evaluated a total of seven different ratio treatments of R and B light (R, R:B = 5:1 (R5B1), R:B = 3:1 (R3B1), R:B = 1:1 (R1B1), R:B = 1:3 (R1B3), R:B = 1:5 (R1B5), B) under the background of uniform light intensity (200 ± 10 μmol m^{-2} s^{-1}) and photoperiod (16-h/8-h light/dark). The results showed that the total yield of R:B = 3:1 (R3B1) was 16.11% and 30.61% higher than monochrome R and B treatments, respectively, the photosynthetic rate (Pn) and stomatal density were increased, and the nitrate content was decreased. Monochromatic light has adverse effects on crops. Monochromatic R light reduces the CO_2 assimilation amount. Monochromatic blue light treatment lowers chlorophyll concentration and net photosynthetic rate.

Keywords: Coriander; Artificial lighting; Photosynthetic characteristics; Stomatal development.

OS04-06

Adjustment of equipment operation in a plant factory under solar power generation

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Although a plant factory with a photovoltaic power-generation system requires a substantial initial investment outlay, the amount of electricity subsequently purchased is significantly reduced and surplus electricity can be sold to the main grid, thus contributing to the demand response. However, given that solar power generation depends on the weather and the storage capacity of batteries is limited, it is necessary to control the operation of LEDs and other equipment during hours when there is a shortage or surplus of electricity. Conventional plant factories assume an ideal environment for plant growth. However, no research has been conducted on how to maintain rapid plant growth with regulated power consumption in a plant factory in response to solar power generation. Our objective is to establish a method to operate a plant factory using only solar power as much as possible by adjusting power consumption through operational control of LEDs, air conditioners, and culture-medium circulation pumps. When LED lighting was stopped for 4 days, leafy crops showed physiological disorders. These disorders could be suppressed by using battery-stored power to operate blue and red LED lighting at low intensity. When LED lighting and air conditioning were stopped simultaneously to reduce power consumption, the heat stored by the LED devices caused the air temperature to rise, which in turn caused condensation. Therefore, it is suggested that the shutdown of the air conditioner should be delayed in relation to the

shutdown of the LED lighting. When the culture-medium circulation pump was stopped, the dissolved oxygen concentration in the culture medium decreased. Therefore, it was indicated that the pump should be operated at regular intervals to supply oxygen to the roots. Based on these findings, we have developed a plant-factory energy management system (PEMS) to control the operation of each device.

Keywords: lettuce, energy management system, photovoltaic power generation.

OS04-07

Lettuce plant morphology and nutrient solution physiochemical properties in response to the recycled nutrient solution in a plant factory with artificial light

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The recycling of nutrient solution is a common practice in protected horticulture and is used to save water and nutrients. However, a reduction in plant growth and yield was often reported as variations in physiochemical properties of nutrient solution. To improve the efficiency of nutrient solution recycling, plant growth and morphology, nutrient element composition, and water use efficiency were analyzed and quantified in lettuce (*Lactuca sativa* L.) plants grown with recycled nutrient solution. The experiment included three cultivation periods (each with 21 days). The three cultivation periods were recorded as nutrient solution used for one (U_1), two (U_2), or three consecutive production cycles (U_3). The results indicated that: 1) the fresh weight of lettuce grown under treatment U_1 was 45.7% and 77.7% higher than that under treatments U_2 and U_3, respectively; 2) the number of leaves was unaffected by the number of nutrient solution cycles, with mature leaves accounting for 82.5%, 79.6%, and 78.6% of total fresh leaf weight under treatments U_1, U_2, and U_3, respectively; 3) lettuce leaves became smaller and flatter. The root length increased as the number of nutrient solution cycles increased; 4) concentrations of NH_4^+-N, NO_3^--N, phosphorus, potassium, and iron decreased, while concentrations of calcium, magnesium, and sulfur increased as the number of nutrient solution cycles increased; 5) instantaneous water use efficiency decreased, while the actual water use efficiency increased as the number of nutrient solution cycles increased. These results indicate that the reduction in lettuce yield was mainly because of the decrease in concentrations of NH_4^+-N, NO_3-N, phosphorus, potassium, and iron, and by the decrease in the weight of mature leaves as affected by recycling of nutrient solution. It can be a feasible way to improve the efficiency of nutrient solution recycling by enhancing the concentrations of NH_4^+-N, NO_3^--N, phosphorus, potassium, and iron in replenisher.

Keywords: recycled nutrient solution; nutrient stress; growth model; source-sink; WUE; leaf morphology.

ORAL SESSION 5 / Climate control and modeling II

OS05-01

Dimensioning the reverse osmosis desalination system for a tomato greenhouse using the SIOM simulation software

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A proper design for any greenhouse project aims at covering the heating, cooling, and dehumidification needs of the greenhouse with minimal use of resources. This is even more critical when resources are under scarcity, such as water in arid and semi-arid areas. In addition, during the greenhouse design, the lack of data regarding the water flows for different processes results in the over-dimensioning of systems related to water management or in options that cannot adequately cover the specific needs.

Water desalination systems such as reverse osmosis (RO) are often used in greenhouse projects to improve irrigation water quality and/or to supply low-salt water to a high-pressure fogging system used for evaporative cooling and humidification. This study presents a methodology for selecting the capacity of a reverse osmosis desalination system in combination with water storage tanks required. The simulations were done using the SIOM simulation software developed by TNO in collaboration with the Hortivation Foundation. Calculations were made for three different areas and different scenarios related to the quality of the available water and the use of RO water, which could be for irrigation, and/or to feed the high-pressure fogging system used for cooling and/or humidification. The simulation software, taking into account the operational characteristics of the RO system and the water requirements for different processes, calculates for every hour the amount of water recovered from the RO system, the water rejected, the electricity consumption of the system, the water required to clean the filters and the volume of water stored in the water tanks.

The results of the simulations showed that the quality of the available water is the determining factor for the selection of the RO system because it is directly related to the potential recovery ratio of clean water from the system. The operating time per day significantly affects the volume of tanks required to store clean water for each process. The use of the SIOM simulation software proves to be particularly useful when analysis of different scenarios is required for the selection of a desalination system such as a RO system.

Keywords: water management, scenario analysis, irrigation, high pressure fogging, climate control strategies, greenhouse simulation.

OS05-02

Towards a modeling and control approach based on the drying product in greenhouses

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The dryer's control has focused on conditioning the air to dehydrate the products; however, few have been studied about the product during the dehydration process. The central assumption is the thermal equilibrium between the air and product temperatures. Still, the presence of water in the product generates a temperature difference, given the heat exchange between both elements. Two control conditions for a greenhouse-type solar dryer were studied; the first was based on the air temperature, and the second was on the product temperature, using tomato as the product to be dehydrated and as actuators the greenhouse exhaust fans. It was found that using an on/off control based on the product temperature resulted in an advantage by allowing the air temperature to be as high as possible before the slice reached the desired temperature. Given the internal or external greenhouse environment, the product-based approach could bring discussions on how to carry out the measurements and establish future control strategies and product modeling. We designed control strategies based on model predictive control using the previous result. A reduction in exhaust fans activation time was found through simulations compared to an on/off controller.

Keywords: modeling, tomato drying, greenhouse dryer, MPC.

OS05-03

Combining plant sensor measurements and decision tree analysis to better understand the 'plant stress-reducing ventilation' strategy in greenhouses

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In spring and summer, tomato plants grown in greenhouses often experience high levels of irradiation and vapor pressure deficit during the day. On such hot days, resulting high transpiration rates greatly deplete the internal water storage pools (i.e., living cells) of the plant, which gives the plant higher daily stress and may result in irreversible plant or fruit damage. To assist the plant in replenishing its internal water storage pools more quickly, Belgian and Dutch greenhouse farmers apply a specific ventilation strategy, which we titled the 'plant stress-reducing ventilation' strategy.

This is a commonly used, though scientifically largely understudied technique in greenhouse cultivation, which means that there are no ground rules yet. This makes the strategy difficult

to master, leaving growers divided on its effectiveness. To better understand and quantify the effects of the stress-reducing ventilation strategy, we equipped tomato plants (*Solanum lycopersicum* L.) in a commercial Belgian greenhouse with sap flow and stem diameter variation sensors to continuously measure the plant response during application of the technique. Climate and greenhouse control data were taken from the greenhouse climate computer. The data from the plant sensors were used to quantify the plant response. This response was classified and used to generate a decision tree using machine learning. The decision tree algorithm pointed to the most important factors affecting the plant's stress-reduction response when applying the technique. Our approach included plant sensor measurements in a decision tree algorithm for climate control, which appeared to be crucial for fundamental interpretation of the in practice often used and now physiologically better understood 'plant stress-reducing ventilation' strategy.

Keywords: tomato, greenhouse climate control, machine learning, plant sensors, sap flow, stem diameter variation, plant stress-reducing ventilation strategy.

OS05-04

Effect of shading in evaporatively cooled greenhouses in the Mediterranean region

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Greenhouse ventilation is an effective way to remove the extra heat from the greenhouse through air exchange between inside and outside, when outside air temperature is lower. However, in the Mediterranean areas during summer, most of the day the outside air temperature reaches values above 25 C; and natural ventilation can not remove the excess heat outside the greenhouse. Shade screens and whitewash are major existing measures used to reduce the greenhouse air temperature during summer by reducing the solar radiation entering the greenhouse. However, the greenhouse air temperature is reduced with a cost in radiation reduction. In addition, due to high air temperature values outside the greenhouse, generally these systems are not sufficient for extracting the excess energy during sunny summer days and therefore, other cooling methods such as forced ventilation combined with evaporative cooling are needed. Evaporative cooling by means of pad and fan or fog systems is a common technique to reduce sensible heat load by increasing the latent heat fraction of dissipated energy. In most of the cases the greenhouse growers, when all the above systems are available, apply both shading and evaporative cooling. If a movable screen is available, then the screen is usually activated when a certain radiation level is reached. It is not clear whether the shading screens should be used over the growth cycle or only during the most sensitive stages when the crops had a low leaf area and the canopy transpiration rate cannot significantly contribute to the greenhouse cooling. Furthermore, it is not clear which is the optimum radiation level that screen must be

activated. This work aims to present the microclimate and cucumber crop physiological response and yield observed in two greenhouse compartments equipped with a pad and fan evaporative cooling system and a thermal/shading screen that is activated at different radiation levels: when the outside solar radiation reaches 700 or 900 W/m^2. The greenhouse is located in Velestino, in Central Greece and the measurements are performed during the spring –summer period with the outside air temperature during summer reaching values up to 42C.

Keywords: microclimate; shading screen; pad and fan; cucumber.

OS05-05

Light fluctuations affect morphological and physiological processes and biomass in tomato

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Greenhouse horticulture plays an important role in the year-round production of fresh and healthy fruit and vegetables. However, the sector faces the challenge of reducing energy consumption in order to reduce CO_2 emissions. Since the autumn of 2021, the prices of electricity and gas have risen sharply, which further reinforces the urgency of reducing energy consumption. Energy costs can be reduced by reducing the amount of electricity for lighting, but also the timing, since electricity prices fluctuate depending on the availability of solar or wind energy. However, a fluctuating lighting regime might affect plant growth and development. In this study, we cultivated young tomato plants under constant and fluctuating lighting regimes, where both frequency and amplitude was varied. Light intensity was kept constant at 100 µmol·m^{-2}·s^{-1} or varied 125/75, 175/25 and 200/0 µmol·m^{-2}·s^{-1} at frequencies of hours, 30 min or minutes. Plant biomass after 23 days was significantly reduced when light intensities of 200/0 µmol·m^{-2}·s^{-1} were applied, regardless of the frequency. Chlorophyll content, leaf light absorption and photosynthesis were also reduced. Light intensity amplitudes of 125/75 and 175/25 µmol·m^{-2}·s^{-1} did not affect biomass, chlorophyll content and photosynthesis rates significantly. These results indicate that plants can be grown under fluctuating light intensities without negative consequences, as long as no dark periods occur in these fluctuations.

Keywords: fluctuating light conditions, LED lighting, photosynthesis, light absorption characteristics, tomato.

OS05-06

Application of solar water circulation heating system in Chinese solar greenhouse

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Chinese solar greenhouse is a special horticultural facility in China, which has the characteristics of good thermal insulation, low cost and energy saving, and makes a significant contribution to the production of fruits and vegetables in China. Because the northern regions of China is cold in winter, it is difficult for traditional solar greenhouse to meet the temperature demand of thermophilous vegetables without heating. The northern regions of China are relatively rich in solar energy resources. If the redundant indoor solar radiation heat in daytime can be effectively collected for heating at night, it is undoubtedly a low-carbon measure to solve the problem of indoor low temperature at night. To solve the above problems, this study developed a low cost, high efficiency, pollution-free solar water circulation heating system, and tested indoor temperature distribution in a experimental greenhouse. The results show that the heating system has a good effect on heat collection efficiency and heating performance, and can effectively realize the transfer and utilization of solar radiation heat in time and space. In cold regions, the heating system can raise the minimum temperature by more than 3.0°C at night. The warm water obtained by absorbing heat in the daytime operation of the system can be used for irrigation, effectively raising the soil temperature. This study provides theoretical methods and technical guidance for the overwintering production of solar greenhouses in cold northern regions of China.

Keywords: Chinese solar greenhouse, Solar energy, Heating, Water, Thermal performance.

ORAL SESSION 6 / Greenhouse crops modeling and management modelling II

OS06-01

Evaluation of the VegSyst-DSS for the management of nutrients in fertigation of a soil-grown tomato crop in Mediterranean greenhouses

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The new software tool VegSyst-DSS (v2) provides recommendations of the concentration of N, P, K, Ca and Mg in the fertigation nutrient solution for vegetable crops grown in soil in plastic greenhouses. These recommendations are based on modelled crop nutrient uptake and the amounts of available nutrients in the soil. One application of this tool is its use for prescriptive-corrective fertilizer management, combining the DSS recommendations with in-situ nutrient analyses in plant and/or soil to verify or correct inputs. A demonstration trial

of the combined use of VegSyst-DSS and nutritional monitoring was conducted to validate this management system in a greenhouse tomato crop under representative conditions of commercial greenhouse production in Almeria, Spain. The trial was conducted in a plastic greenhouse with a tomato crop grown in soil with an autumn-spring growing cycle. Two fertigation treatments were applied, a conventional treatment with nutrient applications representative of the area and a DSS treatment with prescriptive-corrective management of the macronutrients N, P, K. In the DSS treatment, the applied concentrations of N, P and K were those recommended by VegSyst-DSS, and fortnightly petiole sap analyses were conducted for corrective management. In the DSS treatment, the resultant applications of N and K were 60% of those applied in the conventional treatment. The application of P was only 15% of the conventional treatment due to the high available (Olsen) P content in the soil. Corrective adjustments of N and P were conducted in the final phase of the cycle when it was observed that the concentrations of these nutrients in sap were below critical values. There were no differences between treatments in fruit production or fruit quality. These results show that under the conditions of this study prescriptive-corrective fertigation management based on the VegSyst-DSS enabled a considerable saving in N, P and K inputs in greenhouse tomato without compromising production. These fertilizer savings represent a significant reduction in costs and likely environmental impact.

Keywords: models, fertilization, environmental impact, crop nutrition.

OS06-02

Exploring the Potential of YOLOv8 for Real-time Strawberry Flower Detection in Greenhouses

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In greenhouse cultivation, flower monitoring is a critical practice to evaluate the growth status of crops. Flowers, regarded as crucial organs during the entire cultivation period and turning into fruits following fertilization, serve as visible indicators of how actively crops are growing during the generative growth phase, as well as predictors of the potential yield. For strawberry flowers, monitoring is both labor and cost-intensive due to their small size and often overlap with neighboring flowers and leaves. Therefore, without the assistance of an automated vision-based detection, monitoring tasks cannot be carried out as frequently as the importance of flowers requires. Recently, with the application of computer vision techniques in agriculture, sophisticated algorithms for object detection have emerged as a viable solution. One of the well-known object detection algorithms is YOLO, which has been continuously developed since its first release in 2016. The latest version, YOLOv8, which was introduced in 2023, has yet to be assessed for strawberry flower detection. In this study, three scaled YOLOv8 models – nano, small, and medium – were trained and tested on a strawberry flower dataset collected from a greenhouse to evaluate their suitability for agricultural datasets. Regarding flower detection performance, the mean average precision (mAP) for nano, small, and medium-scaled models was 97.9, 97.8, and 98.3, respectively. The

respective inference time per image for nano, small, and medium-scaled models was 6.1 ms, 6.4 ms, and 8.3 ms. During model setup, the GPU utilization was consistently at around 13%, while in the inference phase, it was 2%, 3%, and 6% for the nano, small, and medium-scaled models, respectively. In conclusion, this study has demonstrated the potential of YOLOv8 for strawberry flower detection. The results show that YOLOv8 provides a viable solution for strawberry flower detection in greenhouses.

Keywords: YOLOv8, multi-scaled, strawberry flower, object detection

OS06-03

Controlled Environment Cannabis Cultivation: Current Status, Challenges and Future Trends

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The rapid spread of legalization of *Cannabis sativa* (cannabis) cultivation and utilization for medical and recreational purposes in regions across the world has made it an economically and socially important crop. Controlled environment (CE) can provide optimized growing conditions and produce plant material with consistent high quality and yield; therefore, it has been a top choice when come to cannabis cultivation for medicinal and recreational purposes. Cannabis was legalized in Canada for medical use in 2001 and for recreational use in 2018, which made Canada the first developed country, and the second country after Uruguay, in the world to legalize cannabis for recreational use. In the last decade, Canada's CE cannabis industry has experienced booming, companies merging and consolidation, and currently struggling. This presentation will use Canada as an example to explore the current status, challenges and future trends of the CE cannabis cultivation industry in the world. It will also provide an overview of our CE cannabis cultivation research over the last decade to focus on lighting (light intensity, spectrum and photoperiod) and rootzone management (e.g., growing media, irrigation and fertilization) in cannabis cultivation.

Keywords: cannabis, controlled environment agriculture, fertilization, integrated rootzone management (IRM), light intensity, photoperiod, UV.

OS06-04

Use of marble gravel mulching for tomato production inside a Mediterranean naturally ventilated solar greenhouse

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The albedo, or fraction of incident solar radiation reflected by a surface, influences the availability of shortwave radiation and the energy balance on this surface. In the case of greenhouses, soil albedo can affect the microclimate and production. Gravel mulching has

been widely used in agriculture to reduce surface evaporation from the soil. The traditional '*arenado*' sand mulching inside greenhouse of Almeria (Spain), allows to increase the shortwave radiation reflected towards the plants. White plastic mulching is also used in greenhouses to increase the available light during periods of low radiation and thus benefit plant growth. Black mulching is used to increase solar absorption and increase soil and air temperatures in cold periods. With the objective of reduce solar radiation absorbed by the soil and avoid the reflection of direct radiation, in September 2022 a white marble gravel mulch was installed in the western half of a multispan greenhouse in Almería, with a tomato crop inside. In the East sector, a black polypropylene plastic mulching was maintained and cover was whitewashed. In the West sector, a weaker whitewashing was carried out that allowed to have 10% more photosynthetic active radiation (PAR). The increase of radiation reflection, from the 11% produced with the plastic black mulching to the 44% obtained with the marble mulching, allowed reducing 10% the net radiation at 2 m height. As consequence, the PAR radiation was increase at the level of the tomato leaves while maintaining the same temperature of the air and the plants. Photosynthetic activity was 25.9% higher in plants with the marble gravel mulching (3.0 µmol CO_2 $m^{-2}{\cdot}s^{-1}$) compared to the standard black polypropylene mulching (2.4 µmol CO_2 $m^{-2}{\cdot}s^{-1}$). As consequence, cumulated marketable tomato yield was 4.3% greater with the marble gravel mulching (5.02 kg/m^2) compared to the standard black mulching (4.82 kg/m^2).

Keywords: white marble gravel mulch; tomato crop; whitewashing; radiation transfer; natural ventilation.

OS06-05

Effects of Rooting Hormone, Light, and Carbone Dioxide Enrichment on the Rooting of *Cannabis sativa* Cuttings

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The production of *Cannabis sativa* for medicinal and recreational use is projected to increase due to its legalization in the US. Asexual propagation from vegetative plant cuttings is one of the main strategies to maintain consistent yields and quality. However, recommendations for optimal propagation are limited and can vary. Therefore, the objective of this research was to study the effects of three factors (three experiments) affecting root development: 1) IBA-auxin (rooting hormone), 2) light intensity, and 3) CO_2 concentration on the rooting of cuttings of *Cannabis sativa* under controlled environment conditions. The cultivar 'Suver Haze' was used to evaluate the three rooting factors, while three additional cultivars (all high CBD chemotypes) were added to the CO_2 experiment. In experiment 1, the IBA treatments were 0 or 4500 ppm, and the experiment was carried out in a greenhouse with a misting system and 18 h photoperiod. Experiments 2 and 3 were done in custom rooting chambers. In experiment 2, the light treatments were 51, 101, or 200 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ PPFD, while in experiment 3 the CO_2 levels were 464 or 1041 $\mu mol{\cdot}mol^{-1}$. The three experiments were carried out for two weeks. In experiment 1, IBA increased root dry mass 2.6x when compared to no-IBA (no-IBA: 14.7 and IBA: 38.5 mg per plant). In experiment 2, the increase in light intensity linearly increased root dry mass. For

example, the light increase from 52 to 200 μmol·m^{-2}·s^{-1} increased root dry mass 4x from 22.5 to 80.5 mg, respectively. In experiment 3, CO_2 enrichment increased root growth of the four cultivars by an average of 20%, or 86.7 and 104.2 mg of dry root per plant for 464 and 1041 μmol·mol^{-1} treatments, respectively. These results indicate that the rooting of *Cannabis sativa* cuttings can be drastically increased under optimal conditions.

Keywords: Cannabis, propagation, LED, vertical farm.

OS06-06

Fine dust reduction system in agricultural facilities for worker's respiratory safety

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The peach sorting stations have been operated by mechanical and closed ventilation systems and are enclosed to reduce the influence of the external environment. Internal air in the station has a high concentration of fine dust, including peach fuzz, organic dust, and agricultural chemicals resulting in a high possibility of allergies and respiratory diseases. Developing a fine dust reduction system is necessary to improve the worker's respiratory safety. This study aims to develop a fine dust reduction system and to analyze the effect in the peach sorting station. Using an optical particle counter, the concentration of fine dust before and after operating the fine dust reduction system and inside the facility was monitored. Fine dust monitoring was performed in the working area and the non-working area in the same enclosed facility at the same time. As a result, fine dust with a particle size of over 10 μm was mainly generated, and the concentration of fine dust was, on average, 6.89 times higher in the working area than in the non-working area. The fine dust reduction system makes a descending airflow to prevent fine dust from reaching the worker's respiratory system and prevent the fine dust from re-scattering through the wet dust removal parts. The effect of the fine dust reduction system, the concentration of TSP was reduced by 87.9%.

Keywords: Agricultural facilities, Dust reduction system, Fine dust, Worker respiratory safety.

ORAL SESSION 7 / Covering materials

OS07-01

Impact of Insect Proof Nets on the Microclimate and on the Risks of Fungal Development inside a Greenhouse Crop

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In France, unheated greenhouses cover an area of more than 7000 hectares. They allow the production of ornamental plants, fruits, and vegetables with high added value. In summer, it is

important to open the greenhouse during the day to promote ventilation and avoid excessive temperatures. These conditions can however be favorable to the penetration and proliferation of insect pests inside the shelters. In Mediterranean regions, where pest pressure is more important, insect-proof nets are quite often used. They allow for the reduction of the pressure of pests and represent an alternative and complementary strategy to diminish phytosanitary treatments. However, nets also limit ventilation and thus increase the confinement of crops, inducing an increase in temperature and hygrometry that can be responsible for the physiological blockade of plants and enhanced fungal risks. To evaluate the influences of these phenomena, two tunnels with and without Insect Proof nets were studied. The vertical heterogeneity and differences in temperature and hygrometry were assessed. In both compartments, a vertical gradient of temperature and humidity among the different heights of the greenhouse was observed. Indeed, warmer and drier air was present above and below the canopy during the day, whereas it became colder and more humid in the evening. Nevertheless, at a location close to the plant canopy, non-significant differences in temperature and humidity were found between both tunnels. In addition, a dew temperature analysis was performed to highlight the periods of risk of condensation, which is an important factor that can increase the development of most fungal agents. The risk of condensation appeared to be more important in the canopy and in the compartment with insect-proof nets.

Keywords: unheated greenhouse, temperature, hygrometry, insect proof nets, fungal agents, condensation.

OS07-02

Solar spectrum modification by luminescent agriculture films for enhanced light use efficiency in greenhouse plant trials

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Modifying the spectral quality of light provided to crops grown in controlled environments has been shown to have a large influence on plant development in terms of plant morphology and photosynthetic efficiency. While the majority of research focused on light quality have been conducted with LEDs in growth chambers, these findings are limited to applications such as vertical farming or supplemental lighting that are added to greenhouses for use in low-light conditions. In this work, a new luminescent film technology has been developed that passively modifies the solar spectrum to reduce blue wavelengths and enhancing the red wavelengths of sunlight through a photoconversion process. This technology utilizes a nanotechnology called quantum dots to offer a sustainable option for enhanced light quality in greenhouse applications that doesn't require electricity and instead relies on the power of the sun. Greenhouse plant trials were conducted under luminescent agriculture films that were installed over crops and the growth metrics were compared to crops grown under a clear control film that did not modify the solar spectrum. Both

vegetative and harvest metrics are measured and compared as well as improvements in light use efficiency are discussed. Future applications for quantum dot agriculture films will also be presented based on the findings from these greenhouse trials.

Keywords: Quantum dots, luminescence, light use efficiency, controlled environment agriculture, agriculture film, nanotechnology.

OS07-03

Implementing of Semi-transparent Organic Photovoltaic Modules in a Tomato Greenhouse

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This study examines the potential of using semi-transparent organic photovoltaic (OPV) modules in a greenhouse with a tomato crop to increase renewable energy production in agriculture. The flexibility, potential for lower manufacturing and installation costs, the tunable spectrum of radiation transmission, and OPV recyclability make it a promising approach for integration in greenhouses**.** In the last three years, an extensive experimental study was carried out on OPV modules installed above the canopy in small and large greenhouses (24 and 131 m^2 floor area). The modules examined had about 30% transmittance, 15% reflectance, and 55% absorptance of solar radiation. The peak power conversion efficiency was approximately in the range of 2 – 3.4%. High efficiencies were mainly observed in the morning or under days with high diffuse radiation. The temperature of the modules heated up to approximately 50–60°C at midday. Thermal images of the modules revealed non-uniform temperature distribution, with differences of 5 – 10°C between regions. The level of diffuse radiation in the global solar radiation affected the temperature of the modules. There was no statistically significant difference in the mean seasonal air temperature and humidity between the OPV and control greenhouses. The nonhomogeneous shading by OPVs did not affect the greenhouse's spatial variability of temperature and humidity. In the winter season, the accumulated yield was higher in the control greenhouse than in the greenhouses with OPV modules by about 10-15%. There were no significant differences among the greenhouses concerning the total soluble solids of the tomatoes. Neither did we observe differences among the greenhouses with respect to total acidity. Yet the absolute acidity values decreased during the growing season in all greenhouses.

Keywords: Agrivoltaics, OPV Greenhouse, Solar spectral distribution, microclimate control.

OS07-04

Lettuce Photosynthesis and Light Response Curves under Semi-transparent Solar Cells

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Greenhouses are substantial energy consuming structures. Costs and ecological footprints of greenhouses are large. In collaboration with the University of Georgia's Physics department, we have taken their research on semi-transparent perovskite solar cells to the agricultural level. They supply us with different semi-transparent perovskite solar cell samples to examine plant physiology under them. The goal is to see how beneficial these panels would be to use on greenhouses. The solar cells are lead halide perovskites. We are testing various combinations of the iodide and bromide perovskites. Those combinations are $MAPbI_3$, $MAPbI_{2.5}Br_{0.5}$, $MAPbI_2Br$, $MAPbI_{1.5}Br_{1.5}$, $MAPbIBr_2$, $MAPbI_{0.5}Br_{2.5}$, and $MAPbBr_3$. A CIRAS-3 photosynthesis analyzer by PP Systems is being used to quantify assimilation rate of 'Green Towers' lettuce under these samples. An LED fixture sits over a lettuce plant. PPFD ($\mu mol \cdot m^{-2} \cdot s^{-1}$) of the LED fixture begins at the lowest value possible, around 20 $\mu mol \cdot m^{-2} \cdot s^{-1}$. The PPFD was doubled each time until the limit of the LED fixture, which was around 1700 $\mu mol \cdot m^{-2} \cdot s^{-1}$. Six replications are done. $MAPbI_3$ has been the only one tested so far. Light response curves were surprising in that plants photosynthesized slightly more efficiently under the $MAPbI_3$ samples than the control. The transmittance showed $MAPbI_3$ passing more red and far-red light than blue light. Speculation on the performance of the plants under $MAPbI_3$ might be a synergistic light effect with far-red light and how $MAPbI_3$ blocks more blue light. Red and far-red light are used more efficiently by plants for photosynthesis. Building off these results, we will create more light response curves for lettuce under the other perovskite compounds listed above. Our hope is to show that plants will perform well with these solar cells embedded in greenhouses, while producing energy.

Keywords: Photovoltaic panel, Sustainable production, Plant physiology, Greenhouses, Perovskite.

OS07-05

Economic analysis of a photovoltaic field on a greenhouse roof

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Greenhouses are known for providing appropriate climatic conditions to enhance crop growth, which is also dependant of the solar radiation available. On the other hand, photovoltaic technology is an environmentally friendly (and profitable) way of generating power in places with a certain amount of sunlight per year. The purpose of this work is to analyse the profitability of a facility that consist of a photovoltaic field placed on a greenhouse

roof, which needs to be designed according to the trade-off between increasing the area of the field to produce more energy (with the subsequent shading on the crop) and the maximization of fresh fruit yielded. To give an answer to this problem, apart from the expected energy and fruit prices, it is necessary to use several kinds of models: a model for power production considering the solar geometry and an equivalent circuit for photovoltaic modules, a greenhouse climate model that depends on the external weather conditions, and crop growth model to estimate the fresh fruit production over a campaign. By coupling the said models particularized for a real facility located near the University of Almeria campus, it can be stated whether the greenhouse owner should invest on a photovoltaic facility or not from an economic point of view.

Keywords: Climate, crop growth, power production, design.

OS07-06

Analysis on Insulation Effects of Wind Environment and Cover Materials for Greenhouse Energy Design in Reclaimed Land

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In Korea, a large-scale high-tech greenhouse complex has been designing and creating a horticultural complex facility for cultivating and export of functional crops by utilizing a large area of reclaimed land. The external weather environment in reclaimed land is different from inland. In winter reclaimed land, low temperature and high wind speed cause high heat loss from inside the greenhouses. In order to maintain an appropriate growth environment for crops, greenhouses require a lot of heating energy during winter season, which is closely related to heating costs. Efficient energy management of greenhouses is important to prevent heat loss through the supply of renewable energy and greenhouse covering materials insulation. Energy efficiency of greenhouse cover material was evaluated by the weather environments in reclaimed land according to the real-time wind environment by chamber experiment. The chamber for evaluating insulation effect was manufactured for four types of greenhouse covering materials commonly used in glass greenhouses, and a real-time monitoring system was applied to measure the insulation effect and heating energy consumption according to changes external weather conditions. On average, the wind speed on the windward side was 53.1% higher than that on the leeward side. Based on the greenhouse covering material, the maximum temperature difference between the inside and outside of the chamber on the windward was found to be 52.0%. Greenhouse covering material made important different by maximum 39.2% of energy load.

Keywords: Energy Management, Greenhouse covering materials, Overall heat transfer coefficient, Heating load.

ORAL SESSION 8 / Plant factory and vertical farming II

OS08-01

Effect of different lighting under various wavelengths on seed germination inside a vertical farming system

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Controlled-environmental agriculture (CEA) refers to innovative agricultural systems that apply precise environmental control, such as humidity, temperature, light and CO_2. The regulation of environmental conditions inside the cultivation area optimizes plant growth and productivity. Vertical farms (VFs) are CEA systems that use artificial lighting, with specific dimensions, for plant growth and can be designed to operate in different environments, sizes and locations. VFs take advantage of the vertical orientation and plants grow on shelves, thus multiplying production per square meter. VFs, with local food production can contribute significantly to the reduction of CO_2 emissions due to food miles elimination. The most important disadvantage of VF systems is the high energy consumption for lighting. This study aimed to investigate the effect of five different lighting conditions and three different photoperiods on seed germination in a small-size VF system. The applied lighting conditions were a) red light, b) blue light, c) far red light, d) red-blue light and e) a combination of red-blue-far red light. These light spectra were tested on four different types of seeds: lettuce, cabbage, spinach and arugula. Seeds were placed in different seedbeds inside the VF and exposed to different lighting conditions and photoperiods for a period of eight days. The seeds were exposed to light for 12 hours and 24 hours per day at a distance of 60 cm from the light source and 4 hours per day at 20 cm distance. Energy consumption was monitored for all lighting treatments. The purpose was to examine which spectra gives higher rates of germination with lower photoperiodic demand and consequently reduced energy consumption. Results showed that lighting has a great effect on seed germination, while the photoperiod of 4 hours can provide satisfactory germination results, with significantly reduced energy consumption.

Keywords: vertical farms, control-environmental agriculture, lighting, wavelength, germination, seeds.

OS08-02

Water Use Efficiency in a Vertical Farm with Artificial Lighting: first results from AlmaVFarm

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Vertical farms (VFs) are innovative urban production facilities consisting of multi-level indoor systems provided with artificial light in which all the environmental conditions are controlled

independently from the external climate. VFs are generally provided with closed loop fertigation system to optimize the use of water and nutrient solution. The objective of this study, performed within an experimental VF of 43 m^2 of plant cultivation area at the University of Bologna, was to quantify the water use efficiency (WUE, ratio between plant fresh weight and the volume of water used) for a lettuce growth cycle (*Lactuca sativa* L.) obtained on two different growing systems: an ebb and flow hydroponic and a high pressure aeroponic system. Considering the total water consumed (water used for irrigation and climate management), WUE of hydroponics and aeroponics were 23.5 and 41.1 g L^{-1} H_2O, respectively. During the growth cycle, the contribution generated by the dehumidification of the internal air, to recover water transpired by the plants, was quantified. Indeed, by reusing water recovered from the dehumidifier, water use decreases dramatically (by 67%), while WUE increases by 206%. Further improvement of WUE in hydroponics was analyzed by adopting different management strategies: in particular, by increasing planting densities (e.g., 144, 270 and 733 plants m^{-2}) and by optimizing the light spectrum used for plant growth (e.g., adjusting the amount of far-red light in the spectrum between 26 and 60%). This study provides some important insights on water use efficiency and management strategies in high-tech urban indoor growing systems.

Keywords: Plant factories with artificial lighting (PFALs), Aeroponics, Hydroponics, Closed-loop hydroponics.

OS08-03

Lettuce growth and light use efficiency under non conventional diel cycles and noctoperiods

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Full control of the growth environment in vertical farming promises unprecedented yield and quality in agriculture. Vertical farming enables shorter/longer diel cycle length than the natural 24-h cultivation, which might enhance plant growth, quality, and light use efficiency. The endogenous clock regulates key biological functions in plants. A diel cycle length matching the endogenous clock results in optimal growth. In several species, like arabidopsis and tomato, the endogenous clock length is cultivar-dependent and ranges between 20 and 28 h. We aim to study the effect of diel cycle length (20, 22, 24, 26 or 28 h) × noctoperiod (2, 4 or 6 h) on biomass, morphology, and light use efficiency for three lettuce cultivars after a 19 days growth period. All treatments received equal cumulative photosynthetic photon flux (254 ± 1.2 mol m^{-2}) provided by white LEDs. Our study shows the plasticity of lettuce in response to diel cycle length and noctoperiod, which resulted in similar growth and light use efficiency for rather different light regimes with some differences between cultivars. This has strong implications for growers to choose the most efficient lighting schedule.

Keywords: diel cycle, endogenous clock, lettuce, noctoperiod, vertical farming.

OS08-04

Agronomical comparison of hydroponically grown sweet basil cultivars for vertical farming

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By 2050 it is estimated that the Earth's human population will be approximately 10 billion people. To improve input use efficiencies and mitigate greenhouse gas emissions, hydroponic production systems can represent an alternative to conventional methods of food production. Traditionally, leafy greens and herbs have always been associated with indoor agriculture and continue to be extremely popular among vertical farmers. More than half of indoor and vertical farms produce leafy greens. Among the grown herbs in vertical farms, basil (*Ocimum sp*.) represents one of the most popular choices and is cultivated for culinary purposes as a fresh herb or dried spice. It is mainly produced hydroponically or semi-hydroponically with very short growing cycles (usually 10–20 days after germination) and is considered the functional food of the 21st century. Our objectives were to quantify productivity and characterize the growth of basil cultivars grown in stacked hydroponic production systems. Twelve basil cultivars were chosen. Seedlings were transplanted into nutrient film technique (NFT) systems and grown for several weeks. Depending on the cultivar, a delayed harvest time was observed with 35 to 38 days of growth after sowing seed. Basil cultivars differed greatly in fresh weight from 2.1 to 3.2 kg/m^2 after one cut. The fresh weight showed a correlation with transpiration rate, whereas no correlation was found with the essential oil rate. In addition, two cultivars with the highest yield displayed the highest concentration of mineral contents. Further investigations are needed to analyze essential oil composition in order to determine cultivars with a positive nutritional value.

Keywords: vertical farm, basil, hydroponic.

OS08-05

The added value of indoor products: the strawberry case

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Indoor production systems without sunlight are seen as the latest revolution in agriculture thanks to the fully closed environment, which enables the optimization of yield and quality of the final product without depending on external weather conditions. On the other hand, indoor farming still requires high operational costs, mainly due to the high energy requirements. This leads to the production of pricey products and makes it difficult to compete with other Controlled Environment Agriculture (CEA) systems such as greenhouses. From a consumer and market perspective, indoor products therefore need to offer an

added value. In Europe, strawberries represent a high-value market and consumers demand a high quantity and quality of continuously available locally produced strawberries, calling for further investigation to achieve this by means of indoor production systems.

This study investigates the effect of fluctuating growth conditions (light intensity and air temperature) and light spectrum (R:B ratio) on the yield and the nutritional quality (vitamin C and anthocyanins content) of everbearing strawberry cultivar *Favori*. An experiment was conducted in two indoor research cells were a stable climate (20/14°C d/n and a DLI of 11.5 mol m^{-2}) was compared to fluctuating conditions with the same final light and temperature sum. In each cell the effect of a reference light spectrum (R:B = 4:1) was compared to a high blue spectrum (R:B = 2:1). The aim was to analyze the possibility of producing strawberries with a high yield and quality (dry matter content, Brix, firmness and acidity) and the potential of steering the production and nutritional quality under controlled conditions. Under fluctuating climate conditions a lower production peak was observed during cultivation and the flower truss number and dry biomass at final destructive harvest were higher compared to the stable climate. These preliminary results show that manipulation of cultivation conditions can lead to a more constant yield and quality of strawberries produced indoor.

Keywords: CEA, vertical farming, climate, LED lighting, berries, quality, consumer

OS08-06

Faster than fast: accelerating flowering for the speed breeding of lettuce (*Lactuca sativa*) with far-red radiation

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Lettuce (*Lactuca sativa*) is one of the most important leafy crops in the world and one of the most common crops grown in vertical farms. Lettuce is one of the main leafy crops grown in the field and vertical farm. Modern lettuce varieties have been selected against flowering. Prior to flowering, bolting occurs which is characterised by rapid stem elongation. However, this transition to generative growth leads to a bitter taste and hence the loss of commercial value. Typically, modern lettuce culitvars may take up to twenty weeks to flower, which leads to a long seed-to-seed cycle that greatly stalls the breeding program and the introduction of new cultivars. Speed-breeding is a new concept of using optimized and tailor-made environmental control to promote the growth and development of crops to shorten seed-to-seed cycles and to accelerate generation advancements in a breeding program. Elevated temperatures above 25 °C and extended photoperiods longer than 16 hours were known to accelerate flowering in lettuce. Recently, increasing studies proposed that far-red radiation (700-800nm) leads to accelerated flowering in several species. Here, we conducted an experiment in a completely controlled climate chamber where two cultivars were grown in a flowering-promoting condition of 30 °C and 20 hours of light. Far-red radiation was added during the photoperiod to evaluate its effect on plant growth and development. Plant height was destructively measured during growth and analyzed with split-line analysis to identify the bolting time. The bud

appearance and flowering time were registered. Far red significantly accelerated bolting, bud appearance, and flowering in both tested cultivars. This acceleration reduced the total flowering time by 34% and 37% in the two cultivars tested. The germination test showed no difference in germination rate between light treatments, indicating that the accelerated flowering did not compromise seed quality. This research demonstrated the substantial effect of far red in accelerating lettuce flowering and its potential in speeding up lettuce breeding with vertical farming.

Keywords: Bolting, Far Red, Flowering Time, Lettuce (*Lactuca sativa*), Speed Breeding, Vertical Farming.

OS08-07

Performances of fruit-bearing crops in indoor farming: the case of dwarf tomato

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Controlled-environment Agriculture (CEA), including vertical farms with multi-tier production, could provide a wide range of perishable crops to contribute to the urban diet. However, most commercial operations produce leafy vegetables and herbs. Fruit-bearing crops (e.g., tomatoes, cucumbers, berries) are high-value, highly nutritious, and tasty crops but may have a longer growth cycle, lower harvest index, indeterminate development, and/or maybe more challenging in terms of crop management. Some of these fruity crops already exist in their determinate or bushy forms and over the years, genetic improvement has enabled the development of additional varieties with improved traits (e.g., compact size, improved nutritional compounds) that are better suited to layer production and can increase indoor yields. In this study, we first present the state-of-the-art review of perishable fruit production in high-tech controlled environments. Secondly, we chose dwarf tomato (*Solanum lycopersicon*) as a reference crop, and we conducted an experimental study with two cultivars under different combinations of temperature and daylight integrals in two climate cells of a vertical farm facility of Wageningen University & Research (Bleiswijk, NL). The main goal was to analyze and compare the performances of dwarf tomatoes in terms of productivity, crop parameters, and nutritional quality from sowing to harvest. The results are discussed with respect to literature and compared with other cultivation systems (e.g., greenhouses) to evaluate the feasibility of growing fruit-bearing crops in vertical farms and further requirements for future production in cities.

Keywords: LED lighting, nutritional value, tomato crop, crop yield, plant factory with artificial lighting (PFAL), indoor farming.

Oral presentations: Tuesday October 24, 2023

ORAL SESSION 9 / Lighting technology II

OS09-01

LED Light Technology in Mexican Agriculture

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The development of LED technology has allowed for a significant advancement in understanding the interaction between light and plants. Light is a key factor in the growth and development of crops, and with specific wavelengths, crop quality and productivity can be enhanced. However, LED light technology is not only applicable to plant growth but also to product disinfection systems for fresh produce using ultraviolet LEDs. Similarly, the use of light treatments in post-harvest processes yields significant effects. In this context, we will showcase some applications of LED technology addressing issues raised by Mexican producers.

OS09-02

Acclimation to either daytime or nighttime supplementary UVB light increases leaf photosynthesis and photoprotection of young cucumbers

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Raising young plants is important for modern greenhouse production. Upon transfer from the raising to the production environment, young plants should maximize light use efficiency while minimizing deleterious effects associated with exposure to high light intensity. Ultraviolet-B radiation (UVB, 280–315 nm) is a key environmental signal that influences plant growth and development. In this study, we explored the acclimatory effects of daytime and nighttime UVB light on leaf photosynthetic and photoprotective capacity of young plants. Cucumber (*Cucumis sativus*) seedlings were grown under sunlike LEDs at the light intensity of 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$ in a climate room. When plants unfolded the 1st true leaf, they were treated with UVB supplementary light (5 $\mu mol \cdot m^{-2} \cdot s^{-1}$) during the day (8:00–20:00) or night (20:00–8:00), or with no UVB (control). Both daytime and nighttime UVB treatments decreased plant biomass at a same degree, by 30~40% compared to control plants. However, both UVB treatments increased leaf photosynthetic capacity by 22–23% compared to control leaves, along with an increase in leaf electron transport rate and trios-phosphate utilization rate. UVB treatment also increased internal water use efficiency due to the simultaneous decrease in stomatal conductance and an increase in leaf photosynthetic

rate. Acclimation to UVB did not affect the rate of photosynthetic induction, but induced faster induction and relaxation on non-photochemical quenching under dynamic light intensity. Besides, we observed an increase in gene expression of NPQ-related proteins (including photosystem II subunit S, PROTON GRADIENT REGULATION-LIKE1 and PROTON GRADIENT REGULATION5) in UVB acclimated leaves compared to control leaves, within two hours of high light exposure. In conclusion, acclimation to UVB supplementary light either during the day or night can improve both light and water use efficiency and diminish photoinhibition under high light exposure, which can benefit young plant growth after transferred to a dynamic high light intensity.

Keywords: UVB, cucumber, photosynthesis, photoprotection, dynamic light.

OS09-03

Effect of Light Intensity and Branch Origin Position on *Cannabis sativa* Inflorescence Density and THC Content

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To investigate the effects of light intensity and stem origin position on the inflorescence density and Δ^9-tetrahydrocannabinol (THC) content of *Cannabis sativa* (cannabis), "Blue dream" plants were grown in a commercial greenhouse in Southwest Ontario, Canada from vegetative stage to inflorescence maturity. There were two groups of plants with one group as trained and one group not trained as control. A bottom branch originated from the same position for all the experimental plants was selected and marked along with the inflorescence of the main stem (top). For the trained plants, the inflorescences of the bottom branches and the inflorescence of the main stem were brought to have the same heights using gentle force and clips, resulted both the top and bottom inflorescences to have experienced the same light intensities during the experiment. The untrained plants were grown in their natural form with the top inflorescence higher than the bottom inflorescence resulted in the bottom had lower light intensity than the top. Plants were harvested at maturity and all the inflorescence densities and THC contents were measured. The were no differences in THC contents (averaged 17.2%) among all the bottom and top inflorescences for both trained and not trained plants, which indicates that neither light intensity nor branch origin position affected the inflorescence THC content. There was no difference in the densities of the top and bottom inflorescences for the trained plants, but the densities

of the bottom inflorescences were lower than the tops for the not trained control plants, which suggests that light intensity is important for producing inflorescence with high density. The results of this study can be used in guiding cannabis plant training and lighting, especially in controlled environment cannabis cultivation.

Keywords: branch origin, cannabis, inflorescence density, light intensity, plant training, THC, CEA.

OS09-04

Effects of LED light spectrum on light use efficiency, resilience and gene expression in a high-wire cucumber cultivation

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In horticulture, supplementary LED lighting is increasingly being implemented as a means to reduce energy costs compared to conventional lighting, and to be able to provide an optimal light spectrum to crops during the winter season. Although LED lighting is an energy efficient technology, in practice it is not necessarily applied in an energy efficient way. An important cause is the lack of knowledge of which light spectrum the plant actually needs in a sunlight background. Light spectrum can have a major impact on crop morphology, biomass production, assimilate partitioning and resilience against pests and diseases. In this study the effects of LED light spectrum in a sunlight background on biomass production, development and resilience of two cultivars of *Cucumis sativus* were investigated in four lighting treatments. Far-red (FR) light was added to the photosynthetic photon flux density (PPFD) or replaced partially the PPFD compared to the reference treatment, resulting in two different photon flux density (PFD) levels of 222 and 244 $\mu mol \cdot m^{-2} \cdot s^{-1}$. In addition, a fourth treatment added FR light in an increased white LED light background. A cultivar depended response to these treatments was observed for leaf area and internode length while petiole length consistently increased under an increased FR dose irrespective of the PPFD and cultivar. In addition, leaf photosynthesis rates increased significantly under an increased FR dose under similar PPFD, but not in a background of increased white light. For one cultivar, this lead to an increased fruit yield and light use efficiency. The establishment of biotrophic fungus powdery mildew (*Podosphaera xanthii*) investigated in bioassays was strongly dependent on the cultivar while the establishment of the herbivorous arthropod western flower thrips (*Frankliniella occidentalis*) was reduced depending on the cultivar under increased FR at similar PPFD. Gene expression analysis revealed that cultivar and light spectrum affected the expression of resistance genes and flavonoid biosynthesis genes, coinciding with the observations from the bioassays and flavonoid measurements. These results show that the supplementary LED light spectrum is of vital importance in the development of resilient and sustainable greenhouse cultivation systems.

Keywords: LED, supplementary lighting, LUE, Far-red, resilience, greenhouse.

OS09-05

An assessment of lettuce growth performance using GREENBOX technology with different light concentrations and colors

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GREENBOX Technology was developed using a novel low-cost independently functioning unit capable of fresh crop production in warehouse settings. GREENBOX technology consists of individual climate-controlled units which includes a thermally insulated growing apparatus, an artificial lighting source, a soilless cultivation method (hydroponics), and environmental controls. These units may be integrated with existing urban infrastructure, such as buildings, garages, and warehouses to allow for an avenue of urban agricultural production. Previous studies have investigated the technical feasibility of lettuce *(Lactuca sativa* 'Rex Butterhead') crop growth using GREENBOX technology that utilized solely white lighting elements. To our knowledge, no existing literature assesses the efficacy of different lighting color spectrums using GREENBOX technology. The APS Laboratory for Sustainable Food aimed to fill this gap by assessing how different lighting element treatments (white, orange, and purple light) affected the production of 'Rex Butterhead' lettuce using GREENBOX technology. We conducted comparative crop growth studies using purple, orange, and white (control) colored light treatments. The crop production cycle began with all lettuce plugs being cultivated for 15 days under the same treatment conditions and then plugs (randomly selected) were transplanted to the NFT channels and grown for 30 days to maturity, ready for harvest. We fertigated using a standard concentration nutrient solution. Each GREENBOX unit had a designated light component and a 4x6 configuration with 24 plugs of lettuce for each lighting treatment. Collected biomass data included wet weight (g), dry weight (g), leaf area (cm^2), leaf count (n), and chlorophyll concentration (mg/cm^2). We then derived additional data, including the Leaf Area Index (LAI, cm^2/cm^2), Specific Leaf Area (SLA, cm^2/g), and biomass productivity (kg/m^2). We used descriptive statistics and an Analysis of Variance (ANOVA) to understand the differences in biomass parameters between the lettuce grown under different lighting treatments. In addition, we compared the biomass performance parameters of our lettuce with existing peer-reviewed literature to observe how it compared to commonly found industrial output. The differences in the crops grown under higher lighting intensities and with different color treatments were statistically significant. Results from this study will inform the future iterations of GREENBOX design.

Keywords: biomass productivity, DLI, chlorophyll concentration.

OS09-06

Light Distribution in a Two-level Unit with Supplemental LED Lighting in a Hydroponic Greenhouse

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Plant growth in a multi-level controlled environment allows intensive cultivation with minimal use of soil and water resources. Modern grow plants are usually fully equipped with modifying LED lights (adjusted to specific crops and growth stages), hydroponics, and intelligently designed climate control and fertilization systems, to reduce the risks of yield losses. However, multi-level plant factories have not been widely utilized due to high energy consumption and complex design. The current study aims to demonstrate that the effective sharing of solar light between plants grown in additional levels reduces the amount of supplemental lighting, heat overload, and energy consumption. Taking advantage of the construction of an operating hydroponic greenhouse located in the central part of Israel, optical and thermal models using ANSYS software have been developed to explore the optimal structure of a second layer of hydroponic growth channels. In addition, three-dimensional flow and temperature distribution inside and around the multi-level unit has been modeled with the aim of providing a uniform internal microclimate and evaluating the energy consumption of the system. The modeling results were validated by experimental measurements conducted in the commercial greenhouse with hydroponic growth channels installed above the conventional hydroponic system for leaf crops. The study also examines the effect of artificial lighting intensity with supplemental solar radiation on the three types of lettuce variety. Several growth cycles were carried out with and without additional LED lighting. It has been demonstrated that it is possible to double the growing area without yield harming by spreading the growth channels above the growth tables, with half of this area equipped with LED lighting (to compensate for the solar radiation losses), a water supply system, and necessary ventilation.

Keywords: multilevel greenhouse, hydroponics, lettuce, optical and thermal modelling.

OS09-07

Impacts of LED light intensity on the transient expression of GUS gene in soybean (*Glycine max*) with half-seed transformation method

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Soybean (*Glycine max*) is a crop with major economic and food value worldwide. Soybean plants are constantly improved using biotechnology techniques for better agronomic traits. *Agrobacterium*-mediated transformation is commonly used to deliver desired genes to the

meristem of the half seeds. However, the efficiency of the gene delivery is low, hindering plant improvement of soybean. Light promotes meristem growth and is also involved in signaling pathways in plants, especially relating to stem cell activities. The goal of the present study is to investigate the impact of light intensity during co-culture (transformation) on soybean transformation efficiency. In general, half-seed explants undergo a co-culture phase with *Agrobacterium* for five days under light prior to transgenic shoot regeneration. Transient expression is an effective approach to study transformation product in a short period. The hypothesis of the present study is that increasing light intensity during co-culture could increase the transient expression percentage of *GUS* gene. In this experiment, various light intensities of white LEDs (50, 100, 150, 190) and fluorescent light (100) were implemented on half-seeds during co-culture for five days. The meristem area of half-seed explants was examined for *GUS* transient expression by *GUS* histochemical assay. The meristem area with distinct blue circles was considered as transient event. Results indicated that the percentage of GUS transient expression was low under high light intensity during co-culture. The light intensity of 50 and 100 yielded the highest transient expression percentage, while fluorescent light treatment delivered 10 % less of transient expression than white LED at 100. Furthermore, this research outcome justifies investigations of the effects of various light intensities during co-culture on the stable transformation efficiency for different genes of interest.

Keywords: LED, transformation, PPFD, biotechnology, tissue culture.

OS09-08

Do we light enough? Optimization of light use efficiency in a vertical farm by modulation of light intensity, photoperiod and far-red radiation

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Energy and light use efficiency are crucial parameters for the economic and environmental sustainability of indoor growing systems, such as vertical farms (VFs). For leafy greens' growth, increasing light intensity (PPFD) leads to increase biomass accumulation, but at the same time, besides an optimum, increasing PPFD decreases light use efficiency. The objective of this work was to test different combinations of photoperiod and light intensity, keeping the daily light integral (DLI, 14.5 mol d^{-1}) constant, on the growth of lettuce plants (*Lactuca sativa* cv. Canasta) in a high-pressure aeroponic system. Specifically, DLI was distributed to plants with a photoperiod of 16 hours day^{-1} and a light intensity of 250 mmol $m^{-2}{\cdot}s^{-1}$ (16/250) or with a photoperiod of 24 hours day^{-1} and a light intensity of 170 mmol $m^{-2}{\cdot}s^{-1}$ (24/170). These two combinations were associated with a spectrum consisting of only red (600-700 nm) and blue (400-500 nm) radiation (with a red:blue ratio of 3, RB_3) or with a spectrum in which 50 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ of RB_3 were replaced by 50 $\mu mol{\cdot}m^{-2}{\cdot}s^{-1}$ of far-red (700-780 nm) radiation (RB_3-50Fr). The 4 combinations of light treatments were applied from transplanting until the final harvest, during which

morphological and physiological measurements were performed. Results show that starting from a standard condition of 16/250 with RB_3, the use of 24/170 led to a significant yield increase (+28%), while combining 16/250 with RB_3-50Fr led to an increase of +34%. The use of these two light treatments also led to substantial increase in the light use efficiency (+25-40%) and lighting energy use efficiency (+30-32%). The results highlight how the extension of the photoperiod (at the same DLI) or the integration of far-red radiation into the spectrum constitute two possible strategies to increase energy and light use in VFs.

Keywords: Resource Use Efficiency, LED lighting, Aeroponics, Continuous Lighting.

ORAL SESSION 10 / Fertigation, water and growing medium I

OS10-01

Ozone-nano Water can Promote the Growth and Secondary Metabolites of Horticultural Plants in Hydroponic Systems

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This study investigated the effect of ozone-nano water on the growth and secondary metabolite content of horticultural plants in hydroponic systems. Leaf mustard (*Brassica juncea* (L.) Czern.), red mustard (*Brassica juncea* L.), and kale (*Brassica oleracea* L. *var. acephala* (DC.) Alef.) were grown under hydroponic systems for three weeks. They were treated with ozone-nano water for 1, 2, 4, and 8 minutes with 1 $mg{\cdot}L^{-1}$ twice a week and 5 $mg{\cdot}L^{-1}$ once a week. Whole plants of Korean mint (*Agastache rugosa*) were soaked in ozone-nano water once a week for 0, 1, 10, 20, 40, and 80 seconds with 1 $mg{\cdot}L^{-1}$ and grown under a deep flow technique system for 39 days. The results showed that shoot fresh and dry weights, leaf number, leaf area, and secondary metabolite contents of leaf mustard, red mustard; kale was significantly higher than the control. In the case of Koran mint, the stem length was decreased as the soaking time in ozone-nano water increased. However, flower fresh and dry weights were increased at 20, 40, and 80 seconds compared to the control. The secondary metabolites, flower fresh/dry weight, and flower weight ratio were increased under 20, 40 seconds. Therefore, if ozone nano water is used in hydroponic systems, secondary metabolites may increase in a well-ventilated environment. The plant height was lower in treatments than in the control; it is considered that the plant cultivation height can be made lower and the plant cultivation space can be increased. Since Brassicaceae, showed different effects of ozonated water depending on the species, further studies should be conducted on ozonated water and antioxidant enzymes.

Keywords: acacetin, anthocyanin, glucosinolate, oxidative stress, tilianin.

OS10-02

Hydroponic crop production with low-pH nutrient solution for mitigating risks of root-rot diseases

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The optimum pH range typically considered for hydroponic nutrient solution is 5.5-6.5. Outside this range, plants tend to show specific nutrient disorders due to nutrient availability and ion competition. Pathogens for root-rot diseases such as *Pythium spp.* have been shown to be negatively affected by acidic conditions (e.g., < 5.0). However, under low pH, plant growth and crop yield are often compromised, mainly due to unoptimized nutrient uptake directly or indirectly affected by acidic nutrient solution (pH 4.0-4.5). Our objective is to develop a methodology to grow leafy greens in a low-pH nutrient solution as a low-cost strategy to mitigate root-rot diseases. We grew six leafy green species (11 cultivars) in a hydroponic deep water culture system with varied pH (4.0 – 5.5) to examine their sensitivities to low pH. Lettuce, bok choy, and basil were classified as crops with low sensitivity, kale with moderate, and arugula and spinach with high sensitivity. Mineral nutrient concentrations in shoot tissue of the relatively sensitive species (spinach, arugula and kale) showed that Ca, Mg, Fe, Mn, and Cu uptake significantly declined at least two of the three species, and Zn declined in spinach as pH decreases. When these mineral concentrations were doubled in the nutrient solution formula, fresh shoot mass at pH 4.0 significantly increased to the level comparable to those at pH 5.5 in arugula and spinach, but not in kale. Kale plant growth reduction at low pH may be due to the direct impact of high hydronium ion concentration. The results of our research suggest that 1) lowering pH of nutrient solution can be an effective mitigation method for the risk of introducing root-rot disease, 2) sensitivity to low pH is species- and cultivar-specific, and 3) yield reduction of arugula and spinach can be minimized by optimizing nutrient solution formula for use in low pH (4.0-4.5). However, for unknown reasons, a small percentage (4%) of spinach plants were found stunted at pH 4.0, regardless of nutrient adjustment. Further research is needed to adopt this new approach in commercial production where various substrates and recirculation systems were used.

Keywords: controlled environment, root-zone management, plant health, nutrient uptake.

OS10-03

Improving the sustainability of hydroponic systems through optimisation of the nutrient solution composition

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Closed hydroponic growing systems where the drained nutrient solution is re-used can be environmentally friendly if managed optimally. Hydroponics tomato production systems are, however, operated with high to even excessive nutrients, with nutrient concentrations

applied varying between 3.5 and 9.0 $mS.cm^{-1}$. Closed-loop drip-irrigated hydroponic systems run at different nutrient solution compositions were used to evaluate the effect on yield and quality of greenhouse tomatoes (*Solanum lycopersicum*, cv Daniella). The nutrient solution differed in total salt content (EC 1.5, 3.0, 4,5 6.0 $mS.cm^{-1}$) and nutrient ratio combinations (Standard N, low N, and reduced N, end of the season). Yield and quality parameters were analyzed, as well as the mineral composition, soluble solids, lycopene, and organic acids of fruit. Both high and low total salt concentrations in the nutrient solution resulted in a significant reduction in yield. Reducing the N only during the last four weeks of the season had no negative effect on the yield compared to the control. There was a 29% increase in the lycopene content, a 24% increase in the total soluble solids measured in the fruit for plants grown, and an EC of 4.5, where the nitrogen was reduced at the end of the season. These results suggest that a reduction in the nutrient solution concentrations as well as the total N in the solution during the last four weeks of cultivation can increase the nutritional quality of hydroponically grown tomatoes and have the potential to limit the nutrients in greenhouse waste water.

Keywords: Hydroponic, nitrogen, nutrient-use-efficiency, recirculation.

OS10-04

Hy4Dense, a newly developed hydroponics system for leafy vegetables sown at high density

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Intensive horticulture can have an impact on the environment through nutrient and pesticide emissions. These challenges, combined with societal demands, have led to tighter European legislation to reduce emissions from agriculture. Growers face (i) strict legislation to reduce nutrient and pesticide emissions and (ii) difficulty achieving reliable soil disinfection as agrochemicals have been withdrawn and others' use is restricted. The expectation for Europe is that imminently, chemical soil disinfection will be impossible. To tackle these problems, more than 90% of greenhouse cultivation of fruit vegetables has shifted to hydroponics in Flanders; leafy vegetables grown at low plant density (e.g., lettuce) are starting to implement systems. However, no straightforward solutions are available for vegetable crops traditionally densely sown in rows in the field, such as corn salad, spinach, and rocket. In the Hy4Dense project, we developed a novel hydroponic system to grow these crops. Experiments were carried out to optimize the floaters taking into account

different hole dimensions, mesh sizes, and floating capacity. In the next steps, cultivation practices were further enhanced, including germination on the system, sowing density, and light regime. Through co-creation, we involved different stakeholders and finally came to a working pilot installation on which these crops are grown. Results of the different steps from the concept to the pilot system will be showcased together with ideas for further automatization.

Keywords: hydroponics, cultivation system, leafy vegetables, spinach, lamb's lettuce.

OS10-05

Monitoring and control of nitrate in closed-loop hydroponics

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Hydroponics represents an attractive cultivation strategy for numerous crops. In such systems, reuse of nutrients – by nutrient solution recirculation and possibly utilization of waste streams – offers improved resource utilization, reduced fertilizer use, and reduced environmental impact. However, closing a hydroponic loop may cause nutrient imbalance over time as nutrient solutions traditionally are controlled by electrical conductivity, indicating their total strength. Individual nutrient levels, on the other hand, are typically measured by offline analyses unable to provide real-time results and support process control. The presented work targeted nitrate, representing a key input factor for crop cultivation and an environmental concern related to runoff. Near real-time monitoring of nitrate was achieved based on a commercially available optical sensor demonstrating low drift, high specificity, and fast response times. A limited measurement range was mitigated by the development of an auto-sampling and auto-diluting (1:20 to 1:50) unit offering a complete at-line system. A 2-channel version was used to monitor a recirculating nutrient solution in lettuce cultivation, in parallel with nitrate control solutions (100 to 200 mg/L NO_3-N). Automated analyses performed every 2-6 hours over one month demonstrated nitrate measurement accuracies within ± 3 %. Nutrient stock solutions were fed based on the continuously monitored nitrate concentration of the nutrient solution – first to linearly increase NO_3-N from 110 to 150 mg/L over 7 days, then to keep it constant at 150 mg/L. During these phases, the nitrate concentration deviated less than 2 % from the set-point. Ultimately, a final version of the monitoring system was installed into an advanced and closed hydroponic crop cultivation facility and successfully used for nitrate monitoring and control. This work represents key advancements in real-time nutrient monitoring and is to the author's knowledge, the first scientific report of automated and accurate control of nitrate in closed-loop hydroponics.

Keywords: hydroponics, nutrient solution, monitoring, control, nitrogen, NO3-, real-time.

OS10-06

A sustainable eco-friendly approach for vegetable production in hydroponics

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The demand for local and healthy fresh produce is increasing worldwide. Despite the fact that hydroponic is commonly used in vegetable production, growers are looking for a sustainable cultivation system with less negative impact on the environment. Therefore, the objective of this study was to assess potential strategies to replace synthetic chemicals that used as the main source for the nutrient solutions in the hydroponic systems to create a sustainable cultivation system using nutrient solution from organic source, to grow vegetable crops. For this purpose, liquid organic fertilizers derived from four different organic sources were used in auto-pot hydroponic system, to grow lettuce plants. The vegetative growth, yield production, and nutrient content parameters of these plants were determined in comparison to the standard inorganic NS. The results revealed that organic hydroponic performance was sufficient to produce lettuce crop comparable to inorganic in the first four weeks. At harvest, growth of organic lettuce leaves had lower plant height, leaf number, area, and fresh and dry biomass compared to the inorganic lettuce leaves. However, the organic lettuce growth showed higher chlorophyll, carotene contents, and stomatal density than inorganic plants. Leaf nutrient content at harvest was significantly impacted by the type of used fertilizers (plant/animal) source. It is suggested that with organic liquid fertilizer is a potential alternative nutrient solution to develop a sustainable hydroponic for growing safe and nutritious healthy vegetables crops for better health, environment.

Keywords: organic nutrient; hydroponic; production; lettuce, sustainable.

OS10-07

Development of an Ion Selective Electrode-based Nutrient Management System to Maintain Ionic Balance in Closed Hydroponic Solutions

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Closed hydroponic systems can reduce the use of water and fertilizer than open systems. However, conventional closed systems based on the control of electrical conductivity (EC) may cause ion imbalances in the nutrient solution over time. Supplying fertilizers in proper ratios to supplement the deficient ions based on direct measurement of individual ions by the use of ion-selective electrodes (ISEs) may allow efficient maintenance of balance in nutrient ratios for crop growth. In this study, an automated nutrient management system was developed to supply variable compositions of fertilizers based on ionic concentration ratios determined using a laboratory-made fertilizer dosing algorithm in conjunction with the use of ISEs. An array of NO3, K and Ca electrodes was fabricated and their signals were collected via a buffering circuit consisting of differential operational amplifiers and a low-pass filter. The system variably activated seven-solenoid valves for six fertilizers, i.e., Ca $(NO_3)_2{\cdot}4H_2O$, KH_2PO_4, KNO_3, NH_4NO_3, $MgSO_4{\cdot}7H_2O$, and K_2SO_4, and an acid solution of H_3PO_4 for pH adjustment, which were introduced into a mixing tank daily according to target volume ratios of the solution prescribed by the dosing algorithm operated remotely. The target solution was synchronized to the total nutrient absorption by crops based on the drainage ion concentration ratio. Variable amounts of the individual fertilizers were supplied by controlling the duration of each valve of the venturi dosing channel when a measured EC was under a target during the compensation of water. Micronutrients were added in a fixed amount based on the Hoagland nutrient solution. To evaluate the performance of the system, the system was applied in a greenhouse that grew Caipira and Corbana lettuce, and the actual ionic concentration ratios of the drainage solution were compared with the target values. The root mean square error to the target ratios was confirmed to be below 10% in the last stage of cultivation period. The result showed that the developed system could improve ionic balance compared to the conventional system for the closed hydroponics and be an alternative to implement the reuse of drainage.

Keywords: Closed hydroponics, Ion-specific dosing algorithm, Individual fertilizer, Electric conductivity, Ion selective electrode.

OS10-08

To leach or not to leach: water management strategies for hydroponic strawberry production

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Controlled environment (CE) strawberry (*Fragaria x ananassa*) production is becoming increasingly popular as climate change threatens outdoor field production. A common strategy in the CE strawberry industry is to fertigate on a regular basis an amount that results in a certain leaching fraction, usually 20%-30%. This experiment sought to improve this method by using automatic fertigation monitoring and control triggered by soil moisture sensors to reduce water and fertilizer use, increase yield, and improve fruit quality. Strawberries were grown in a greenhouse in Athens,

Georgia, USA in a recirculating fertigation drip substrate-based hydroponic system. The substrate was 50% peat (Sungro Metro-Mix 830) and 50% super coarse perlite (Whittemore) by volume. The strawberry plugs cv. 'Florida Beauty' and 'Florida Brilliance' were obtained from a commercial nursery (Lareault Nursery, Quebec, Canada) and transplanted into the system in October 2022. They were grown uniformly until December 2022, then were subjected to six different fertigation regimes. Four of the fertigation regimes were automatically controlled to maintain a constant substrate volumetric water content (VWC). The four VWC targets were 15%, 22.5%, 30%, and 36%, with the substrate reaching saturation at 42% VWC. The fifth treatment was an automatic, timer-based treatment that triggered fertigation for 3 minutes every 3 hours. The sixth and final treatment was a manually controlled leaching fraction treatment with a target of 20%-30% leachate for each regular fertigation event. Substrate VWC, electrical conductivity (EC), and temperature were regularly monitored for all treatments using capacitance sensors (GS3; Decagon) connected to a datalogger (CR1000X) and a relay driver (SDM-CD16AC) (both from Campbell Scientific). A modified Yamazaki nutrient solution was used for the fertilizer solution, and the pH and EC of all reservoirs were maintained within 5.5-6.5 and 0.75-1.25 dS/m, respectively. Weekly fruit harvests were analyzed for number of fruits, fresh weight, marketability, total soluble solids, and dry weight. The final harvest was conducted in April 2023.The four VWC treatments induced the same or higher fruit yield and quality than the leaching fraction treatment, indicating that automatically triggered fertigation using VWC sensors could be a viable alternative to the industry standard leaching fraction strategy.

Keywords: Hydroponic, strawberry, soil moisture sensor, leaching fraction.

OS10-09

Alternative substrates for arugula and lettuce production in greenhouses

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Peat moss is the most commonly used substrate in the controlled environment industry due to its quality, stable pH, and exceptional water retention properties. However, peat is an organic soil unsustainably sourced from bogs in different parts of the world. European countries are discussing prohibiting peat use in horticulture, which the United Kingdom has already implemented. In anticipation of a wide change with a massive impact on greenhouse operations in North America and, more specifically in Georgia, there is a need to study other substrates for vegetable production due to the constraints of using peat in the next couple of years. We conducted a series of studies in different seasons to identify alternative substrates for leafy green production and evaluate their effect on arugula and lettuce yield and quality. We tested 'Slow Bolt' arugula and 'Rex' lettuce (Mountain Valley Seed) and thirteen commercial substrate mixes from different companies with different compositions and forms. Substrates tested: Phenolic foam (Horticubes Aeromax single seed and multiseed dibble; Oasis), Rockwool (AO 25/40 and AO 36/40 Plug; Grodan), 98% peat (Jiffy 7 Organic Peat Pellet [discontinued], Jiffy 7 Horticulture Pellet, Jiffy 7 Horticulture Peat Pellet; Jiffy), 75% peat + 25% fine coir (Preforma HP DJ; Jiffy), 100% coir (Universal 6-9 and Organic 2.0 paper; Ellepot), peat and coir mix (Universal

6-9 and Organic 2.0 paper; Ellepot), and 100% coconut coir (PCM Coco; Riococo). Plants were cultivated in a deep-water culture system in a greenhouse using 1.2 × 2.4 m trays. Each tray was filled with 302 liters of a standard fertilizer solution with (mg/L) 162 N, 31 P, 210 K, 90 Ca, 23 Mg, 28 S, 0.25 B, 0.023 Cu, 1.8 Fe, 0.13 Mn, 0.02 Mo, 0.16 Zn and had 72 plants on a floating foam insulation board. Each treatment had three plants per experimental unit, and the study had three replications (three individual trays). Greenhouse air temperature and humidity were measured daily. We measured pH, electrical conductivity, dissolved oxygen, chlorophyll, anthocyanin, and plant height and width weekly. We determined canopy and root fresh and dry weight, soluble solids content, leaf area, and foliar and fertilizer solution nutrient concentrations at harvest. Peat-based substrates presented the highest plant height, width, and biomass of arugula and lettuce compared to non-peat substrates over the three seasons. The substrates tested significantly influenced the yield and quality of both arugula and lettuce. However, the peat-based products overperformed the coir and other inorganic substrates. The media with 75% peat + 25% fine coir produced the highest biomass for arugula and lettuce over three seasons. More research is needed to engineer hydroponics substrates without peat for leafy green production that results in comparable yield and quality.

Keywords: Peat, Coconut coir, Leafy greens, Deep water culture; Hydroponics, Growing media.

ORAL SESSION 11 / Sensors, automation, and robotics in greenhouses I

OS11-01

Semantic Explanation and Navigation System for Greenhouse Robotics Systems

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Robots and other autonomous systems must work together with humans in tight spaces performing various crop manipulation actions. Conventional greenhouse robots are limited in their localisation and navigation capabilities. For example, their internal positional mapping can drift or run out of sync with the physical objects and obstacles, e.g., when positional markers are sparse or not positioned perfectly. Solving this and making localisation and navigation more robust requires improvements in perception, mapping, and sense-and-avoid. Furthermore, to enable cooperation with other robots (efficiently delegating tasks) and with humans, the robot's instructions and planned actions (e.g., for moving to the proper locations and deciding how and where to cut which plants) need to be unambiguous, semantically sound, and explainable. Recently a new standard for greenhouse semantics was deployed: the Common Greenhouse Ontology (CGO) [1]. The Common Greenhouse Ontology enables the communication and exchange of semantically correct and

standardised data about the greenhouse and related components [2]. Using the CGO, a software framework and tool have been developed for autonomous robots and systems to support the systems' semantic reasoning capabilities as well as semantic navigation through the greenhouse. This can improve the reliability of these systems, the capability to work in conjunction with other systems and sensors, and the trust of the human (co)operators. Preliminary experiments with human operators indicate that understanding of the autonomous system's status increased in abnormal situations. The next steps include communication with multiple robot systems and extending the scenarios with new categories or combinations of unexpected but foreseeable hazardous situations.

Keywords: semantic, explanation, navigation, greenhouse robots, AI, human-computer interaction, co-learning, hybrid AI, semantics, neuro-symbolic modelling, autonomous greenhouse, robotics, computer vision, knowledge modelling.

OS11-02

Development of Double-Camera AI System for Efficient Monitoring of Paprika Fruits

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In high-tech greenhouses, yield prediction contributes not only to environmental control but also to efficient worker management, pricing negotiation, and shipment planning. To predict crop yields, some large-scale greenhouse growers manually count the number of fruits on some plants weekly. In our previous study, we proposed a fruit monitoring system for paprika plants using deep learning-based object detection (Mask R-CNN). The scanning device, which is attached to a pipe rail trolley, moves at a stable speed along a pipe rail between the plant rows, scanning the crop canopy in a plant row, creating a panoramic image, and automatically counting the number of fruits. Previously, the system scanned one plant row while moving forward and the other row while moving backward. In this study, we updated our device by mounting two cameras facing opposite directions, maintaining a size of 1.3 m [H] × 0.4 m [W] × 0.25 m [D], which is nearly the size of the previous device. This modification allowed us to scan crop canopies in both plant rows simultaneously, saving measurement time. We also automated the data transfer and analysis process so the grower can receive the monitored results promptly. We tested our system in a large-scale commercial greenhouse (with a total cultivation area of approximately 2.4 ha) to monitor the number of paprika fruits and examine the relationship between the number of detected fruits, yield, and harvesting time. Our results showed that the number of detected paprika fruits correlated with the yield and harvesting time of the following week.

Keywords: greenhouse horticulture, object detection, number of fruits, simultaneous measurement, yield prediction.

OS11-03

Decision of Optimal Sensor Location for predicting the Internal Environment of Greenhouse using Machine Learning Model

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The number of large-sized greenhouses has recently increased due to automation and mechanization with the development of information and communication technologies (ICT). To set an appropriate environment for the greenhouse, it is necessary to install and maintain several sensors for internal environmental monitoring and control of the air conditioning system. This requires machine learning (ML) models to determine the optimal sensor location with a minimum number of sensors and which offers good monitoring performance. In this study, the ML models such as ANN, SVR, and LSTM were developed to predict the internal air temperature for each point in a greenhouse, and the optimal sensor location was evaluated based on the best-performing model. The ML models were designed using internal environmental and external weather data measured during the summer season from nine locations in the eight-span greenhouse. The optimal ML model for greenhouse internal temperature prediction was selected, and the optimal temperature sensor location was selected using the model. The final ML model which was developed as the prediction current temperature using optimal sensor machine learning model (PCTO-ML) has been proposed to require a minimum kind of learning features. Among the three ML models, the LSTM model was selected as it showed the highest prediction accuracy of air temperature in the greenhouse. To minimize the number of training features, four LSTM models (Basic LSTM, simple LSTM-1 ~ 3) were developed. As a result, sensor 5 presented in the simple LSTM-3 model (R2 = 0.982, RMSE = 0.020, P-RMSE = 0.380) was recommended for optimal sensor location in case of using one sensor. In addition, the optimal sensor location for using two (sensors 3 and 9) and three sensors (sensors 1, 2, and 7) has been proposed.

Keywords: Air temperature, Artificial neural network(ANN), Greenhouse, Long short term memory(LSTM), Machine learning, Monitoring, Optimal sensor location.

OS11-04

Novel fruit growers advisory system using connected fruit dendrometer, micro-climate data and machine learning algorithms

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The climate is having an increasing impact on greenhouse production. Frequent and unpredictable events lead to physiological adaptations of plants to the detriment of fruit

quality. Tomatoes, for example, split or even burst in the ripening phase, often in the summer when a succession of hot periods occur, and the fruit is not elastic enough to absorb the physical changes due to frequent irrigation. This causes important losses for the growers. This project aims to implement and test a real-time connected fruit dendrometer in a soilless tomato culture, combined with a micro-climate analysis and machine learning algorithms. The objective is to detect a typical signature growing curve for tomato crop production and predict the cracking event. The research has three main outcomes: (i) improve crop quality; (ii) optimize harvest timing; (iii) reduce water usage. A field trial took place in 2022 at the research center of Agroscope, Switzerland. The mechanical and electronic behavior of 60 fruit dendrometers was tested in a soilless tomato greenhouse, together with the setup of a data transmission and storage system. Six micro-climatic stations allowed us to study the dependence between climatic data and fruit growth. Phenological and physiological monitoring of tomato plants and fruit quality analysis allows the characterization of the different climatic environments that could affect the fruit cracking occurrence. The preliminary results revealed promising. The build fruit-growth models can predict the final fruit diameter and the best harvest time. The plants exhibit different transpiration levels and a certain texture variability in response to the different micro-environmental conditions. Monitoring continues to generate additional data on fruit growth behavior. This contributes to developing a precise fruit cracking model, alerting the greenhouse producers about a potential risk that may lead to losses in yield quality.

Keywords: fruit dendrometer, greenhouse, micro-climate, tomato, cracking.

OS11-05

Imaging of strawberry's vegetation indexes by hand-held smartphone

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With the increasing need for digitalization in agricultural practices, numerical indexes representing the crop's growth status are strongly required. For this purpose, the speaking plant approach (SPA), a sophisticated strategy for environmental control in greenhouses, has attracted a lot of attention. The SPA states that optimal crop cultivation conditions should be controlled based on the physiological status of the plants; thus, monitoring the physiological status of plants is the first and most important step. Therefore, weekly measurements of plant growth using various instruments are becoming more common in greenhouse horticultural production. However, to evaluate strawberry plant growth, the number of flowers and fruits are counted as generative indexes, and plant height and leaf area are measured as vegetation indexes which are both labor and cost-intensive. In our previous study, as a cost-effective phenotyping technique, a smartphone-based monitoring system, which is available for counting strawberry flowers and fruits, was developed. In this

study, we developed a Deep Learning-based image analysis technique that makes it able to measure strawberry plant height from the image captured by a hand-held smartphone. The technique employs a Deep Learning-based object detection algorithm, YOLOv3, to detect the upper surface of the medium and the tip part of the strawberry plants. From the detection result, the average height (y coordinate) of each upper surface of the medium and the tip part of the strawberry plants was calculated then the difference of each average height was considered the plant height. As a test of the developed method, 3-month measurements were conducted. The plant height measured by the developed method was compared with the conventional manual measurement. The coefficient of correlation was 0.99. These results indicate that the developed image analysis technique has enough accuracy to evaluate the plant height of strawberries.

Keywords: deep learning, greenhouse, object detection, plant diagnosis, YOLO.

OS11-06

Crop growth monitoring with time series data based on deep learning techniques

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Recent advances in Artificial Intelligence have facilitated the development of practical technologies applied to solving various problems in agriculture, such as recognizing symptoms of diseases and stress or physical changes related to plant growth. Thus, facilitating decision-making processes, especially toward the autonomous management of farms through the knowledge provided by the developed models. However, considering the complexity of the plants and their characteristics, a more precise study of the physical variables and visual representation throughout the entire cultivation process is necessary to analyze the possible causes and effects of the symptoms related to plant growth. This study presents a model based on deep learning to analyze the interaction of variables that influence plant growth in greenhouse crops. To achieve this, a multi-category database has been collected in two types of open and semi-open greenhouses throughout the year during three growing seasons, including three varieties of tomato plants with a sample of 100 plants per season. The database consists of images captured at the growth point of the plants and phenotyping data obtained weekly, and environmental data with a sampling frequency per minute. The implemented model uses time series data to find the relationship of variables and automatically predict the state of the crop at the individual plant level and further extended as a group of plants. In summary, the proposed research shows a practical solution to monitor plants over time. It provides strategies for multi-category data collection that allow a better understanding of the dynamics of plant stress factors.

Keywords: deep learning; plant growth; tomato plant; smart agriculture; data; sensors.

OS11-07

Multispectral imaging for pH induced micronutrient deficiency detection

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A custom built multi-spectral imaging system was used to collect NDVI(normalized difference vegetation index), ACI(anthocyanin content index) and CFI(chlorophyll fluorescence image) for analysis of petunias. Petunia plants were grown in a greenhouse at several pH levels to induce micronutrient deficiencies and imaged twice a week. These images and corresponding analysis were used for early detection of deficiencies, which in a commercial setting would allow for earlier mitigation of detrimental conditions to minimize long-term effects on plants.

Keywords: Multi, spectral, imaging, petunia, micro, nutrient, deficiencies, NDVI, ACI, CFI, Chlorophyll Fluorescence.

OS11-08

Detecting Rice Blast using Hyperspectral Imagery

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Rice is the primary agricultural product in South Korea. However, rice yield has been consistently affected by a fungal infection, rice blast. Rice blast infection may occur in all stages of rice growth, and it affects all regions of the plant. Recently, rice blast has been affecting a greater area in South Korea, owing to the hotter and more humid summer. Rice production is assumed to decrease by at least 10% to a maximum of 40% depending on when the infection has been identified. Therefore, early detection is essential to protect rice yield. To test the plausibility of hyperspectral imagery methods to detect rice blast, test plots were designed with three varying levels of rice blast inoculation and a control plot. Hyperspectral images were acquired a day before inoculation and a maximum of 3 days after inoculation. Environment variables were stabilized by acquiring images within a temperature and humidity-controlled greenhouse at a predetermined time each day. Machine learning methods were used with dimension reduction models to analyze hyperspectral imagery and classify early-stage rice blast samples.

Keywords: Rice blast, Hyperspectral Imagery, Deep learning.

OS11-09

Automated Feature Extraction of Lettuce Grown in Vertical Farms with Image Processing and Deep Neural Networks

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Adequate quantification of plant growth could accelerate finding an optimal environment. In this manner, growth factors such as plant height, leaf area, and fresh weight have been used as target properties of crop production systems. Recently, the importance of the data has increased by its diverse applicability. However, the versatility of the data is derived from enormous data with consistency, and the automation of data processing could lead to a robust database for optimizing crop production. Meanwhile, the performance of the deep learning models was evaluated based only on the model accuracy, although deep learning has other advantages. This study aimed to train deep neural networks and analyze the deeper abstraction of the trained models. A total of 443 images obtained from the three lettuce cultivars were used for the model training. Several deep-learning algorithms such as feedforward neural network (FENN), long short-term memory (LSTM), convolutional neural network (ConvNet), and multivariate linear regression (LinReg) were compared using multivariate linear regression. All models showed adequate accuracies for the given task, except linear regression. ConvNet model showed the highest accuracy. Based on the color mapping and distribution of the two-dimensional t-distributed stochastic neighbor embedding results, ConvNet could understand the differences among lettuce cultivars. Extension of the target domain knowledge with complex models and sufficient data, similar to ConvNet with multitask learning, was possible. Therefore, deep learning algorithms should be investigated from the perspective of feature extraction.

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Keywords: Computer vision, High-level abstraction, Machine learning, Model performance, t-SNE.

ORAL SESSION 12 / Organic Greenhouse Horticulture: Soil health and biological assessments

OS12-01

The riddle of soil biological assessments in organic greenhouse horticulture

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Soil is a dynamic and living resource and base for the production of food and non-food crops, but also an important player in the global balance of ecosystems and ecosystem functions. The quality and health status of soils are used to describe the sustainability of agroecosystem, its environmental quality and are an indicator for plant, animal and human health. In this context, not only soil biological factors matter, but must be viewed within the context of physical, chemical and biological interactivities as well as of other external factors (e.g., temperature, humidity, climate, management practices).

Various methods may be employed to describe the soil biological status and processes in organic greenhouse horticulture. The challenge is to embrace the complexity of interactions to draw adequate conclusions on implementation. Recent development of high-throughput methods for culture independent description of microbial community composition, gathering a copious volume of data, increase the level of complexity even more.

Conceptualization and contextualization with respect to method choice, collection procedure, analysis and interpretation of soil biological data is a mean to disentangle soil biological properties and interactivities. The presentation is based on cases from various national Swedish and European projects on organic greenhouse horticulture.

Keywords: Organic farming; soil health; soil biological properties, microbial community composition, soil biological data

OS12-02

The effect of using biofertilizers on yield and quality in endive lettuce (*Cichorium endivia* l.) cultivated in soilless culture

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The cultivation of vegetables called "Mediterranean greens", which are generally included in salad-lettuce group vegetables, has started to increase more than ever due to the interest in healthy living and its appetizing appearance, especially in recent years. It is a vegetable

group that can be grown in every period in the world and in our country, which is in demand in the market for 12 months of the year. In this study, the effects of biofertilizers on leaf yield and quality in hydroponic endive lettuce cultivation were investigated.

The deep-water technique is the oldest, the simplest to implement, and the most common soilless farming technique used in the cultivation of leafy vegetables in the world. It is a research conducted to reduce the nitrate accumulation harmful to human health and to provide better quality and cleaner production in such freshly consumed vegetables by reducing the chemical fertilizer ratio in the nutrient solution prepared for Endive lettuce grown in deep-water culture by adding microbial fertilizers. These techniques are needed to reduce the use of chemical fertilizers. Three different biofertilizers were used in the study. The effects of microbial fertilizers containing different bacteria and algae on yield and quality were investigated. Plant nutrient elements content and nitrate ratio were also analyzed. Biofertilizers had a positive effect on plant growth and quality.

Keywords: Soilles cultivation, *Cichorium endivia* L., biofertilizer, yield, nutrient elements, nitrate.

OS12-03

Short crop rotations in organic greenhouse production: consequences for soil health

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Organic greenhouse production of vegetables needs to increase to comply with the Swedish National Food Policy. However, new EU-regulations has radically changed the prerequisites for organic farmers: it limits the possibilities of a highly intense greenhouse production, and instead promotes the adoption of production directly in soil. Demands are made on use of crop rotations in greenhouses, and that one of those crops is for green manure. This entails high risks of productivity loss, along with a shorter production period for the cash crop with risk of economic loss on top. Implementation of the rules is complex under Nordic climate conditions, considering low winter temperatures and lack of light. Plant production in soil poses large challenges, including difficulties with nutrient mineralization and proliferation of soil borne pathogens. Crop rotations, with production of vegetables directly in natural soil, is tested in polytunnels at the Swedish University of Agricultural Sciences, Alnarp, with the aim of investigating potential consequences on soil health of the current EU regulation. Analyses of soil microbial communities, soil nutrient availability, and production yields are made. Results from this 3-year experiment will be presented at the symposium.

Keywords: organic greenhouse production, vegetables, soil health, microbial pathogens, microbial communities.

OS12-04

Legume cover crop nitrogen contributions in organic high tunnels in the United States

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High tunnels in cold northern regions of the United States allow vegetable production for longer periods of the year, yet intensive cultivation can reduce soil health and fertility. Cover crops are non-harvested crops intentionally planted to improve soil health and fertility and are an important component of organic farms. Legume cover crops are particularly valuable due t their capacity to contribute biologically fixed nitrogen (N) since synthetic nitrogen fertilizers are prohibited. High tunnels may allow greater cover crop growth than in open fields, potentially increasing their capacity to contribute N. We compared cover crops including legumes and legume-grass mixtures in an organic high tunnel rotation to determine total biomass N contributed to soils, and the proportion of that N derived from the atmosphere via nitrogen fixation. Treatments includedcowpea (*Vigna unguiculata*), a cowpea-sorghum-sudangrass (*Sorghum bicolor*, sudex) mixture, hairy vetch (*Vicia villosa*), and a vetch-rye (*Secale cereale*) mixture. Vetch and cowpea legumes grown in combination with a non-legume had higher rates of nitrogen fixation than legumes grown alone, measured as biomass nitrogen derived from the atmosphere (7% and 38% greater, respectively). Legumes did not compete well with grasses. Thus, despite greater total cover crop biomass (legume+grass) of mixtures, legume biomass was greater in monocultures, 715 kg ha^{-1} (vetch) to 1776 kg ha^{-1} (cowpea). As a result, legume contributions of total fixed N to the system were also higher in monocultures than mixtures, with both legume species contributing approximately 27 kg ha^{-1} of new fixed N when in monoculture.

Keywords: legume, nitrogen fixation, organic, high tunnel, hoop house, soil, cover crops.

OS12-05

Soil health and local recirculation ensuring organic cucumber cultivation in Norway

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New European organic regulation claims cultivation directly in soil in greenhouses. Cultivation practises in accordance with organic principles imply application of sustainable growing media and compost added for soil improvement. Local resources may be preferred. Goal of soil improvement is soil health including biological soil activity, nutrient availability, and physical properties. Only few studies are done on biological soil health in greenhouses.

Biological soil activity was monitored in a greenhouse cucumber experiment on organic soil enriched with biochar and addition of local (1) compost, (2) solid digestate after biogass or (3) imported organic peat. Effects of silage mulching was tested. Biological activity was measured by three indicators: soil parameters, plant growth and yield, nutrient status and fluctuation.

Results indicated that the mixture with compost contained more organic matter than mixtures with solid digestate and peat. Biological activity in the compost mix, was lower and started later than in the two other mixtures and was in all mixtures more pronounced where silage mulch was added. Respiration rates and fungi content classified all three mixtures as stable growth media.

Nitrogen content and pH in all three mixtures were similar at the start of the experiment. The peat mix needed most amendments, while phosphorous content was highest in solid digestate and lowest in peat.

Plant nutrient turnover to plants was appropriate except lack of micronutrients. Yields performed well.

Preliminary conclusion is that although compost is based on microbial activity and taken for protagonist in soil health, the results showed later and lower biological activity than in the other mixtures. Balance between fungi and bacteria ere in all three mixtures similar and equal to measurements in Norwegian, organic managed soil. Indicators were useful on farm level but could be diversified more. Local compost and digestate functioned as good as imported peat.

Keywords: greenhouse, new regulation, compost, solid digestate, indicators, Norwegian standard.

OS12-06

Leveraging By-Products of the Agri-Food Industry for the Application of Anaerobic Soil Disinfestation in Organic High Tunnel Vegetable Production

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The expansion of the U.S. organic vegetable industry is currently restrained by the lack of sustainable and effective solutions for managing soilborne pests and pathogens. Anaerobic soil disinfestation (ASD) represents an innovative microbial-driven approach to the management of a range of soilborne biotic issues. Based on the amendment of the soil with readily labile carbon (C) sources, ASD requires the selection of effective and low-cost

organic amendments, thereby offering an opportunity to recycle by-products of the local agri-food industry. However, the selection of alternative organic amendments as C sources for ASD treatments requires a prior understanding of how different amendments affects the efficacy of the treatment and the soil nutrient dynamics during and after the ASD treatment. To this purpose, we conducted a field study in an organic-certified farm at the Penn State High Tunnel Facility to compare the amendments of wheat middlings (WM), soybean meal (SM), and molasses (M) for ASD treatment. Treatments included WM, M, SM, WM+SM, and M+SM applied to reach the equivalent of 6 Mg/ha of total C, SM0.5 applied to reach the equivalent of 3 Mg/ha of total C, and untreated control with (UTC+W) and without (UTC) initial irrigation. Romain lettuce was used as a test crop planted three weeks after the ASD treatment. Organic amendments tested were characterized by a C:N ratio that ranged between 6.3 in the case of SM to 57.2 in the case of M. The threshold of soil anaerobicity was achieved with all the amendments. The C:N ratio of the amendments significantly influenced the availability of nitrate-N during and post-ASD. Thus, also affecting lettuce crop yield and quality. The treatment with molasses (with the highest C:N) reduced the availability of nitrate-N during and post-ASD, while SM (with the lowest C:N) ensured the availability of higher nitrate-N levels.

Keywords: Biological soil disinfestation, soilborne pests, soilborne pathogens, organic amendments, carbon, nitrogen, C:N ratio.

OS12-07

Reusing organic substrates and plants increases irrigation water use efficiency without affecting plant yield in a day neutral strawberry pot production system

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Reusing organic substrates for home production in urban and peri-urban horticultural systems may result in environmental and economic benefits. This research aimed to compare the yield, irrigation water use efficiency (I-WUE), and nutrient solution costs among 'San Andreas' strawberry plants grown in bags with substrates containing compost (new or reused) against plants with standard soilless strawberry systems in volcanic gravel. New plants were also compared against one-year-old plants. Plants were in a RCBD under a plastic high-tunnel. Treatments were: 1) new plants in gravel (GV); 2) new plants in compost-based new media (CBN); 3) new plants in compost-based one-year-reused media (CBR); 4) one-year-old plants in compost-based one-year-reused media (CBR2); and 5) one-year-old plants in compost-based one-year-reused media, with initial hand-defoliation (CBRD). Either new or one-year-reused compost-based substrates were 20 % compost +

40 % coir + 40 % gravel (V/V/V). The same Steiner nutrient solution was used for all plants, but irrigation schedules were different across treatments. Plants received 300 and 150 mL per day of solution (average) throughout the growing season when in GV or in compost media, respectively. Yield of marketable fruits (8.0 g or heavier; without deformations) with GV (138.9 g per plant) was not statistically different compared with CBR2 (117.3 g per plant). Marketable fruits were heavier with GV (16.1 g) than with CBR2 (12.3 g). I-WUE increased from 588.0 to 165.5 mL g^{-1} fruit with GV and CBR2, respectively. Nutrient solution costs decreased from MX$ 44.7 to MX$ 5.8 kg^{-1} fruit with GV and CBR2, respectively. Treatments CBN and CBR resulted with statistically poorer means for almost all variables analyzed. We conclude that reused compost base media alongside one-year old 'San Andreas' strawberry plants may increase the I-WUE, decreasing costs of the strawberry pot production without affecting their yield compared with standard soilless systems.

Keywords: Media reutilization, Soilless, Sustainability in horticulture, Circular horticulture, Profitability.

OS12-08

The feasibility of growing media originated from greenhouse waste for plant seedling and growing

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Greenhouse waste is inevitable and might limit the development of greenhouse farming. Meanwhile, peat is the upmost material for greenhouse farming. In our previous study, slight carbonization of greenhouse waste was found to be capable of regulating the phytotoxicity, water retention capacity, pH and EC to be suitable for growing media. Therefore, we proposed an idea to slightly carbonize greenhouse waste into peat alternative as a new type of sustainable growing media. This work intended to evaluate the feasibility of this peat replaced growing media for seedling and growing. Cucumber straw and rose straw was sightly carbonized to replace peat in the seedling media and growing media formulas with a ratio of 5, 10, 20 and 40 vol%, respectively. Celery cabbage, lettuces, tomato, cucumber have been sown in the prepared seedling media. The growth vigour in seedling stage was analyzed and found that biomass yield increased by at least 1.2 times than control. On the other hand, conventional seedlings of three commercial ornamentals were transferred to peat replaced growing media. Dry weight, number of flowers, SPAD value and nitrogen content were analyzed. The highest biomass yield for fairy primrose and cineraria is observed at 20% and 30% replacement rates, respectively, while the highest replacement rate (40%) gains the highest biomass yield (1.13 times) for kale. Fairy primrose and cineraria have more flowers than the control. The highest SPAD values were obtained at the 40 vol.% replacement rate for fairy primrose and kale and at the 30 vol.% replacement rate for cineraria. Nitrogen content has a similar trend as SPAD values. The analysis of proline, MDA,

soluble protein, soluble sugars and the activity of antioxidant enzymes has been conducted. In conclusion, greenhouse waste undergoing slight carbonization could replace 20% to 40% of peat in growing media for plant seedling and growing.

Keywords: greenhouse waste, peat alternative, growing media, seedling, plant growth.

ORAL SESSION 13 / Greenhouse systems and design

OS13-01

Transforming Agriculture for a Changing Climate: Harnessing Precision Technologies and Controlled Environments to Enhance Food Security in Arid and Semi-arid zones

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Many innovations in agriculture have the potential to improve the livelihoods of smallholder farmers in poor and developing countries, while facing, mitigating, and adapting to climate change. *Inter alia*, Precision agriculture, integrated pest management, conservation agriculture, cover cropping, and renewable energy-powered farming can significantly reduce input costs and increase yields productivity and nutritive value. Those innovative ways in agriculture also provide better job opportunities for women and youth while it is possible to create a sustainable and resilient food system that benefits both farmers and vulnerable communities. For instance, Precision Agriculture (PA), which involves the use of high-tech sensors and analytical tools to optimize crop production and aid in management decisions, is becoming an increasingly popular type of farming that has the potential to enhance yield, reduce inputs, and improve resource efficiency. It may help lower CO_2 emissions and save resources. Controlled Environment Agriculture (CEA), on the other hand, allows for the cultivation of crops in a fully controlled environment, mitigating the impact of external environmental factors on crop growth, and enhancing the adaptation to climate change.

This paper examines the impact of climate change on agriculture and the different adaptation strategies through the use of Precision Agricultural Technologies and CEA for sustainable crop production under future climatic conditions. It examines how climate change is affecting food security around the world, especially in arid and semi-arid zones of developing countries. It presents case studies of the successful implementation of different technologies of controlled agriculture, including greenhouses and vertical growing systems, and explores their potential to protect crops from extreme weather conditions, reduce resource use and improve crop yields. Additionally, this paper highlights challenges and

opportunities to reach the adaptation potential of Precision Agricultural Technologies and Controlled Environment Agriculture and discusses how these strategies can contribute to more resilient and sustainable food systems. The paper will also discuss the need for systemic change in terms of policies that encourage farmers to adopt new technologies and crop production systems to grow their crops. The research analysis will draw on evidence from a variety of sources, including academic studies, government reports, and international case studies. The paper also offers a glimpse of Data-driven agriculture's crucial role in precision agriculture by providing farmers with real-time information (e.g. on soil moisture, nutrient levels, and crop health), enabling them to make informed decisions and optimize their farming practices and hence improving agricultural productivity and sustainability.

In summary, this paper offers a comprehensive analysis of the potential of precision agricultural technologies and controlled environment agriculture in building resilient agriculture for a changing climate and presents a roadmap for their successful implementation to address food security challenges.

Keywords: Climate change; Controlled Environment Agriculture; Precision agriculture; Adaptation strategies.

OS13-02

Development, Correction, and Testing of a Semi-Open Chamber System for Gas Exchanges Measurement of Cucumber Seedlings

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The net CO_2 assimilation rate of the whole crop canopy directly affects yield. The massive data on photosynthetic characteristics enable phenotyping of crop status to improve yield. To date, there were time constraints to collecting data on photosynthetic characteristics. Faster collecting data that provide the biochemical limits of carbon assimilation requires instantaneous measurements of photosynthetic rates over a wide range of CO_2 concentrations in an unsteady state. In this study, we developed a semi-open chamber system for whole canopy gas exchange rates with steady and unsteady state measurement techniques for collecting biochemical photosynthetic data. In the process of correcting measurement errors caused by a chamber volume, measurement total errors caused by three factors in terms of changes in reference and sample CO_2 concentration and leakage rate were confirmed. The measurement method was evaluated by comparing Farquhar-von Caemmerer-Berry (FvCB) model parameters and the estimation value of photosynthetic rate on steady and unsteady state measurement techniques. The total measurement error

did not exceed 10%. The root mean square error of the FvCB model with steady and unsteady states were 0.48 and 0.64, respectively. Results indicated that the developed system was appropriate for measuring the gas exchange rates of the whole canopy. In addition, it revealed that the developed semi-open chamber system accelerates data collection for biochemical photosynthetic models.

Keywords: whole canopy, phyosynthesis, semi-open chamber, steady state, unsteady state.

OS13-03

Cultivar selection of mizuna for optimal space station performance

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Despite the precise control over environmental conditions provided by modern CEA technologies and practices, the plant genotype remains a key factor in optimizing phenotypic expression of desirable horticultural and nutritional traits. This genetic element becomes increasingly important when environmental conditions are less flexible, as they are on the International Space Station (ISS) and other spacefaring endeavors. *Brasssica rapa* var. nipposinica (mizuna) is a leafy green vegetable that matches the desired nutrient profile for supplementing the limitations of the space diet. However, the manner in which mizuna responds to the fixed environmental conditions of the space station, including the hyper-elevated levels of carbon dioxide, is unknown. It is also unclear if there are more inter-varietal (mizuna - mustards) or intra-varietal (mizuna - mizuna) differences in response to the environment of the space station. This study aims to determine which cultivar provides the best genotype for further light optimization studies.

Twenty-two cultivars of mustard greens including 12 cultivars of mizuna were grown under ISS like conditions to determine which would provide the greatest yield and highest nutrient concentrations. Plants were grown for 31 days, harvested, and flash frozen. Morphological and fresh mass data were collected prior to freezing. Half of the plants were processed and analyzed to determine concentrations of carotenoids, anthocyanins, and vitamins C, B1, and K1. The remaining half were analyzed to determine concentrations of calcium, potassium, iron, and magnesium. This was conducted thrice and the resulting data was then normalized and weighted to determine which cultivar would provide the best phytonutrient and morphological profile for further optimization of space-based cultivation. It was found that 'Green Amara' (B. carinata) provided the best overall nutrient profile, while 'Hybrid Red' mizuna provided a complimentary profile for a more complete dietary supplement.

Keywords: anthocyanin, Brassica, carotenoid, mustard, vitamin.

OS13-04

Modeling and Optimization of Ultraviolet LED Nutrient Solution Sterilization Module

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In order to reveal the influence of structural parameters on distribution of ultraviolet radiation in the ultraviolet LED nutrient solution sterilization (UV-NSS) module and optimize, the optical engineering software Tracepro was used to model and ray-trace the UV-NSS module, where the inner diameter of tube, the thickness of tube wall, the tube-lamp distance and the bidirectional reflectance distribution function (BRDF) of the inner surface of light bar are the parameter factors, the effective UV radiation ratio (EURR) and the irradiance dispersion (ID) are the response, together they are studied by response surface method for optimization. The results show that when the UV-NSS module model has the tube inner diameter of 28 mm, the tube wall thickness of 2 mm, the tube-lamp distance of 4 mm, and the BRDF of 0, its EURR is 12.14%, ID is 0.320 6, and the difference between its ultraviolet irradiance and the measured value is only 3.68%, meaning that the model can accurately show the irradiance distribution in the module. Based on the model, the central composite bounded design was carried out, and the response surface method was used to analyze the quadratic regression equations of EURR and ID. Their determination coefficients were 0.962 0 and 0.967 8 respectively, which means the fitting is significant. With the goal of maximizing EURR and minimizing ID, the optimal combination of parameter factors is determined with response surface method under the consideration of actual situation: the inner diameter of tube is 50 mm, the thickness of tube wall is 3 mm, the tube-lamp distance is 0.6 mm, BRDF is 0.55. After being substituted into model, its EURR is 32.11% and ID is 0.317 8, respectively increased and decreased by 164.50% and 0.87% compared with before optimization. Using these parameters to manufacture the UV-NSS module, the difference between the measured value and the simulated value of the ultraviolet irradiance is only 1.73%.

Keywords: UV sterilization, Tracepro, model, central composite inscribed design, parameter optimization.

OS13-05

Comprehensive CFD model to analyze potential Mexican greenhouse horticulture zones

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México has significantly increased crop production using protected systems as a result of strategic governmental policies to augment the high-quality produce as well as to maintain throughout the year such products in the market. Crop production in greenhouses requires knowledge about crop management and adequate management of the environment. In this sense, it is essential to know the availability of the local natural resources to make the greenhouse an advantageous agricultural production system. It has been identified for several regions of México favorable weather for horticultural production, such as mild weather either in winter or summer with thermal jumps lower than 10 degrees and high radiation. Notwithstanding these advantages, it is still necessary to rely on low-tech greenhouses capable to handle the great variability of weather conditions as a result of the national geography. Then, the cost of production can vary considerably since some regions demand for heating and/or cooling to cover environmental requirements. To have an insight into this issue, the objective of this work is to perform a benchmarking of a typical greenhouse using numerical results derived from Computational Fluid Dynamics (CFD). This investigation is focused on a greenhouse with a chapel cross-view shape. Then, the internal environment of a greenhouse is analyzed by considering air temperature. Given that this type of greenhouse is often found in different regions of México, this research evaluates the influence of weather conditions and finds out their impact of them by means of energy efficiency assessment. As well, this study looks for an analysis of thermal gradients that could be observed. Processing all these outcomes derived from a series of simulations can be proposed useful information on the planning and management of the crop cycle, considering local climatic factors to predict better planting dates, mechanical conditioning, and ancillary systems for the greenhouse.

Keywords: Simulation, weather, warm period, cold period.

OS13-06

Vinblastine production of *Catharanthus roseus* in the plant factory using artificial lighting

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In this study, we propose a suitable cultivation method for *Catharanthus roseus* in a plant factory using artificial lighting (PFAL) for vinblastine production, a material used in the production of anti-cancer drugs. The biomass of *C. roseus* was higher in the plants cultivated under monochromatic red light for 28 d than that of those cultivated under the light including blue light. Vinblastine precursor concentrations exhibited no difference in plants cultivated under various light conditions. Therefore, among the light conditions, monochromatic red light proved superior for *C. roseus* cultivation. Plants cultivated under monochromatic red light over 28 d accumulated maximum vinblastine when irradiated under ultraviolet A (UV-A)

light for 5 d. In particular, effective UV-A wavelength and intensity for vinblastine accumulation in the leaves was 385 nm and 25 W m^{-2}, respectively. However, vinblastine accumulation efficiency in the plant cultivated under monochromatic red light using UV-A light irradiation was decreased by increasing the plant size due to the increase in the effect of the mutual shielding of light by leaves. Thus, the most suitable cultivation method of *C. roseus* using PFAL for vinblastine production was cultivation of plants under monochromatic red light before the occurrence of mutual light shielding by leaves, after which they were irradiated with UV-A light at 385 nm and 25 W m^{-2} for 5 d. This cultivation method will enable high efficiency of vinblastine accumulation in the plant using UV-A light irradiation and a short cultivation cycle.

Keywords: UV-LED, Secondary metabolite, Alkaloid, Madagascar periwinkle, Pharmaceutical ingredients.

ORAL SESSION 14 / Fertigation, water and growing medium II

OS14-01

Agrotopia, a platform to test alternative water sources for urban horticulture

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In this highly urbanized world, there is a growing demand to supply fresh food to the cities. Urban farming can deliver an answer, but the experience is still limited. At the same time, greenhouse horticulturalists face important challenges, such as space availability and high energy costs. To address these challenges, INAGRO has built Agrotopia, a state-of-the-art 9000 m^2 rooftop greenhouse, for research into the latest greenhouse cultivation techniques and professional urban farming. Located on top of a warehouse of the agricultural auction market, Agrotopia is a striking example of integrating food production in an urban or urbanized environment with multifunctional use of space shared between different parties. Agrotopia aims to synergize with its surroundings by investigating how the functions of agriculture, industry and the city are intertwined. One of the examples includes innovative water usage and recycling. Because of climate change, drought periods are expected to become more frequent and more severe. This poses a risk for greenhouse owners to deplete their water buffers during summer time. To avoid using non-sustainable water sources such as surface-, ground- or tap water, we need to look at alternative sources of water. However, quality and sufficient supply or storage need to be ensured. Here, we will study the effect of alternative water sources on yield and plant physiology during tomato cultivation. We will investigate, amongst others the use of condensate from CHP installations and run-off water from impervious surfaces in an urban environment (e.g., roofs, parking lots). These results will lead to new insights into how professional horticulture may be integrated into an urban environment.

Keywords: Urban farming, rooftop greenhouse, alternative water sources, hydroponics.

OS14-02

Consumption of and preference for NH4+ versus NO3- of hydroponically cultivated lettuce in different NH4+/NO3- ratios

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Crop cultivation based on organic waste typically requires mineralization processes. For nitrogen (N), ammonification and nitrification provide inorganic ammonium (NH4+) and nitrate (NO3-), and the resulting NH4+/NO3- ratio varies with the raw material and mineralization process. In closed-loop hydroponics, nutrient solution recirculation improves resource utilization but may cause nutrient imbalance over time if the nutrient resupply does not match the plant uptake. Furthermore, the plant preference for NH4+ versus NO3- will affect the nutrient solution NH4+/NO3- ratio, and elevated ratios may result in ammonium toxicity. In this work, lettuce was cultivated in batch deep water cultures to investigate nutrient consumption and development of nutrient solutions over time. Nitrogen was provided as a mix of ammonium and nitrate, and treatments varied in nutrient solution total strength and NH4+/NO3- ratio (0 to 1 mM/mM). The results demonstrate that nutrient consumption varied with the nutrient solution NH4+/NO3- ratio, exemplified by a decreasing potassium consumption with increasing NH4+/NO3- ratio. The plant preference for NH4+ versus NO3- was similar across different treatments, and the ratio of NH4+ consumption to total N consumption was higher than the ratio of NH4+ to total N in all nutrient solutions. In consequence, the nutrient solution NH4+/NO3- ratio was reduced over time, even when starting with an unfavorable high NH4+/NO3- ratio of 1 mM/mM resulting in reduced biomass production. In a closed-loop perspective, this illustrates important perspectives on how plant cultivation conditions may develop over time towards more unfavorable or favorable conditions, and - for defined processes - towards a long-term semi steady state. The paper details resulting plant biometrics and nutrient consumption profiles, providing insight into effects of NH4+/NO3- ratios and nutrient solution development relevant for optimized crop cultivation and the design and integration of upstream waste treatment processes for nutrient recycling in closed-loop hydroponics.

Keywords: nitrogen utilization, ammonium, nitrate, consumption rates, nutrient preference, hydroponics, nitrification.

OS14-03

Can they dig it? Hydroponic system comparison for greenhouse strawberry production

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Hydroponic production of strawberries (*Fragaria x ananassa*) in controlled environments has become more attractive to growers in recent years due to the precision and stability of

indoor systems. In hydroponic production, there are two main categories of systems: substrate and water culture. It is commonly heard colloquially that strawberries do not grow well in water culture systems; however, there is little to no published research to support this assertion. This experiment compared a common substrate culture system with three different water culture systems to gauge the feasibility of water culture strawberry production systems. Strawberries were grown in four hydroponic systems in a greenhouse in Athens, Georgia, USA. The first system was a substrate-based system with recirculating fertigation drip.The substrate was 50% peat (Sungro Metro-Mix 830) and 50% super coarse perlite (Whittemore) by volume. The other three systems were water culture systems: a modified nutrient film technique (NFT) system, a vertical system (Tower Garden), and an aeroponics system. The strawberry plugs cv. 'Florida Beauty' and 'Florida Brilliance' were obtained from a commercial grower (Lareault Nursery, Quebec, Canada) and then transplanted into the substrate, NFT, and vertical systems in October 2022, and into the aeroponics system in December 2022. A modified Yamazaki nutrient solution was used as the nutrient solution in all systems, and the pH and EC of all reservoirs were maintained within 5.5-6.5 and 0.75-1.25 dS/m, respectively. Weekly fruit harvests were analyzed for the number of fruits, fresh weight, marketability, total soluble solids, and dry weight. Final plant harvest analysis consisted of shoot fresh weight, leaf area, and shoot dry weight. The substrate culture system produced higher fruit yields and larger plant biomass than each water culture system, indicating that substrate culture systems are superior for greenhouse hydroponic strawberry production.

Keywords: Hydroponic, strawberry, system comparison, NFT, aeroponic.

OS14-04

Drainage management in a cascade hydroponic system: Combination of cucumber and melon crops

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Cascade hydroponic systems have the potential to minimize environmental impact and improve resource efficiency by recycling the nutrient solution drained from a hydroponic (primary-donor) crop to irrigate another (secondary-receiver), less sensitive to salinity crop. However, it remains unclear if the drained solution from the primary crop can fully meet the nutritional requirements of a secondary crop, and whether the productivity of the secondary crop is affected. To address this question, a prototype cascade hydroponic system was designed and tested using a cucumber crop as the donor crop, and a melon as secondary crop. The performance of the system in terms of productivity and water and nutrient use efficiency was evaluated by measuring plant growth, fresh and dry matter production, nutrients content, and photosynthesis rate in the secondary crop. The amount of water and nutrients used for the primary and secondary crops was also recorded. This work was

carried out under the ECONUTRI project that has received funding from the European Union's Horizon 2020 research and innovation programme under the Horizon Europe Grant agreement: 101081858.

Keywords: water use efficiency; nutrients use efficienc; greenhouse; soilless; nutrients.

OS14-05

Transpiration rates for suitable crop combinations of Cascade hydroponics systems

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A Cascade hydroponics system uses the drainage solution of a primary crop to irrigate a secondary one. The different transpiration rates of primary and secondary crops in the system influence the water and nutrient requirements for fertigation. We analyze different crop combinations through simulation scenarios according to the climate conditions, growing area, and growth cycles. The initial model is validated using experimental data of water amounts for irrigation and drainage tanks. The crop yield is evaluated through plant growth and fresh weight measurements. The analyzed system considers a tomato the primary crop and lettuce the secondary crop. The expected result is a guideline for suitable crop combinations for a Cascade hydroponic system for water use efficiency.

This work is part of the ECONUTRI project funded by the European Union's Horizon 2020 Research and Innovation Program under the Horizon Europe Grant agreement: 101081858.

Keywords: Hydroponics, cascade hydroponics, transpiration, multi-crop.

OS14-06

Spent Mushroom Compost as an Alternative to Peat-based Soilless Media for Greenhouse Potted Basil Production

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Peat moss is the most popular growing medium used for horticultural productions. However, with the continues expansion of the greenhouse industry and the slow regeneration rate of peat bogs, the cost of peat is increasing along with concerns about the sustainability of peat-based soilless media. In Pennsylvania the *Agaricus bisporus* (Agaricus) mushroom industry generates over 1.1 M tons of spent mushroom compost (SMC) annually. While considered a waste, often used as a soil amendment, SMC has a relatively high content of minerals and could potentially be recycled to substitute at least in part peat moss as a growing medium, contributing to improve the sustainability of both the mushroom and greenhouse industry. To this purpose, a study was conducted to evaluate the potential of SMC as an alternative to peat as a soilless

substrate. Peat moss was mixed with SMC and perlite in different ratio to obtain five growing media mixture: T1 (50% peat, 50% perlite), T2 (12.5% SMC, 37.5% peat, 50% perlite), T3 (25% SMC, 25% peat, 50% perlite), T4 (37.5% SMC, 12.5% peat, 50% perlite), T5 (50% SMC, 50% perlite). A commercial peat and perlite mix (T6, Premier Tech Growers, PRO-MIX BX) was used as a control. The alternative substrate mixes were compared for their physicochemical characteristics and their effects on yield and quality of potted Italian Genovese basil (*Ocimum basilicum* L.). Significant differences were observed in the mineral composition, pH and soluble salt content of the substrate mixes tested. Substituting 50% (T3) or 75% (T4) of the peat with SMC provided a yield comparable to the commercial control (T6), while lower yield levels were observed with T1 and T5 mixes. Substrate mixes also influenced basil quality and mineral profile. In conclusion, SMC with its residual fertility could be used to partially substitute peat without reducing basil yield and quality.

Keywords: Growing media, peat substitute, *Ocimum basilicum*, sustainable greenhouse production, spent mushroom compost, residual fertility, mineral profile

ORAL SESSION 15 / Sensors, automation, and robotics in greenhouses II

OS15-01

Autonomous greenhouse and crop control in cucumber

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Greenhouse horticulture plays an important role in the year-round production of fresh and healthy products with a continuous, high quality. Currently, the horticultural sector is facing a number of challenges. A major challenge is the limited availability of sufficient highly qualified staff that can oversee all aspects the production system. Other challenges are the increasing costs of resources, such as electricity, natural gas, CO_2 and fertilizers. The increasing complexity of the production system require the step to a more data-driven approach. In the public-private partnership project AGROS, we work on the realization of an 'autonomous greenhouse' in which cultivation is controlled remotely via artificial intelligence, based on measurements of crucial crop properties with the help of intelligent sensors in which crop management is supported by intelligence in order to achieve a sustainable and profitable cultivation system. In the AGROS project, we have been working on the building blocks to realize an autonomously controlled cucumber cultivation. Plant traits that are essential to take decisions on crop management and climate control were selected, and the required sensors were selected and tested. For the traits that could not yet be automatically measured, such as the number of newly formed cucumber leaves, vision technology was developed and tested. For the autonomous control, two approaches were selected. The first approach

is a Digital Twin, a virtual representation of the cucumber greenhouse and crop, based on crop and climate models. Based on continuously received information of the greenhouse climate and crop sensors, it will determine its control strategy. The second approach is Reinforcement Learning, which is a machine learning training method based on rewarding desired behavior, in this case net profit of a cucumber cultivation. Reinforcement Learning takes the optimal choice based on the information on the environment and the actions it can take. At every moment, the available information is evaluated and optimal setpoints are determined again. In this way, the RL model learns how to act when a certain situation occurs, without specific instructions being given. The controls were tested in three greenhouse compartments with cucumber crops. Each compartment was controlled by either the Digital Twin, the Reinforcement Learning algorithm or a group of crop and irrigation experts representing the growers' knowledge. All compartments were controlled based on a goal function, which is the net profit. Net profit is determined by the balance between costs (electricity, natural gas, CO_2) and benefits (harvested cucumbers). In the coming months, we will follow the results and learnings of these controls, which can be shared at the Greensys symposium.

Keywords: autonomous control, Digital Twin, Reinforcement learning, cucumber, AI, physiology, sensors, algorithms.

OS15-02

Utility-Purpose Small Robots for Farmers: A Case Study on Harvesting Apples

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The agricultural industry is facing a significant problem with labor shortages, particularly in the case of apple farming where the task of harvesting and transporting the fruit requires a lot of workers. To address this issue, a small, utility-purpose robot has been developed. This robot, which is of the crawler type, is designed to navigate rough terrain and slopes, and is equipped with LiDAR detection for self-driving capabilities. In our study, we tested the robot's ability to transport apples and found that it was able to transport a total of 297.5 kg of harvested apples over a total distance of 1.4 km, equivalent to the work of two human workers. These results suggest that the use of this robot could result in significant labor savings for the apple farming industry. By increasing the number of robots and optimizing their usage, apple farmers could reduce their labor costs and increase their productivity. In conclusion, the utility-purpose small robot presents a viable solution to the labor shortages faced by the agricultural industry. Its ability to reduce the need for manual labor can greatly enhance farmers' productivity and efficiency. Additionally, it can also help to lower labor costs and improve the safety of workers. With continued advancements and development, this robot has the potential to become a crucial tool for farmers in the future.

Keywords: agricultural robots, utility-purpose, Labor savings, LiDAR, self-driving.

OS15-03

Seedling Vigor and Germination Rate of Lettuce Cultivars Quantified Using a Simple and Automated Imaging Technique

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Accurate evaluation of seed quality is important for growers and seed banks to identify potential seeds and young plants that can tolerate various environmental conditions, have high vigor and result in a good yield crop. However, most of seed evaluation methods are slow, destructive, and require specialized skills. There are some commercially available, computer-based tools, but those too are expensive. For that reason, in our study, we used a non-invasive, quick, and inexpensive image analysis technique to quantify germination rate, seedling uniformity (how similar are seedling sizes), germination uniformity (how similar is germination time), and seedling vigor (how fast the plant grows). We seeded nine lettuce (*Lactuca sativa*) cultivars in cell trays with soilless mix (MM830-F3B RSI; Sungro® Horticulture, Agawam, MA, USA) and kept them in a growth chamber. Seedling images were taken three times a week for two weeks using chlorophyll fluorescence imaging (a sealed dark tent equipped with a monochromatic camera with a long wave pass filter and Blue light LEDs). Images were downloaded and analyzed using Python code. We observed germination less than 50% in three cultivars three days after seeding, germination was above 80% in all the cultivars starting on day six after seeding. In all the cultivars, lettuce seedling dry weight was positively correlated with canopy size obtained thirteen days after sowing (R= 0.8). Therefore, using a linear model, we could estimate the final dry weight of lettuce plants by looking at seedling canopy size counting for cultivar (R^2= 0.82, P < 0.001). Our results demonstrated that a simple, cost-effective, and automated image technique can help evaluate seed lots, germination, and seedling vigor. To further increase the efficiency of our method, the image acquisition and image analyzing steps could be automated using inexpensive microcomputers such as Raspberry Pi.

Keywords: Seed, seedling vigor, germination, image analysis, automation, cost-effective

OS15-04

The impact of automation and digitalization on management and labor in greenhouse operations in German horticulture – a mixed methods investigation

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Shortages of skilled workers, rising energy prices, or structural changes are challenging greenhouse operations in German horticulture. Technological innovations can contribute to solving these problems. However, most research on agricultural innovations focuses on the perspective of farmers. However, the adaption of new technologies directly affects and

changes the work environment and everyday working tasks of employees. Our study focuses on both horticultural managers and employees and aims to answer the research question of how digitalization and automation affect them and their work. We used a mixed methods design approach combining qualitative and quantitative empirical fieldwork. We first conducted a systematic literature review (SLR) using the PRISMA approach. Results from the SLR suggest that digitalization and automation affect horticultural employees in five central aspects: the (i) amount and (ii) type of work they have to carry out their (iii) health, and (iv) income as well as (v) the skills they need for the occupation. In 2021 we secondly conducted a qualitative field study with 8 managers and 15 employees in German horticultural companies with relevant greenhouse production. Here we find that most of the results discovered in the SLR are enriched and confirmed by the field study evidence, but also some findings are contradictory. A quantitative online survey in Spring 2023 with both actor groups shall explore the beneficial and obstructive factors of technological innovations in greenhouse operations using the technology acceptance model (TAM). These results are expected in Summer 2023 and will be included in the presentation and paper submission. Our findings are relevant for horticultural managers who aim to enhance workings condition in the horticultural sector and to make workplaces more attractive.

Keywords: Employee research, technology acceptance model, Germany, Greenhouse horticulture.

OS15-05

Navigation of a Differential Robot for Transporting Tasks in Mediterranean Greenhouses

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Agriculture is key to sustaining the population growth of society, as it plays a key role in animal and human nutrition. Another key factor is also the sustainability of processes, which is why it is important for agriculture to be sustainable. In the pursuit of this sustainability, automation and in particular robotization can be tools for problem optimal solving. On the other hand, precision agriculture in greenhouses makes it possible to optimize quantity and

quality production while maximizing profit. 92% of the world's greenhouse area is used as Mediterranean-type greenhouses (Rijswick, 2018). There are many tasks that are carried out in a greenhouse, but not all of them are feasible using robots. One of the most common tasks is transport. This paper explains one of the results of the Agricultural Collaborative Robots inside IoT (AGRICOBIOT) project. In particular the AGRICOBIOT I robot (Fig. 1), which is part of a fleet of multi-functional robots destined, among other tasks, to transport harvested fruit, tools, etc. inside greenhouse. The robot has been designed on the basis of a generic commercial differential mobile platform, which has been adapted to carry out this task collaborating with the human. The work describes the details of this robot and validates its operation in Gazebo using a 3D model of a greenhouse located in Almeria (Southern Spain) (Fig. 2). Specifically, a solution is proposed to the problem of navigating the entire greenhouse (Fig. 3), taking into account for the presence of unexpected or dynamic objects and people in the corridors by means of a global and local planner from those available in the Nav2 framework (Macenski et al, 2020).

Keywords: Mobile Robotics, ROS2, Gazebo Simulation, Navigation, Mediterranean Greenhouse

OS15-06

Food production in future human space exploration: when and how to envisage a crop production system

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In the context of human space exploration, several space agencies study, develop and test crop production systems as a way to supply the crew members with important nutrients. As a matter of facts, although the number of crew members is low, the quantities of nutrients to be embarked increase quickly with the mission duration and can jeopardize the feasibility of the mission. Therefore, in-situ production of such nutrients, based on crop production, offers an attractive alternative. The introduction of a crop production system comes however with its pros and cons. Its impact on the space mission resources varies depending on the mission characteristics and the other metabolic supplies. A subsequent question emerges: when does an in-situ crop production become equivalent to embarking the nutrients?

The question is investigated for various space mission scenarii and tentative recommendations are elaborated with regards to when to produce crops in-situ and how to integrate the crop production system within the mission.

Keywords: space mission, life support system, crop production, break-even point.

ORAL SESSION 16 / Organic Greenhouse Horticulture: Crop systems and management

OS16-01

Assessing the Benefits and Limitations of a Dynamic Agrivoltaic Greenhouse for Crop Protection and Yield Optimization in a Changing Climate

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As climate change continues to intensify, protecting crops from excessive radiation and heatwaves has become increasingly important. Techniques such as shading tarp or bleaching are used to protect crops, but they require a significant workforce and are often left in place throughout the entire growing season. To address this issue, Sun'Agri has developed an agrivoltaic greenhouse with solar panels above the greenhouse that can be steered to shade crops or let the light pass according to crop needs.

The greenhouse for this study is located in the South-West of France and composed of 9 asymmetric chapels. The north part of the structure is covered, in between chapels, by rows of solar panels that can be individually steered. The south half of the greenhouse serves as a control zone and has a shading tarp which can be deployed.

The experiment was carried out in 2021 and 2022 on organic tomatoes, eggplants, and cucumbers. Despite a similar fruit weight, number of flowers per cluster and plant mortality and even a higher number of clusters, yields for tomatoes under solar panels were reduced by 20% for both seasons. Yields were similar between control and agrivoltaic eggplants in 2021. However, yields were 50% higher under panels for eggplants in 2022 and cucumbers in 2021 and 2022. Pests caused defoliation in control plants reducing their shoot and leaf dry mass and increased plant mortality while plants under panels had lower pest pressure.

Further experiments are expected in 2023 to better understand the performance of these three crops in agrivoltaic greenhouses and establish a link between shading and pest pressure.

Keywords: Agrivoltaic greenhouse, Crop protection, Climate change, Asymmetric chapels, Dynamic solar panels.

OS16-02

A new rotating vertical growing system for the production of organic lettuce

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To meet the vegetable and fruit needs of the world's population in the coming years, while limiting the environmental impact of greenhouse and controlled environment agriculture, we have studied the agronomic performance of a new vertical rotative growing system (VRGS) using LEDs as a complementary lighting system compared with a horizontal growing system (HGS) using HPS top lighting. We hypothesized that VRGS double the yield of lettuce per m^2 of greenhouse floor used compared with HGS. We also evaluated the impact of using two types of organic fertilizers (OF), one derived from animal-based products (OAF; poultry pellets, feather meal), and a second made from a mixed of animal and plant-based fertilizers (OMF; shrimp meal, feather meal, poultry pellets, alfalfa meal). For both type of OF, three nitrogen concentrations (C1-330 mg L^{-1}, C2-700 mg L^{-1}, C3-1000 mg L^{-1}) were incorporated within an organic peat-based growing medium at the transplantation. We made the assumption that the incorporation of 700 mg N L^{-1} achieves the highest yield compared with a lower or higher concentration, the latest having a too high salinity. Treatments were compared within a three-level factorial design with system as whole plot factor and dates as sub-plot factor with 3 to 5 replicates and 10 plants per experimental unit. The chemical and biological properties of the growing media as well as the photobiological and plant growth parameters were measured at 7, 14, 21, 28 days after transplantation. Our results showed that the fresh and dry plant biomass per m^2 were 2.10 and 3.5 times higher, respectively, for the VRGS system compared with HGS. Regardless of the growing system, after 28 days of growth, we observed a higher fresh biomass for C2 (+7.5%) and C3 (+10%) compared with C1 for plants receiving OMF, while their dry biomass per m^2 was higher for C2 (+8%) compared with C1 and C3. However, no significant impact of the N concentration treatments was observed when OAF was applied, suggesting that a lower N concentration was sufficient to achieve a high yield. During that presentation, results will be discussed in terms of microbial activity and available nutrients in the growing media and plant development. In conclusion, results of this study showed that VRGS is promising for optimizing the greenhouse land used. However, the concentration of OF that should be incorporated into the growing medium at the transplantation depended on the type of OF; animal-based OF requiring a much lower concentration than OMF where plant-based OF was added.

Keywords: Greenhouse, Controlled environment agriculture, Vertical agriculture, Innovation technologies and agriculture, Sustainable agriculture, Organic farming, Organic fertilizers.

OS16-03

Development of a hybrid aeroponic-water-buffer system for intensive tomato production

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Since the 1970s, rockwool substrates have been used in intensive vegetable production. Disadvantages are that they are produced with an enormous energy input (high CO_2 emissions) and are often disposed of in landfills after the end of cultivation (150 m^3 substrate waste/ha a). Therefore, substrateless hydroponic systems such as Aeroponics (AP), Deep Flow Technique (DFT) or Nutrient Film Technique (NFT) have been developed. However, these are mainly used for plants with short growth cycle due to their susceptibility to lack of buffering capacity during pump failures and oxygen reduction in the root zone. To overcome these drawbacks, we combined and further developed different hydroponic systems (AP+NFT and AP+DFT) for use in intensive tomato cultivation. The focus was on plant development compared to conventional tomato production on rockwool and plant resilience to simulated pump failure in the culture systems.

No differences were observed in terms of leaf area. Yield increased significantly by the hybrid systems AP+NFT (+35%) and AP+DFT (+25%) compared to the rockwool variant. This was probably due to the higher oxygen concentration (+1.5 mg/l) and root temperature (+1 °C) in the hybrid systems. Soluble solids and titratable acids did not differ between the variants. In contrast, after the simulated power outage (18 h), fruit coloration was accelerated by the hybrid systems compared to the rockwool variant. This was significantly more pronounced by the hybrid AP+NFT, with wilting of leaves also occurring. Water consumption per week was identical between the Hybrid AP+DFT system and the control. The water consumption of the Hybrid AP+NFT system was increased by 64% compared to the rockwool version. Consequently, the Hybrid AP+DFT system is recommended for intensive tomato cultivation.

Keywords: aeroponic, deep flow technique, nutrient film technique, rockwool, hydroponics, sustainable plant growth.

OS16-04

Development of a Seasonal Leafy Vegetable Crop Model for Rooftop Greenhouse Energy Model

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Greenhouse cultivation is becoming widespread worldwide, with South Korea's per capita greenhouse area occupying the first in the world. However, a large amount of energy load is

required to adjust the internal environment due to four distinct seasons. At the same time, climate change is lead to increase in energy load for greenhouse. In order to reduce this, it is necessary to analyze the energy of the greenhouse over time. Among the many factors that create the internal environment of the greenhouse, the energy load associated with crops is particularly nonlinear. This is because each crop's photosynthesis and respiration depend on microclimates such as solar radiation, air temperature, and humidity. And, because the shape of the leaves is not homogeneous, the opening and closing mechanism of the pores cannot be accurately identified, and it is difficult to obtain the saturated water vapor pressure of the leaves representing the entire canopy space. However, about 40% of the solar energy introduced into the greenhouse is used for energy exchange in crops, and crops with large canopies such as tomatoes use up to 75%. Therefore, in this study, multiple regression equations representing the amount of sensible and latent heat exchange according to the growth stage were developed to dynamically simulate the amount of heat exchange between the internal air and the crop in the greenhouse. The experiment was conducted in a rooftop greenhouse, and the experiment was conducted three times for winter, summer, and change of season. While growing red leaf lettuce in a rooftop greenhouse, the microclimate around the crops and nutrient solution environment were measured at all times, and destructive measurements obtained growth data at 5-day intervals. The developed regression equation will be used to dynamically simulate the more accurate internal environment of the greenhouse. Through this, it will be possible to present the optimal scenario for saving the energy load of the building-integrated rooftop greenhouse.

Keywords: Crop energy, Evapotranspiration, Red lettuce, Rooftop greenhouse.

OS16-05

Energy Saving Design and Control Strategy for Sustainable Rooftop Greenhouse with Passive and Active Heat Transfer Methods

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Domestic protected agriculture has greatly increased its production per area through modernization and large-scale, accounting for about 60% of the total agricultural production. Greenhouse cultivation enables stable mass production throughout the year, and yield per unit area is 1.2 times higher than open field cultivation. However, since the greenhouse has an envelope with relatively low insulation to use sunlight, it is vulnerable to changes in the external environment, so the energy load per unit area is large. Rooftop greenhouse, building-type urban agriculture, has a structural advantage that can reduce the energy load of buildings and greenhouses. The purpose of this study is to analyze the passive and active load-saving effects of rooftop greenhouses and buildings by season and time through experiments and simulations. As the greenhouse is located on the roof of the building, the

amount of passive energy load that can be saved compared to a normal greenhouse was analyzed. In addition, the surplus air heat of the building was exchanged with the greenhouse to actively reduce the energy load. For this, the dynamic energy simulation model was verified using the experimental data in the demonstration rooftop greenhouse. The result of the natural ventilation calculated by the computational fluid dynamics model was input into the energy model, and also the value measured at the greenhouse site was input for the forced ventilation. The load reduction was analyzed according to the thermal factors affecting the greenhouse energy load using the dynamic energy model. As a result, using this result, it will be possible to derive an energy load-saving scenario of the building-rooftop greenhouse integrated model.

Keywords: Building-integrated agriculture, Energy saving, Rooftop greenhouse.

OS16-06

Testing the Interaction of Strawberry Cultivars with organic and conventional cropping systems in Morocco

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The growing demand for organic strawberries in the world necessitates the identification of strawberry cultivars that are more adaptable to the organic system. With this goal in mind, the Agronomic and Veterinary Institute Hassan II within the frame of MEDBERRY project within the PRIMA program, led this study at the national level. The research was carried out over the course of two years. Ten selections were evaluated for agronomic performance and fruit characteristics during the first year at Ain Aouda organic farm. In the second year, 5 genotypes were added to the first set, and field trials were conducted in two locations: Larache with a conventional cropping system and Ain Aouda organic farm. The experimental trials, scheduled for 2019 and 2020, were planned using a randomized design with two blocks and four replicates per block in the first year and four blocks with one replicate per block in the second year. Each replicate had 20 plants. The experiment was carried out in a high tunnel lined with thermal polyethylene. As a control, the cultivar 'Fortuna' was used for both years. Data on productive (total plant production, marketable production) and quality (flesh firmness, °Brix, predominant color, predominant fruit shape, homogeneity, skin resistance, and brightness) parameters were collected during harvest multiple dates. The results revealed a significant difference in some cultivars' adaptability, yield, and satisfactory quality. A highly significant differences between cultivars in fruit homogeneity, firmness, and brightness was revealed. The cultivar An151955 had the lowest homogeneity and firmness ratings, while the control 'Fortuna' had the highest. Differences in total and marketable yield, as well as sugar content, were highly significant between the two sites/cropping systems. Cultivar x site is highly significant for total production and significant for marketable yield. An122053 and An131355 performed the best in the organic production system, while An131362 performed the worst. In the conventional cropping system, the same cultivars

An131362 and An142051 performed best, while An124460 and Exp121 performed worst. As a result, the cropping system must be considered when selecting cultivars, as they are better suited to organic or conventional cropping.

Keywords: *Fragaria×ananassa*, short-day, organic.

Oral presentations: Wednesday October 25, 2023

ORAL SESSION 17 / CFD Modelling

KEYNOTE LECTURE 3

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There is a growing world-wide effort to increase the efficiency of any production system and embed in them circularity principles, with the ultimate goals of saving resources for an increasing world population and of reducing the environmental impact associated to the production of goods and services. While agriculture is often at the center of the debate on how human activities may be a real menace for our planet, it is actually among the least impactful sectors (https://www.epa.gov/ghgemissions/sources-greenhouse-gas-emissions). Moreover, it is one of the sectors in which resource use efficiency has substantially increased in the past 20 years and circularity principles have been increasing become part of the production processes. To highlight these achievements and discuss further opportunities to make circular solutions a fundamental part of agricultural activities, we will limit our discussion to the greenhouse production systems which are amongst the most suited for a reliable control and measurement of the resource used during the production process as well as the waste generated through it, which in turn can become *per se* a new resource. Specifically, we will focus on the proposed solutions to improve water, nutrients, and energy use efficiency and on the strategies for reducing waste or for channeling waste in new production processes that can generate high value products (i.e. bioeconomy). These strategies and solutions can possibly help to achieve a more circular greenhouse horticulture if they are supported by research and technology transfer and encouraged locally by policies to enhance sustainable development.

Keywords: bioeconomy, nutrients use, renewable energy sources, waste management, waste recycling, water use.

OS17-01

Diversifying the application of CFD technology on Greenhouse R&D

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The first CFD (Computational Fluid Dynamics) program was developed in the 1960s. At that time, CFD was used very limitedly with poor computer resources, but with the advent of commercial CFD codes in the 1980s, its scope of application expanded mainly to the aviation, automobile, and nuclear fields. Since CFD was first used in greenhouse research in the 1980s, it has been widely used not only in the agricultural field but also in greenhouse research for a variety of studies such as ventilation, structural design, environmental control, plant physiology, energy, etc. Along with the development of CFD programs and related theories as well as the development of computers, the computational time has been greatly decreased and the accuracy of CFD calculations have improved significantly. In addition, depending on the research purpose, not only commercialized CFD but also license-free open -CFD is being utilized in various ways. Recently, attempts have been made to develop algorithms through big data analysis, modularize them, and then integrate them into the CFD main module, greatly improving the reliability of CFD computational results. In this lecture, I will explain the various CFD developments mentioned above using various examples.

OS17-02

Evaluating possibilities to create homogeneous greenhouse climate at night time through 3D climate simulations

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Greenhouse climate is typically controlled based on climate data recorded by a measuring box representing a rather large greenhouse area. However, it is known that the greenhouse climate can vary significantly from one spot to another horizontally and also vertically. A uniform climate is desired due to several advantages, such as uniform crop growth and development rate, uniform quality, and possibilities for energy saving. Precise climate control must take into account the spatial variations in greenhouse temperature and humidity but this aspect is missing from existing climate control options with a centralized climate measurement box and can be only managed based on growers' intuition, yet. Greenhouse climate distribution can be studied and visualized by using Computational Fluid Dynamics (CFD) techniques. A validated 3-dimensional greenhouse model is used to simulate the effect of several climate control equipment on greenhouse climate homogeneity, such as the use of energy-saving screens, applying screen gaps, use of screen fans, and vertical screens or foils that separate the greenhouse into smaller compartments. The simulations focus on the night-time situation when low outside temperatures occur, and the screens are deployed (with or without the required screen gaps to release excess humidity). Under these conditions, local cold spots are created. The simulation results show

that using vertical screens to separate the greenhouse into smaller compartments can reduce climate heterogeneity by up to 50% both in terms of the absolute difference between the coldest and warmest spot of the greenhouse as well as in temperature and humidity variation across the length and width of the greenhouse at crop height. However, the orientation of those screens has to be considered together with outside wind directions. Small separations above the screens and screen fans were also shown to improve greenhouse climate homogeneity by up to 40%.

Keywords: greenhouse climate, climate homogeneity, climate simulation, CFD.

OS17-03

Snow Load Computation of Greenhouse using CFD-DEM Method

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As climate changes cause more frequent and severe extreme weather events, the frequency of heavy snow has also increased. According to the "extreme weather report in 2021" provided by the Korea Meteorological Administration, the amount of snow fell in 2021 was three times higher than that of recent snow, and it was concentrated in specific areas and times. As a result, property damage of 10 million dollars occurred in 2021, especially because of the collapse of greenhouses with low safety factor. The collapse of the greenhouses causes secondary damage not only due to the cost of recovery but also to the inability to grow crops during the recovery period. The destruction in greenhouses by snow is caused by excess load or eccentric load. Eccentric load is caused by the unequal distribution of snow depending on the wind environment and roof type. However, it is difficult to prepare for collapse according to eccentric load since the design standard of domestic facilities assumed that the snow load on the roof is uniform. Therefore, the purpose of this study is to identify the snow load distribution characteristics of greenhouses. In order to identify the snow load distribution of greenhouses, series of laboratory experiments using artificial snow were conducted on greenhouse models and sloping plates. In addition, numerical analysis models were developed based on models linking Computational Fluid Dynamics (CFD) and Discrete Element Method (DEM). CFD-DEM model was validated through comparison with laboratory experimental results (Errors 4.9% to 7.4%) and simulation results. Simulation was performed according to the wind environment, roof shape, and span number through the validated CFD-DEM model. Based on the results, the structural safety of greenhouses considering the snow load distribution can be evaluated and the foundation of prediction and warning system for the destruction of greenhouses can be prepared.

Keywords: Computational Fluid Dynamics, Discrete Element Method, Greenhouse, Snow load, Snow load distribution.

OS17-04

CFD model design optimization and verification in large-scale Venlo greenhouse complex for tomato cultivation

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Greenhouse cultivation has emerged as an effective way to address climate change and food insecurity challenges. Small-scale production and energy efficiency are rampant hurdles hindering efficient greenhouse cultivation. As it is necessary to carry out pre-studies on aerodynamic-related factors for crop growth and energy efficiency before commercialization, construction of large structures for pilot study is not financially feasible; hence difficult to carry out field experiments. CFD modeling and simulation are an alternative for carrying out these pre-studies. Large-scale CFD models are not only limited by computational capability resulting from large volumes of computational grid cells but also by model validation impossibility because of challenges related to field data acquisition. Consequently, it is difficult to simulate large-scale CFD models, including multiple greenhouses with atmospheric conditions at the same time. The major aim of this study was, therefore, to develop a guideline for CFD model design optimization and verification for large-scale Venlo greenhouse complexes without field data, which is not possible to obtain before construction. Model design optimization and accuracy verification were implemented in 2D iterative simulations of a 2ha model greenhouse using the improved grid independence test (GIT) and wall Y+ approaches. Aerodynamic characteristics were analyzed in 3D-32ha greenhouse complex, including sixteen independent 2ha-greenhouses when the wind direction was 0^0,45^0 and 90^0. As a result, it was established that a grid resolution of 0.8m and a first inflation layer height of 0.04m was optimal for making large-scale greenhouse models with RMSE as low as 3.9% and R^2 of 0.968, resulting in a 38% reduction in grid cells. For the greenhouse complex, average ventilation efficiencies within the complex ranged between 0.15~0.3AE/min, 1.32~1.52AE/min, and 0.25~0.5AE/min when the wind direction was 0^0,45^0 and 90^0, respectively. These results will be used as a basis for establishing design standards for large scale greenhouses where experimentation and model validation are limitations.

Keywords: Computational Fluid Dynamics, natural ventilation, verification, large-scale greenhouse**.**

OS17-05

Ventilation Rate Prediction for Naturally Ventilated Greenhouses using CFD-Driven Machine Learning Model

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Despite the decrease in Korean agricultural land, the area of greenhouses is increasing due to an increase in demand for stable crop production. In order to maintain high productivity

in greenhouses, internal air environments such as temperature, humidity, and carbon dioxide must be maintained under appropriate growth conditions. In particular, properly controlled natural ventilation is an efficient and economical means of maintaining an appropriate internal air environment because additional energy is not consumed. Computational fluid dynamics (CFD) techniques have actively been used for quantitative analyses and predictions of natural ventilation. However, limited simulation cases can usually be performed because a considerable computation time is required for CFD modeling. Conversely, techniques based on machine learning (ML) models have relatively shorter computation times but the construction of training datasets requires significant effort. Therefore, the purpose of this study is to develop ML models to predict the natural ventilation rate by zone at the height of the crop group for an greenhouse and used CFD computed results to create a training dataset. The CFD simulation was performed considering external wind direction and wind speed, as well as vent opening conditions. The ventilation rate computed by the tracer gas decay (TGD) method was computed for 27 zones of the greenhouse. Multiple regression, random forest, support vector regression, and deep neural network models were developed to predict the ventilation rate. The training dataset of wind direction and speed were supplemented, and accuracy analysis was conducted to improve the accuracy of each model; the number of data was supplemented by applying the bootstrapping technique to complement the limitations of a finite number of CFD cases. The validity of developing ventilation rate prediction ML models using CFD was assessed by evaluating the accuracy of the developed ML models.

Keywords: Computational fluid dynamics, Greenhouse, Machine learning, Natural ventilation, Ventilation rate.

OS17-06

Recirculating the air from the attic as a pre-renovation control strategy in a greenhouse-type solar dryer

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In greenhouses with natural convection, the difference in air densities causes the warmer and less dense air to move up in the inner volume and the coldest and dense air to move toward the floor. In a greenhouse-type solar dryer, natural convection is the primary phenomenon used until the air temperature is excessive for drying or is saturated with water which causes the air to be exhausted. However, most facilities do not take advantage of the vertical temperature stratification due to natural convection and the greenhouse's cover heating. In this study, the possibility of recirculating the air in the greenhouse's attic was examined as a strategy before air exhaustion to improve the air's internal homogenization, increase air movement and provide a better environment for drying. The air behavior inside the greenhouse was simulated through Computational Fluid Dynamics

using ANSYS-Fluent. Two different strategies for positioning the air intake in the attic and distribution under the drying tables were tested, finding that the best result was to take the air from the back of the greenhouse and recirculate it in three different rows below the drying benches. Using this principle, prototypes of recirculation systems can be proposed according to the greenhouse and the requirements of each product to be dehydrated.

Keywords: drying, greenhouse dryer, CFD, air-recirculation.

OS17-07

Analysing the Local Climate in a Plant Factory in CFD by Simulating the Heat and Mass Transfer of the Plants using a Realistic Plant Model

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Climate control is a critical factor in achieving optimal plant growth in vertical farms or greenhouses. Computational Fluid Dynamics (CFD) is a valuable tool for simulating the desired climate conditions, enabling the comparison of different ventilation methods. In previous studies, plants were represented as porous zones with additional source terms in the transport equations for energy and transpiration. However, this study introduces a more realistic approach by incorporating the actual geometry of plants, including multiple leaves, within the enclosure model. The heat and mass transfer of the plant are accurately accounted for at the leaf boundaries, resulting in a realistic representation of temperature and humidity throughout the plant canopy. The model was validated using experimental data from basil grown in a plant factory-like environment, employing a jet-like velocity-inlet. The results revealed a left-to-right transpiration gradient at night and a top-to-bottom transpiration pattern during the day. This model not only provides insights into the specific case but also holds promise for simulating alternative ventilation methods and accurately predicting the climate within enclosed environments.

Keywords: Basil, CFD, Climate, Plant factory, Energy Balance, Vertical Farm, climate control.

OS17-08

Numerical evaluation of organic photovoltaics on greenhouse microclimate spatial distribution

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The European Green Deal provides a roadmap with actions to boost the efficient use of resources by moving to a clean, circular economy and stop climate change, revert biodiversity loss and cut pollution. In the agricultural domain, fossil fuel use has

negative effects and it is becoming a major source of greenhouse gas (GHG) emissions, with significant contributions to global climate change and the risk of food security. One of the most energy-consuming sub-sectors of agriculture is the horticulture industry (greenhouse/glasshouse) which is mainly based on fossil fuel use. In this aspect the use of Renewable Energy Sources is vital for the sustainability of intensive farming production systems. Organic photovoltaics (OPV) is an emerging solar power technology, provides unique properties, such as transparency, flexibility, and especially customizability (e.g. color and shape) and integrability, offering the potential to serve a plethora of applications that cannot be addressed by the classical PV technologies.

Aim of the study is the numerical (CFD) evaluation for a wide range of different parameters (climate conditions, greenhouse types, OPV structural specifications, crops) of OPVs incorporated in the roof of greenhouse structures on microclimate spatial distribution. The numerical model has been developed for the 160m^2 plastic experimental greenhouse located in Central Greece, using the commercial CFD software (ANSYS FLUENT 19.2). The Reynolds-averaged Navier–Stokes equations are solved for continuity, momentum and energy. While the flow was at steady state conditions and it was modelled as incompressible and viscous. The semi-implicit method for pressure-linked equations (SIMPLE) algorithm is used for the pressure–velocity coupling. The convective terms of the momentum, turbulence model and energy equations are discretised using a second order upwind (SOU) scheme, while the diffusion terms are central-differenced. The turbulence used for this case is the standard k-ε with scalable wall functions. Full buoyancy effects were considered using the Boussinesq approximation for fluid density. The radiative heat transfer is solved using the discrete ordinate (DO) method. The crop was modelled as porous media which has been proven an accurate method with low computational cost. The viscous and inertia coefficients required for the porous media model were provided by literature. Moreover, a transpiration model was introduced via User Defined Functions (UDF) to capture more accurately the interaction between the crop canopy and fluid zone in terms of energy and mass balance.

Results are presented for a wide range of different of structural specifications and focused on the spatial heterogeneity of internal greenhouse microclimate (air velocity, air temperature and distribution of solar radiation).

Keywords: OPV, CFD, microclimate, sustainability, energy.

ORAL SESSION 18 / Fertigation, water, and growing media III

OS18-01

Customizing a slightly carbonized biochar as peat alternative in growing media

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Biochar has been widely studied to replace peat in growing media due to suitable water retention capacity, non-phytotoxicity, stability, and some nutrients. However, most studied biochar (pyro-char/hydro-char/torrefied-char) is deeply carbonized, resulting in different properties from peat, e.g., pore distribution and chemical composition, which are unnecessary as growing media. That is, 1) biochar has a large number of small nanopores resulting in great surface area but contributes little to neither reserve plant available water nor benefit plant growth; 2) biochar has severely degraded cellulose and lignin, yet cellulose and lignin are considerably present in peat and show no phytotoxicity. Therefore, this work hypothesizes that deep carbonization is not mandatory for generating peat alternatives. The main concerns could be the removal of phytotoxic compounds along with the formation of safe and stable products with proper pH and EC, as well as suitable water retention capacity. Superheated steam (SHS) torrefaction is a recently proposed incomplete carbonization process, which could selectively boost biomass decomposition and regulate features favoring growing media. This work chose greenhouse waste with strong phytotoxicity as the feedstock. Temperature (200, 230, 270, 300, and 350 °C) and resident time (1, 5, 10, 15, 30, and 60 min) were investigated to customize product properties aiming to remove phytotoxicity compounds, increase water retention capacity, prolong half-life, and obtain proper pH and EC. It was found that the physicochemical properties of products could be customized by varying temperatures and resident times. The phytotoxic compounds from greenhouse waste could be removed in 5 min at 350 °C. The water retention capacity of products could be adjusted to be comparable to that of peat. The half-life could be improved to hundreds of years. Finally, slightly carbonized biochar could replace up to 50 vol.% peat and benefit plant growth.

Keywords: peat alternative, biochar, greenhouse waste, slight carbonization.

OS18-02

The effect of peat moss amended with three engineered wood substrate components on suppression of crown and root rot in floriculture crops

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In greenhouse production, plants are grown in soilless growth substrates. For decades, peat moss has been the primary substrate for container-grown crops. Substrate manufacturers have identified wood byproducts to be some of the most promising alternative sources of

raw materials for use in substrate formulations. Unfortunately, a change in substrate can be very disruptive to a grower's production system affecting everything from water to pest control. In our previous research, radish plants grown in sphagnum peat blended with disc-refined wood and hammer-milled pine tree substrate at a volumetric ratio of 70:30 had lower damping-off disease severity compared to the peat control. The objective of this research was to evaluate the effects of commercially available wood components for their impact on crown and root rot on three floriculture species. Wood components are manufactured in multiple ways with the three most common being hammer milled, twin-disc refined, and single or twin-screw extruded. In this study we evaluated the three differently processed wood components for natural suppression against crown and root rot caused by *Rhizoctonia solani* on chrysanthemum, geranium, and impatiens. Our findings provide evidence that the inclusion of wood components may lessen the effect of crown and root rot on floriculture crops. Additional research is needed to determine if the trends we observed hold true for other soilborne pathogens.

Keywords: Soilless growing media, wood fiber, disease suppression, *Rhizoctonia solani*.

OS18-03

Sizing lettuce growing surface in aquaponic systems based on evapotranspiration and fish feed

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Due to the lack of healty soils and water in the cities, there is a need of implementing more eficient production techniques such as aquaponics, which provides benefits of generating protein from aquatic species in addition to vegetables. It makes efficient use of water and energy. The objective of this study was the estimation of the optimal lettuce growing surface, depending on the amount of nitrates generated by the fish and taken into account the evapotranspiration. The experiment was carried out in a greenhouse located at the Autonomous University of Chapingo. Small aquaponics units of 200 cm by 85 cm surface with a 150 L tilapia pond and a 72 cm of hydroponic unit were implemented, with 3 repetitions. 21 lettuce plants were transplanted on December 5, 2022 and the harvest took place on January 2, 2023. Each pond have 16 tilapias with an average weight of 200 gr. The fish tanks were oxygenated by means of a 370W air pump, the temperature was maintained with a 100W submersible resistance and the water was recirculated at a flow of 8.8 liters per minute. A sensor system was installed to monitor the environmental variables such as temperature, relative humidity and solar radiation every 15 min inside of the greenhouse. Five weekly samplings were carried out in the nutrient solution and fish pond to estimate the amount of ammonium (NH4), Nitrogen from nitrites (N-NO2–) and nitrogen from

nitrates (N-NO3–). Also, measurements were taken on lettuce plants to calculate the leaf area index and biometrics in the fish. The daily record of fish feeding was used for the calculation required plant area according to the amount of the average feed input. The results can be used as the starting point for the design of aquaponic systems in cities.

Keywords: temperature, solar radiation, Tilapia, Nitrates, Amonium.

OS18-04

Developing a screening pipeline for the identification of phosphorus-solubilizing bacteria

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Phosphorus (P) is an essential nutrient with low availability for plant uptake. High media pH levels can cause the formation of insoluble compounds with calcium (Ca). Phosphorus solubilizing bacteria (PSB) can enhance P availability for plant uptake by producing organic acids to acidify the rhizosphere. The identification of PSBs requires both in-vitro and in-planta evaluations. In-vitro protocols allow for the screening of extensive bacterial collections, but the number of bacterial isolates that can be tested in the greenhouse is limited by the amount of space and time required to evaluate the plant responses to PSB inoculation. Digital phenotyping is an emerging tool for high throughput and precise evaluation of plant performance and health. This project aimed to develop a PSB screening pipeline using an in-vitro protocol and digital phenotyping with the TraitFinder (Phenospex) Greenhouse system. In-vitro P solubilization was quantified using the malachite-green assay. Eighteen isolates were identified as PSBs from a collection of around 1000 isolates. Digital phenotyping data was validated in a greenhouse experiment with Marigold (*Tagetes patula*) 'Durango Orange,' Radish (*Raphanus sativus*) 'Cherry Belle,' and Tomato (*Solanum lycopersicum*) 'Bush Beef Steak.' Plants were grown in a peat-based substrate and irrigated with 100 ppm N from a 15-0-15 fertilizer. P was provided weekly as insoluble $Ca_2(PO_4)_3$ via drench. Three in-vitro-identified PSB (OSU1, OSU2, and OSU3) and two microbial-based products (Lalrise Vita and MycoApply Endo) were tested. The growth index and shoot dry weight measurements were consistent with the digital biomass data calculated by TraitFinder. Lalrise Vita promoted growth in all plant species evaluated. Lalrise Vita also improved marigold health, which was assessed using the hue index, green leaf index (GLI), and plant senescence reflectance index (PSRI). The malachite-green assay and digital phenotyping are suitable tools for the rapid identification of phosphorus-solubilizing bacteria.

Keywords: plant uptake, Digital phenotyping data, PSB, Marigold, Radish, Tomato.

OS18-05

Evaluation of automatic irrigation control systems and shade mesh position for strawberry crop growth (*Fragaria sp.*)

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At the national level, the application of electronic systems of automatic control in agricultural production processes is becoming more frequent. The development and application of automatic control systems allow the adaptation of cultivation techniques to environmental conditions to achieve a more profitable and rational crop in small areas of the same agricultural exploitation. This work contemplates developing and evaluating an automatic irrigation control system and automatic control system to control the opening or closing of a shadow mesh based on the incident radiation in the crop. An algorithm and program that automates the placement of the shadow mesh were developed with the help of a programmable logic controller (PLC Millenium III) for ease of implementation. The developed system was applied to the strawberry crop (*Fragaria* sp.). Tests and evaluation were carried out with three strawberry beds: open field, fixed mesh, and mobile mesh controlled according to the radiation. A shadow mesh position control system consists of a radiation sensor, two position sensors, a step-down motor, PLC, and accumulators. The shadow mesh opens if the radiation is less than 400 W/m^2 or closes if the amount of radiation is greater than 600 W/m^2 when measured with a sensor; in addition, it can be opened and closed manually to carry out the harvest and maintenance. In each treatment, irrigation control was carried out according to the needs, controlling with a control system consisting of three soil moisture sensors, PLC, solenoid valves, a pump motor, a water tank, and pipes. One of the results obtained is that the production in the bed under the mobile mesh is greater by 13.0% than in the fixed mesh and in 37.0% than in the open field.

Keywords: Automatic irrigation control systems, shade mesh, strawberry.

OS18-06

Providing more nitrogen with high light levels can accelerate hydroponic lettuce production

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The amount of sunlight greenhouse crops receive varies and often is not enough for consistent year-round crop production. Therefore, many growers use supplemental lighting to provide adequate light for plant growth. With more light provided plants can achieve faster growth and therefore growers can increase the number of crop cycles per year. However, at high light levels plants may need more nutrients, such as nitrogen (N). Therefore, to determine whether more N is needed for crops grown at high light levels, we grew butterhead lettuce (*Lactuca sativa* 'Rex') hydroponically under six photosynthetic photon flux densities (PPFD) and three different N concentrations. The six PPFDs were 179, 245, 316, 375, 383, and

468 µmol·m^{-2}·s^{-1} and the three N concentrations were 100, 200, and 300 mg·L^{-1}. We observed more shoot weight gain (fresh and dry) with the increase of PPFD and N concentration (*P=0.03*). When more N added to the hydroponic solution, the total leaf area per plant and the N concentration of leaves were increased (*P < 0.0001*). In addition to that, we also observed an increase in leaf chlorophyll content when plants were grown at high N concentrations (*P=0.005*). However, the quantum yield of photosystem II was lower with increased N concentrations (*P < 0001*), but no differences were observed in leaf CO_2 assimilation. These results indicate, providing more N at high PPFDs does not accelerate leaf photosynthesis but will promote faster shoot growth. Such faster growth can benefit growers by allowing them to have more crop cycles per year. However, we also noticed an increase in tipburn symptoms at high PPFDs and the symptoms were further increased when more N was provided to the hydroponic solution. Therefore, selecting tipburn resistant varieties and facilitate more canopy air movement is recommended when growing lettuce at high PPFDs with high N concentrations.

Keywords: Nitrogen, Lettuce, Nutrient, PPFD.

ORAL SESSION 19 / Plant production, protection, and quality

OS19-01

Photosynthesis, transpiration and water use efficiency of lettuce (*Lactuca sativa*) under varying light intensities

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Indoor agriculture systems are becoming more popular as an alternative of traditional agriculture. High efficiency in water use, free-pesticide food, production without arable land and closeness to urban centers are some of the benefits of these systems. Yet, there is a high energy cost for lighting and dehumidification. Since plants transform light into biomass, it is important to understand how efficient plants are in that process to reduce energy costs. In a previous study, we identified that there is positive relationship between light intensity and water use efficiency as the same as with net photosynthesis at a leaf level. Additionally, we found that there is a possible tradeoff between the energy used for lighting and dehumidification which would reduce energy costs. In this study we measured photosynthesis at a whole plant level and we generated light response curves under different light intensities to describe photosynthesis rates as a function of the light provided. We grew two sets of 'Rex' lettuce (*Lactuca sativa*) in a walk-in chamber with a temperature of 25 °C, relative humidity of ~50%, and a CO_2 concentration of 800 µmol·mol^{-1}. One set of plants was grown under Photosynthetic photon flux density (PPFD) of 125 and the other one under 400 µmol·m^{-2}·s^{-1} provided by white LED lights with a photoperiod of 20 h. Subsequently, plants were moved into a whole plant gas exchange system to measure CO_2 exchange. While being in this system, plants were subjected to PPFDs of 100, 200, 300, 400, 500, 600, 700 and

800 $\mu mol \cdot m^{-2} \cdot s^{-1}$ for an hour for each PPFD level. While plants were being subjected to different PPFD levels, constant weight measurements were taken by using load cells that were placed permanently as base for each pot to estimate plant transpiration.

Keywords: light response curve, light intensity, Photosynthesis, transpiration, water use efficiency, indoor agriculture.

OS19-02

Starwars: The use of lasers for indoor pest control

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Small flying insects, often virus vectors (whitefly, trips), are a key problem in greenhouse horticulture, especially seen in the reduction of pesticides to be used and the fact that viral diseases cannot be treated curatively at all. The use of insect gauze is not effective against these small insects, obstructs ventilation and is difficult to keep clean. We, therefore, explored the use of lasers as part of an integrated pest management system using western flower thrips (*Franklinella occidentalis*) as a pest model. Looking at different lenses and laser parameters such as exposure, emission spectrum, light path, and power output, we created a fiber laser screen covering the greenhouse ventilation ducts. We then determined lethal dosages enabling us to kill thrips at 0.025 s, without obstructing airflow and without harm to plants. Comparing absorption spectra, such a laser is also successful against whitefly. When implemented as a plant scanning system, eliminating trips in a targeted manner, the laser could even destroy thrips on the underside of a plant leaf without any visible damage to the plant unless plants were exposed for a period longer than 2 s. Energy consumption comprised a maximum of 450 Watts, comparable to half a Senseo coffee machine. These results show that a laser system is a promising tool for achieving sustainable crop protection in greenhouses with a minimum to no pesticide use at all and without impact on the greenhouse climate.

Keywords: Lasers, pest control, thrips.

OS19-03

Comparing efficacy of different biostimulants for hydroponically-grown lettuce (*Lactuca sativa* L.)

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Biostimulants can enhance horticultural crop production. However, their application in hydroponically grown lettuce is still limited, and information regarding their relative efficacy

is lacking. A greenhouse trial was conducted to address this issue. Five nutrient solution treatments were evaluated on two lettuce cultivars: butterhead and red oak-leaf. The treatments included a half-strength modified Hoagland solution (Hs-H); a full-strength modified Hoagland solution (Fs-H); and Hs-H supplemented with 50 mg L^{-1} fulvic acid (FA), 334 mg L^{-1} seaweed extract (SE), or 5 ml L^{-1} gamma polyglutamic acid (PGA). The results indicated that all three biostimulants significantly improved shoot biomass compared to that achieved with the Hs-H treatment. Biostimulant supplementation also resulted in notably greater or comparable shoot biomass relative to that achieved with the Fs-H treatment; however, the PGA treatment led to a significantly lower shoot dry weight than that achieved using the Fs-H treatment. Nutrient solutions supplemented with SE and PGA led to a greater increase in the root biomass than that achieved with Hs-H and Fs-H treatments. The Hs-H + FA treatment resulted in the lowest root-to-shoot ratio on a fresh weight basis among all treatments. The nitrate concentration in the shoot was significantly reduced following biostimulant supplementation compared to that achieved with Fs-H and Hs-H treatments. Nutrient solutions supplemented with SE and PGA also decreased soluble sugar concentrations compared to that achieved using Hs-H and Fs-H treatments. FA and SE improved nutrient uptake for both cultivars, but PGA had a minimal effect on nutrient uptake. The two cultivars varied in their responses to biostimulant supplementation with regard to biomass, quality traits, and nutrient uptake. This study supports using fulvic acid and seaweed extract, rather than γ-PGA, in hydroponic lettuce production systems.

Keywords: biostimulants; seaweed extract; fulvic acid; γ-PGA; biomass; quality; nutrient uptake.

OS19-04

ECOFERT: an eco-physiological model for assessing nitrogen fertilization strategies in horticultural crops

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This study elaborates a process-based eco-physiological model (ECOFERT) to investigate the dynamic interactions between soil conditions, crop growth and development, weather and horticultural unit operations, like fertilization and irrigation.

This model was used to simulate leek cultivation in Flanders, Belgium. The simulation of the soil processes is based on the WAVE model; using the 1-dimensional Richards equations for water flow combined with the van Genuchten parameterization of the water retention

curves and the pedo-transfer functions of Weynants to link the water retention to the soil properties. Nutrient- and heat-transport is modelled by diffusion equations. All C-N processes follow first order kinetics. The crop module simulates gross photosynthesis, maintenance- and growth respiration, developmental stage, biomass partitioning into growing plant organs, leaf area and nitrogen demand per organ, driven by the critical N-curve and convective and diffusive nitrogen uptake. A quasi 2D-root growth and development model was designed to accurately describe vertical and horizontal axi-symmetric root length distribution, allowing to simulate the effects of spatial heterogeneous rooting systems on water- and nitrogen-uptake. The FAO 56, adapted Penmann-Monteith approach, was used for evapotranspiration.

Keywords: ECOFERT, soil nitrogen- and water-dynamics, leek.

OS19-05

Comparison of Phenolic Compounds and Antioxidant Activity in three Black Cherry Tomato Varieties Grown Under Greenhouse Conditions

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Phenolic compounds, enzymatic and antioxidant activities were determined in three varieties of black cherry tomato: Indigo Cherry Drops, Indigo Rose, and Kumato®. The tomato cultivation was carried out from the seed to the first harvest in the facilities of the Autonomous University of Queretaro. The content of total polyphenols, flavonoids, anthocyanins, β-carotenoids, antioxidant capacity (inhibition of DPPH and ABTS), and the enzymatic activity of response to the stress of superoxide dismutase-SOD, catalase-CAT, proline-PRO were measured and compared; as well as the enzymatic activity of phenylalanine ammonium-lyase-PAL for the pathway that triggers phenolic compounds. The Kumato® variety stood out over Indigo Rose and Indigo Cherry Drops with a significant difference in the analysis of total polyphenols, flavonoids, carotenoids, DPPH, ABTS, CAT, and PAL. The free radical inhibition activity through the DPPH and ABTS tests was shown above 87.0% and 74.72%, respectively, for the Kumato® variety. SOD enzymatic activity was significant for the Indigo Rose variety (0.21 U mg^{-1} protein). Meanwhile, proline activity was significantly different in Kumato® and Indigo Cherry Drops (6.40 and 6.63 U mg^{-1} protein, respectively) than in the Indigo Rose variety. The results showed that concentrations of the

different phenolic compounds could achieve the antioxidant capacity in the selected black cherry tomato varieties. Finally, the visibility and diffusion of its antioxidant properties and its potential positive impact on human health make it a crop of high value for producers.

Keywords: antioxidants, polyphenols, flavonoids, anthocyanins, carotene, enzymatic activity.

OS19-06

Diverse plant species in relation to improve human nutrition

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The introduction of diverse, underutilized green vegetable species of different origins for cultivation in closed environment agriculture (CEA) systems (vertical farming, plant factories) promotes its competitiveness and economic efficiency regionally and globally. Nutritionally sensitive precise agriculture traits and proposed miscellaneous, rich in different phytochemicals and minerals green vegetable species, would promote the value of vegetable foods. The aim of this research study is the biodiversification of underutilized leafy vegetable species in CEA and the experimental explication of the impacts of tailored cultivation environmental parameters seeking to create cultivation methods for miscellaneous, value-added crops. *Amaranthus sp., Basella sp., Portulaca oleracea, Sanguisorba minor, Plantago coronopus, Mesembryanthemum crystallinum, Perilla frutescens, Chenopodium sp.*, *Brassica carinata*, etc.) were cultivated in CEA conditions under artificial light emitting diode (LED) lighting in a deep water culture (DWC) hydroponic systems. Plant productivity, indices of nutritional value (soluble sugar, phenolic compound, protein contents, antioxidant properties, etc.), as well as organoleptic properties (sweetness, crispness, bitterness, taste), were evaluated and compared between species. Different plants, such as leafy vegetables, species represent the diversity of biochemical properties and different consumer sensory evaluations. A set of plant species is selected with a higher potential for developing species-specific cultivation strategies for CEA.

Keywords: underutilized leafy vegetables, phytochemicals, controlled environment agriculture, artificial lighting, hydroponics.

OS19-07

The feasibility of growing media originated from greenhouse

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Greenhouse waste is inevitable and might limit the development of greenhouse farming. At the same time, peat is the utmost material for facility agriculture. In our previous study, slight carbonization of greenhouse waste was found to be capable of regulating the phytotoxicity, water retention capacity, pH, and EC to be suitable for growing media. Therefore, we proposed an idea to slightly carbonize greenhouse waste into peat alternative as a new type of sustainable growing media. This work intended to evaluate the feasibility of this peat-replaced growing media for seedlings and growing. Cucumber straw and rose straw were sightly carbonized to replace peat in the seedling media and growing media formulas with a ratio of 5, 10, 20, and 40 vol%, respectively. Celery cabbage, lettuces, tomato, and cucumber have been sown in the prepared seedling media. The growth vigor in the seedling stage was analyzed, and found that biomass yield increased by at least 1.2 times than control. On the other hand, conventional seedlings of three commercial ornamentals were transferred to peat-replaced growing media for growing tests. Dry weight, number of flowers, SPAD value, and nitrogen content were analyzed. The highest biomass yield for fairy primrose and cineraria is observed at 20% and 30% replacement rates, respectively, while the highest replacement rate (40%) gains the highest biomass yield (1.13 times) for kale. Fairy primrose and cineraria have more flowers than the control. The highest SPAD values were obtained at the 40 vol.% replacement rate for fairy primrose and kale and at the 30 vol.% replacement rate for cineraria. Nitrogen content has a similar trend as SPAD values. The analysis of proline, MDA, soluble protein, soluble sugars, and the activity of antioxidant enzymes has been conducted. In conclusion, greenhouse waste undergoing slight carbonization could replace 20% to 40% of peat in growing media for plant seedlings and growing.

Keywords: Greenhouse waste; growing meida; plant seedling and growing.

OS19-08

Flower induction and development under extended photoperiod in medicinal cannabis

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Most medicinal cannabis cultivars are short-day plants that require that the photoperiod does not exceed approximately 12 hours to obtain flowers. Short photoperiod limits the daily photosynthesis and, consequently, growth and biomass accumulation. In chrysanthemums, extending a short day of red+blue light with sole blue light did not inhibit flowering. The aim of this study is to explore if it is possible to increase the growth and floral yield of medicinal

cannabis by extending the photoperiod. We conducted a series of experiments in climate-controlled chambers to investigate several options for extending the photoperiod. Unlike what was found for chrysanthemums, extending a short day (SD) of red+blue light with sole blue light inhibited flower initiation. Subsequently, the effects of photoperiod on flower development were studied after the flowers had been induced under SD. When the photoperiod was extended by blue light at low light intensity (250 µmol $m^{-2}s^{-1}$) starting 2 or 4 weeks after the start of the SD period, the plants turned back to vegetative growth, and the maturation of flowers was delayed. Interestingly, when plants were exposed to an extended photoperiod starting six weeks after the start of SD, flowering was not delayed; however, the floral yield was also not increased. This was also observed when the photoperiod was extended by red or white at low light intensity (250 µmol $m^{-2}s^{-1}$). When starting from 6 weeks after the start of SD with an extended photoperiod at high light intensity (600 µmol $m^{-2}s^{-1}$; white light), plants produced higher floral yield compared to plants grown under continuous SD. Delta-9-tetrahydrocannabinol (THC) content in flowers declined by extending the photoperiod from 2 or 4 weeks after the start of the SD, but it was not influenced when the extended photoperiod was applied from 6 weeks after the start of SD.

Keywords: cannabinoids, *Cannabis sativa* L., LEDs, Spectrum.

OS19-09

Evaluation of Alternative Soilless Growing Systems for Resource Use Efficiency, Yield and Quality Performance of Multi-leaf Lettuce

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Soilless growing systems (SGS) are increasingly used for both small-scale and large-scale industry vegetable production. Although these systems offer several benefits, such as increased water and nutrient use efficiency, exclusion of soilborne issues, and improved quality control, their sustainability is often questioned due to differences in efficiency and energy requirement. Only a few studies have examined side-by-side the performance of alternative SGS in terms of crop yield, quality, and resource use efficiency, including water and energy use. To address this gap, a study was conducted in the Spring of 2023 at the Penn State Greenhouse Facility to compare side-by-side within the same greenhouse environment the most commonly used SGS for their resource use efficiency, crop yield and quality using lettuce as a test crop. Five alternative SGS including ebb and flow, deep water culture, drip irrigation, Kratky, and NFT and two varieties of lettuce (Green and Red Salanova) were arranged in a split-plot experimental design with 3 replications. The total volume of water used by each SGS was recorded and at harvest, crop yield and quality components were measured including plant fresh and dry weight, leaf color, mineral profile, and main nutritional quality traits. Results indicated that the Kratky system was the most efficient for water consumption. The NFT

system provided the best yield performance. Green Salanova lettuce had a higher fresh weight, but lower leaf area compared to the Red Salanova lettuce. No differences were observed in terms of leaf CIELAB color coordinates among the SGS tested within each lettuce selection. Analysis of the mineral and nutritional profile, and energy use efficiency are ongoing.

Keywords: Hydroponic systems, water use efficiency, nutrient use efficiency, energy use efficiency, ebb-and-flow, deep water culture, drip irrigation, Kratky, Nutrient Film Technique.

ORAL SESSION 20 / Organic Greenhouse Horticulture: Soil fertility and plant health

OS20-01

Organic fertilizers: as priming agents for enhanced plant defences against pathogens?

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With the increasing prices of chemical fertilizers and the growing demand for vegetables and fruits that are produced in an environmentally friendly way, resorting to organic fertilizers (OFs) becomes a more and more viable option. The latter are animal or plant residues that are mainly used to provide macro- and micro-elements to the plant, especially nitrogen. In addition to being applied as nutrient sources, OFs can also increase crop resistance to pests or abiotic stresses. Much like vaccines in animals, priming agents condition plants for the superactivation of their immune system upon infection with a pathogen which can reduce the incidence of diseases on crops. We hypothesized that some OFs can favour microbial communities in the rhizosphere which are capable of priming plant defences. To test this hypothesis, 3-week-old tomato plants (cv. M82) were transferred onto 9 different growing media, each consisting of the same organic substrate either mixed with one of 7 different OFs, deprived of any fertilizer (Ctrl) or fertilized with a mineral nutrient solution (Min). After two weeks, soil samples were taken for metabarcoding analyses and plants were inoculated with *Pseudomonas syringae* DC3000-LUX (*Pst-LUX*). A day later, leaf samples were taken to measure the expression of defence-related genes. Bacterial speck severity and *Pst-LUX* survival were measured 6 days after the infection. As hypothesized, the RT-qPCR results showed an increase in defence gene expression for some OFs when compared to Min. Although OF alone were not enough to increase plant resistance to *Pst-*

LUX, combining an OF with the mineral fertilization to make up for its nutrient shortfalls, significantly reduced the incidence of bacterial speck on tomato plants. Finally, the metabarcoding data showed correlations between changes in microbial diversity and defence gene expression, which allowed us to identify specific taxonomic groups potentially involved in OF-induced defence priming.

Keywords: Organic fertilizer, Tomato, Defence priming, Pseudomonas syringae, Soil microbiome.

OS20-02

Black soldier fly frass: a new organic fertilizer or biostimulant?

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According to recent estimates, the world's population will reach 9.7 billion by 2050, resulting in an increase in food demand. Consequently, it will be necessary to at least double food production by the year 2100, while minimizing its environmental footprint. Therefore, sustainable fertilizers, such as organic fertilizers (OF) from diverse origins, are sold to support growth and reduce the use of chemical fertilizers and their environmental burdens, while biostimulants are known to improve nutrient use efficiency, plant growth and crop product quality. On the other hand, insect farming, bioconverting organic waste into larval biomass as livestock feed, generates a new source of organic waste in the form of exuviae and frass, which can be valorized for crop production. In this study, we made the assumption that black soldier fly frass (BSFF) can be used as organic fertilizers, although their nutritional values can be influenced by insect diet and processing. To test this hypothesis, we conducted a greenhouse experiment using 6 different BSFF made with one of two diets (1-fruit/vegetable/bakery waste or 2-standard Gainsville diet) and having undergone one of three processing treatments (1-no treatment, 2-dehydration or 3-pasteurization). During this experiment, three-week-old tomato and cucumber plants were transferred onto 8 different growing media, each consisting of the same organic substrate either mixed with one of the 6 BSFFs, a commercially available OF, deprived of any fertilizer or fertilized with a mineral nutrient control solution. BSFF were applied at five rates (0, 0.125, 0.25, 0.375 and 0.5 g of nitrogen per L of dry soil) and plants were kept for four weeks, during which plant height, diameter, SPAD and Fv/Fm values were measured every week. Plants were then harvested for root and shoot fresh and dry weight measurements. The soil was also sampled in order to measure the total microbial enzymatic activity, soluble nutrient concentrations and total organic nitrogen contents. Finally, this experiment allowed us to assess the potential of using BSFF as OF and also determine the optimum rate for each type of frass.

Keywords: Biofertilizer, Black soldier fly, Circular agriculture, Insect-derived products.

OS20-03

Analysis of Nutrient Composition of Organic Liquid Fertilizer for Optimizing Fertilizer Dosing for Hydroponic Crop Production

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Environmental awareness and economic benefits are encouraging growers in controlled environment agriculture (CEA) to adopt organic substrates and fertilizers. However, minimal studies were conducted regarding the application of liquid organic fertilizer for hydroponic crop production. The current study aimed to survey and select commercial liquid organic fertilizers and analyze their nutrient composition for optimizing nutrient dosing. First, organic liquid fertilizers certified by the organic materials review institute (OMRI) were identified based on the listed nutrient profile and reports of other studies. The selected liquid organic fertilizers (i.e., PreEmpt, Neptune harvest, Caos, FoxFarm, Esparon, and Bombardier) were diluted according to the manufacturer recommended rate. The physical changes, such as biofilm accumulation or sedimentation, and chemical composition were recorded at two-week intervals after preparation. The concentration (mg/L) of macro-nutrients (NH_4^+, NO_2^-, NO_3^-, PO_4^{3-}, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}), micro-nutrients (Na^+, Cl^-, F^-, Br^-), total nitrogen (TN), and organic carbon (OC) of each sample were identified. Synthetic fertilizers for hydroponic substrate-based and liquid cultures were used as the control. After two weeks of dilution, biofilm accumulation, sedimentation, and fermentation were observed in some organic fertilizers, which might be solved by sanitization or aeration. The electrical conductivity (EC) of the diluted fertilizers was within the range of 1.5-2 mS/cm, except Esparon (0.69) and Bombardier (0.88), and pH at 5.3-6.8, except Caos (7.3). The total nitrogen concentration was above 100 mg/L in Foxfarm, Bombardier, and PreEmpt and below in Espartan, Caos, and Neptunes. According to the ion analysis, concentrations of NO_3^-, TN, and OC decreased; NH_4^+, NO_2^-, K^+, Ca^{2+}, and Na^+ increased; and Mg^{2+}, SO_4^{2-}, and Cl^- remained the same after two weeks of dilution. The current research will help growers to prepare the target concentrations of liquid organic fertilizer from the tank mixing stage to dosing.

Keywords: bio-film, electrical conductivity, macro-nutrients, micro-nutrients, sedimentation.

OS20-04

The effect of organic liquid fertilizer treatment on growth and yield of Bean (*Phaseolus vulgaris*) grown in soilless culture in greenhouse

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Quality of vegetal products are influenced both by hereditary factors and environmental conditions. Fertilization as an environmental factor can strongly affect not only yield, but also

quality of produce. In the horticulture industry, the focus has traditionally been on yield performance. However, consumers' interest worldwide in the quality of horticultural products has increased in the recent past and will become the driving force in the future. Therefore, soilless culture systems, the most intensive production method in today's horticulture industry, must be based on environmentally friendly technology, which can result in higher yield and quality crops, even in areas with adverse growing conditions. Organic greenhouse vegetable production has high potential for the out-of-season produce market niche, and is a sustainable method of production. In the study, effects of liquid organic fertilizer containing enriched microelements and zinc-soluble bacteria were investigated on plant growth and yield of bean (*Phaseolus vulgaris*) growing. This study, conducted to determine the effects of liquid organic fertilizer (microelements-enriched) on yield, quality and plant development of green beans, conducted at research greenhouses of Malatya Turgut Ozal University in 2018. Liquid fertilizer was applied into the bean-grown pots as four applications during the study. As part of the study, the effects of liquid fertilizer on plant height, main stem diameter, fruit length, flesh thickness, root length, root wet and dry weight, biomass weight, leaf SPAD value and fruit per plant were determined. Results showed liquid fertilizer applications were found significantly effective on the examined parameters when compared to control plants. Plants which were applied with liquid fertilizer yield 21.84% higher yield based on average values. As a result of this study, liquid organic fertilizer applications were found positively affecting plant development and yield of green bean growing.

Keywords: Soilles cultivation, *Phaseolus vulgaris*, organic fertilizer, plant growth, yield, microelements.

OS20-05

Feasibility study on application of organic liquid fertilizer in hydroponic water spinach (*Ipomoea aquatics* Forssk.)

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Hydroponics is a method widely used for horticultural plant production independent of soil fertility. It also can avoid the effects of soil diseases and continuous cropping and eliminate the work required for soil preparation, fertilization, weeding, etc., and enable efficient cultivation by using multiple growing beds vertically. Most of hydroponic cultivations use chemical fertilizers. However, the rising cost of chemical fertilizers has pushed the government to expand organic farming in Japan, including promoting the establishment of organic liquid fertilizers for hydroponic cultivation. Food garbage, plant residue, fish/animal

waste, and other biological waste can be composted for reuse as organic fertilizer. Organic ingredients in the nutrient solutions need to be decomposed and mineralized by microorganisms before it can be absorbed by plants, and the EC value of the nutrient solution will change during this process. Therefore, the management method of nutrient solution based on EC value is no longer applicable in organic cultivation. This study aimed to establish an appropriate application method of organic liquid fertilizer for hydroponic water spinach cultivation, and its feasibility is discussed.

Keywords: microorganism, NFT, water temperature, decomposition.

OS20-06

Evaluating the influence of organic fertilizers on container-grown highbush blueberries in high tunnels

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Canada is the world's second-largest producer of blueberries, and the increasing demand for this fruit is primarily driven by growing awareness of its health benefits, including dietary antioxidants and nutritional value. To enhance growth, yield, and fruit quality while ensuring crop sustainability such as sustainable nitrogen nutrient management, it is essential to consider alternative production systems. Consequently, in a split-plot design over two growing seasons, we compared four different fertilizer treatments: 1) poultry pellets + feather meal, 2) soy protein hydrolyzate + rock phosphate, 3) bone meal + alfalfa meal + seaweed extract, and 4) an inorganic fertilizer control. We conducted this study with three selected cultivars: Liberty, Reka, and Bluecrop. Blueberry plants were potted in 25L containers filled with an organic peat-based substrate, irrigated through a drip system, and grown under high tunnels. The irrigation pH and electrical conductivity (EC) were maintained at 4.5-5.0 and 0.8 mS cm^{-1}, respectively. While soil microbial activity (FDA) tended to be higher under organic management, there was no significant difference compared to the inorganic fertilizer control. Soil N-P-K analyses revealed that poultry pellets + feather meal and bone meal + alfalfa meal + seaweed extract treatments had the highest concentration of available NO_3^-, whereas the soy protein hydrolysate treatment had the highest concentration of NH_4^-, which is the preferred form of nitrogen for blueberries. Leaf chlorophyll content (SPAD) was significantly higher for plants grown under the inorganic fertilizer control, while photosynthetic leaf performance (Fv/Fm, PI) was higher under the bone meal + alfalfa meal + seaweed extract treatment. However, plant productivity (i.e., g of berries per plant) was significantly higher for the inorganic control plants, while the poultry pellets + feather meal treatment had the lowest yield. This suggests that poultry pellet-based fertilizer is not suitable as the primary nitrogen source for blueberries grown in containers. Among the three organic fertilizer treatments studied, the bone meal + alfalfa

meal + seaweed extract treatment performed the best. On the other hand, during the first experimental year, berry qualities, such as polyphenol concentrations, were higher when plants were fertilized with organic fertilizers compared to the inorganic fertilizer control.

Keywords: Organic farming, soilless cultivation, nitrogen organic fertilizers, soil microbial activity, photosynthetic performance, productivity, berry quality, high tunnel.

OS20-07

Lettuce (*Lactuca sativa* L. var. Lalique) Production Using Organic Nutrient Solution Under Hydroponics System

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Lettuce is one of the most widely hydroponically grown crops and studies showed that lettuce has a high yield and good quality under a soilless production. However, the nutrient solution used in hydroponic systems is based on chemical fertilizers. Recently, there has been an increased interest in organic hydroponics as the market for organic food continues to grow. The study was conducted to evaluate commercially available organic nutrient solutions (Vermitea, BioVoltin, Ramils, Healthynest) in comparison to conventional inorganic fertilizers (Snap) in hydroponic lettuce production with water as a negative control. The crop experiment was carried out in a plastic polyhouse with a mesh net at the Institute of Agriculture, Camiguin Polytechnic State College – Catarman Campus, Tangaro, Catarman, Camiguin, from November 1, 2021, to December 15, 2021, using a Randomized Complete Blocked Design with three replications. Results of the study showed that among organic nutrient solution, Treatment 5 (Ramils) and Treatment 7 (Healthynest,), showed comparable results to conventional inorganic fertilizer, Treatment 1 (Snap) in terms of horticultural characteristics, root development, survival rate, yield, nutrient solution consumption per plant and total nutrient solution consumption. and sensory quality attributes and cost and return analysis. Treatment 5 (Ramils) was considered best overall in terms of sensory quality attributes, overall acceptability, and marketability. Also, Treatment 5 (Ramils) showed a comparable resultsto Treatment 1 (Snap) in terms of yield, hence generated a comparable net returns, net profit margin and return on investment.

Keywords: hydroponics, lettuce, organic nutrient solution, sensory quality, yield.

OS20-08

Valorization of greenhouse crop residues using anaerobic digestion

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This research study focused on the use of the anaerobic digestion (AD) to valorize greenhouse crop residues as a source of fertilizer and energy. These agricultural waste-products are rich in nutrients, particularly nitrogen, and can represent a significant environmental burden when

they are disposed of in landfills. The goal of this study was then to determine the biodegradability of greenhouse crop residues during the AD process as well as the amount of nitrogen that is recovered in ammoniacal form. To achieve this, batch digestion tests were performed to measure the potential for biomethane production (BMP) and the apparent nitrogen mineralized potential (ANMP). These trials also determined the effectiveness of some pretreatments, such as thermal pretreatment at different temperatures, steam sterilization, microwave pretreatment and oxidative pretreatment using hydrogen peroxide, in order to increase the biodegradability of crop residues, thereby improving the nutrient recovery. To study the impact of theses on the biodegradability of residues, the fiber composition of fresh and pretreated leaves was determined using the Van Soest method. The pretreatments also aimed to assess the persistence of two very problematic phytovirus in greenhouse production, namely the cucumber green mottle virus (CGMMV) and the tomato brown rugose fruit virus (ToBRFV). Depending on the crop residues and the pretreatment, a reduction in COD of 70 to 100% was observed, which allowed an average production of 308 NmL of CH_4, per gram of organic matter. The mineralization rate of organic nitrogen ranged from 20 to 50%, which resulted in a NH_4 concentration of2000 to 3500 ppm in the digestate. A pretreatment also allowed the deactivation and elimination of a phytovirus. According to our results, a pilot scale AD will be built to validate our processes.

Keywords: Anaerobic digestion, Agricultural waste-products, Greenhouse crop residues, Nutrient recovery.

ORAL SESSION 21 / Energy in greenhouses

OS21-01

Quantifying energy saving by screens – the role of humidity transport

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The application of new energy saving cultivation techniques in Dutch greenhouses heavily relies on using one or more movable screens. Screens affect greenhouse climate by radiation , air and humidity exchanges between the lower and upper part of the greenhouse compartment separated by screens. Screens, especially multiple screens, affect the insulation value of the greenhouse. Therefore, screens have an important role in energy saving. The objectives of this project are to quantify screen properties by standardised measurements: thermal properties such as transmissivity and emissivity for thermal infrared radiation, aerodynamic properties such as air permeability and humidity transport characteristics such as diffusion and hygroscopy, the mechanism of humidty condensation on the lower side of the screen, transport through the material and evaporation at the upper side of the screen. All energy flows around screen materials are separately analysed. From the measured screen properties the overall potential energy saving can then be calculated

under defined growing conditions to obtain an objective comparison of the performance of different screen materials. This helps growers to understand more about screen properties and allows them to make informed choices of investment and practical usage. This also helps screen manufacturers to develop improved materials. The project builds on earlier results of Hemming et al. (2018), it is extended to quantify the energy transport through wet screens with special emphasis on humidity transport mechanisms. A new measurement equipment (TrasnHumidbox) has been designed to measure and quantify humidity transport mechanisms, standardized protocols have been developed, ten different screen materials have been analysed. The results show that low emissivity and high reflectivity for thermal infrared radiation of a screen is correlated to low radiative energy losses. Low air permeability of a screen is correlated to low losses of sensible (and latent) heat. Results further show that investigated materials differ in their humidity transport properties in dry and wet conditions. A low humidity transport of a screen is correlated to a low loss of latent heat. On materials with low air permeability the fraction of humidity transported by hygroscopy becomes more important. Total energy saving of investigated screens differed between 17% and 43% at night with high and low air permeability, respectively, compared to a situation without a screen for the screens studied. Highest energy saving can be reached by adapting the practical usage of a grower such as control on high humidity setpoints and use of mechanical dehumidification with heat regain.

Keywords: energy saving, screens, humidity transport, air permeability, hygroscopy , radiometric properties, emissivity, tomato.

OS21-02

The trade-off between yield and electricity use for sweet pepper production in closed greenhouses in arid environments

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Water is such a scarce resource in arid areas that it frequently becomes the limiting factor for the production of vegetables for fresh consumption. The most common production system, namely greenhouses fitted with evaporative cooling, strains the scarce water resource. Greenhouses fit with mechanical cooling capacity (closed or partly closed greenhouses) are reported to limit water use more than ten times compared to evaporatively cooled greenhouses. This low use of water comes at the cost of large amounts of electricity for cooling. Allowing higher greenhouse temperature reduces the energy (electricity) used for cooling but might have a negative impact on crop yield. A series of trials took place in closed greenhouses in the ESTIDAMAH research center in Riyadh (KSA) to investigate the effect of two different temperature regimes (higher and lower) on the growth and production of 4 different sweet pepper varieties as well as the energy use and the achieved energy and water use efficiency. The experimental results indicated the tradeoff between

cooling energy use and crop yield. Specifically, reducing the greenhouse temperature by 2°C on average resulted in a yield increase of 5.8 $kg.m^{-2}$ (average of all varieties) at the expense of about 160 $KWh.m^{-2}$ additional electricity. Therefore, there is some space for economic optimization of sweet pepper production in closed greenhouses in arid regions based on the ratio between sweet pepper and electricity price. Based on the outcome of the performed trial, the lower temperature regime pays off when 1 kg sweet pepper is worth more than 28 kWh of electricity.

Keywords: energy use, closed greenhouse, arid regions, sweet pepper, greenhouse climate, energy use efficiency, water use efficiency.

OS21-03

Analysis of greenhouse energy consumption in northern China

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By 2022, China's total horticultural area is over 2.8 million hectares, including 810,000 hectares of Chinese solar greenhouses (CSG). Due the difference of climate and material, the heat load of CSG varies greatly. An accurate calculation of heat load and heating requirement in winter can greatly contribute to assess the regional adaptability. In this study, 17 cities in China were selected to analyze the local climate and scale of CSG development. The total solar radiation from October to next February and the lowest air temperature outdoor in winter were extracted using the downloading data from China Meteorological Data Network. The heat balance equations and thermal environment simulation software RGWS-RHJPJ V1.2 were used to calculate the winter solstice heating requirement and the heat load at the lowest outdoor temperature in the coldest month for SA-CSG in 17 cities. Furthermore, the heating requirement was analyzed to select an active heat storage and release system as the heating source for CSG. The results showed that the minimum heat load of CSG occurred in Nanjing with 56.4 W/m^2, whereas, the maximum was found in Altay with 140.9 W/m^2, among 17 cities in the CSG production area of China. The city with the minimum SA-CSG heating requirement on the day of winter solstice was Lhasa with 0.7 MJ/m^2, the maximum heating requirement was in Harbin with 7.7 MJ/m^2. The heat load was in the range of 50~150 W/m^2, where the ratio ranging from 50 to 100 W/m^2 was more than 50%. The heating requirement of CSG ranging from 0-2 MJ/m^2 was about 20% of the regions, 2-4 MJ/m^2 was about 50% of the regions, 4-7 MJ/m^2 was about 20% of the regions, and only about 10% of the regions were in the heating requirement of more than 7 MJ/m^2. This result may provide some guidance to the design of greenhouse.

Keywords: Chinese solar greenhouse, solar radiation, heat transfer coefficient, heat load, heating requirement, active heat storage and release system.

OS21-04

Development and demonstration of a net zero energy greenhouse (ZEG) for contributes to the decarbonization of horticulture

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In recent years, the management of greenhouse horticulture has become increasingly difficult due to soaring energy prices. In greenhouse horticulture, reduction of CO_2 emissions from combustion heaters is required. In this situation, environmental control of greenhouses to increase the productivity of horticultural crops and the efficient use of energy has become a major concern. However, greenhouse environmental control has difficulties such as high temperature and humidity in summer and high energy consumption for heating in winter. Improvements for more sophisticated greenhouse systems to meet these requirements are needed. On the other hand, under mild conditions, using basic techniques may require less resource input than using complex and advanced techniques. Therefore, we are currently developing and demonstrating a net zero energy greenhouse (ZEG) in a Japanese national research and development project. The concept of a ZEG is very simple. We aim to increase the energy use efficiency of greenhouses to reduce energy consumption, while supplying renewable energy to achieve net zero. The objective of this study was to identify the equipment requirements for decarbonizing horticultural greenhouse facilities, including covering material, thermal curtain, environmental control systems, electric heat pump systems and photovoltaic panels. Moreover, we describe recent studies on the new spectral irradiance simulation approach, new curtain materials made with nanotechnologies, new environmental sensing systems, autonomous agricultural robots and new heat pump systems.

Keywords: energy conservation, renewable energy, reduction of CO_2 emissions, covering materials, environmental monitoring and control systems, electric heat pump systems.

OS21-05

Assessment of the solar radiation and microclimate distribution inside a prototypal dynamic photovoltaic greenhouse equipped with solar tracker: An experimental and CFD assisted study

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The agricultural sector is important in many countries, as it accounts for a substantial share of overall employment both directly and indirectly via its relationship with food processing and distribution. In Morocco, agriculture has contributed about 12 % of gross domestic product (GDP) over the past five years (Morocco GDP Annual Growth Rate, 2022) and about 33% of employment (Haut commissariat du Plant, 2021). Low productivity and low incomes cause people to move out of agriculture, resulting in a reduction in employment in the sector. Employment has reduced dramatically from 45% of total employment in 2006 to 38% in 2019 (THE FUTURE OF SKILLS-MOROCCO, 2021). The greenhouse sector as a whole is especially important in agriculture.

To address this evolution in agriculture and the greenhouse sector, the Kingdom of Morocco must confront the energy crisis and the disruption of the energy sector and the soaring prices of petrol, since late 2021 especially with the Ukrain/Russia war which have led to tensions on energy supplies. Until now, Morocco is strongly dependent on foreign energy supplies, which represent significant costs for the kingdom and for agri- culture, especially for solar pumping and heating for greenhouses where the majority of farmers in Morocco use gaz cylinders.

From this observation, the aim of This work is to presents an energy analysis of a dynamic prototype photovoltaic (PV) greenhouse to (1) study the production of energy and the important amount of waste heat discharged outside the greenhouse in order to obtain a production efficiency and (2) to evaluate climatic conditions with different tilt angles of the PV panels inside the structure, in which 10% of its roof surface has been replaced with mobile photovoltaic (PV) panels equipped with solar tracker and (3) To analyseThe effects of shading from the PV array on crop productivity **.**

In this context, solar radiation distribution, thermal air, water vapor and the dynamics fields were simulated using the Computational Fluid Dynamic (CFD) by using a commercial software package Fluent v6.3.26 based on the finite volumes method to solve the mass, momentum and energy conservation equations. The turbulent transfers were described by model. Likewise, the dynamic influences of insect screens and crop on air flow movement were modeled by means of the concept of porous medium.

Keywords: CFD, greenhouse, Solar radiation, Photovoltaics, microclimate.

OS21-06

Energy savings in greenhouses by the use of low emissivity materials in screens

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In heated greenhouses thermal screens are used to reduce energy use in cold periods due to their insulating function. Materials with low thermal infrared (TIR) emissivity can further reduce energy use by decreasing the amount of energy losses toward the sky through TIR radiation. When developing new materials for thermal screens, the following questions arise: what is the role of emissivity of materials on energy saving? What other optical and radiometric material properties have the potential to improve the performance of thermal screens? And what are the tradeoffs between various properties that influence the screen's potential to reduce energy use or increase energy use efficiency? This study used model simulations for greenhouses in The Netherlands to evaluate how optical and radiometric properties influence screen performance. First, a sensitivity analysis was performed, showing that the most important optical property of a screen influencing energy use and energy efficiency was the emissivity of the upper side of the screen. Second, the effect of lowering the screen's emissivity was compared with increasing the screen's transmissivity to photosynthetically active radiation (PAR) and consequently modifying the strategy for use of the screen in daytime during cold periods. Lastly, the interaction between emissivity, PAR transmissivity, and near-infrared (NIR) transmissivity was examined. The results show that lowering a screen emissivity from 0.44 (a typical value for commercial screens) to 0.2 (a theoretical, optimized screen) has the potential to reduce energy use by 13%. Increasing a screen's hemispherical PAR transmissivity from 0.72 (typical commercial value) to 0.9 (theoretical optimized value) and consequently adjusting the daytime screen strategy can reduce energy use by 6%. However, the use of an energy screen with high PAR transmissivity during daytime is only beneficial if the screen also has a high NIR transmissivity to capture as much solar energy as possible.

Keywords: Greenhouse energy saving; Energy screen; Thermal screen; Emissivity; Thermal radiation; Infrared radiation.

ORAL SESSION 22 / Environmental impact and sustainable production

OS22-01

Circular economy – transferring biological control principles into intensive production systems – the zero waste approach

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The still increasing global population puts enormous pressure on the agricultural sector to produce enough food without endangering the environment and resources. To meet this challenge, the circular economy has been presented as a promising approach. Consideration of the circular principle is based on the simple fact that in a finite world, current production methods will have no future without true material circularity. In the foreseeable future, the fossil resources used up to now as sources will be exhausted, while on the other hand the available landfill possibilities for the unavoidable waste and residual materials of chemical production as material sinks will also be exhausted. The circular economy therefore takes nature's material cycle as a model and attempts to use materials and energy as long and sensibly as possible through intelligent, cascading uses without waste (zero waste) and without emission (zero emission). The advantage of such combined systems is high resource efficiency combined with sustainable production. In Berlin, a corresponding research project (www.cubescircle.de) was set up with numerous partners. The production areas linked in a demonstration plant include not only plant production but also fish and insect production. The material and energy flows as well as the mutual dependencies of the different areas are being investigated. Consequently, an unrivaled resource- and energy efficiency is reached. At the same time, the productivity of healthy food is optimized. However, CUBES Circle advances this productivity further in terms of its environmental balance. Energy and material flows like exergy, water and feed will be gained from products, or residuals from the other respective production systems. Further, holistic models of nutrient fluxes will be developed, so that the production can be dynamically adapted to environmental conditions using smart regulation measures.

Keywords: circular economy, zero waste, sustainability, resource efficiency, CUBES Circle.

OS22-02

Model-based optimization of N-fertilization strategies, balancing production and nitrate leaching in horticultural crops

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Intensive horticultural production is linked to pollution of surface and groundwater due to nitrate leaching of overfertilized crops. In Flanders (Belgium), farmers should comply with strict regulations regarding maximal N-application and residual soil nitrate (< 85 kg NO_3^- ha^{-1} at the end of the cycle, between 1st of Otober and 15th of November). However, due to the high nitrogen demand, shallow rooting systems and low nitrogen use efficiency of most horticultural crops, ensuring sufficient nitrogen availability without risking considerable environmental- and/or yield-losses is challenging.

This study aimed to improve the fertilization of leek cultivation in Flanders through a model-based decision support system, limiting nitrogen leaching while maintaining N-availability, resulting in optimal yield.

This was achieved by simulating hundered fertilization strategies with the ECOFERT simulation model using 40-years of weather data and along to a space-filling experimental design. For each simulation, the dry biomass and the residual soil nitrate were determined. Subsequently, a response surface was fitted to estimate both variables for N-application strategies that were not simulated. Finally, the optimal strategy was determined using a genetic optimization algorithm.

This approach was evaluated in two field trials, in which the standard KNS advisory system (H P Lorenz, 1989) was compared to the ECOFERT recommend N-application. One trial had a high soil organic carbon (SOC) content (2.3%), and the other had a low SOC (0.9%). On the field with high SOC, the KNS recommended 136 kg N ha^{-1}, resulting in 118.3 kg NO_3^- ha^{-1} residual nitrate at the end of the cycle. However, the ECOFERT model advised no fertilizer application because the legal residual soil nitrate would be surpassed under many historical weather conditions. This resulted in a 63% reduction of the residual soil nitrate (43.5 kg NO_3^- ha^{-1}) but also in a 10% yield loss (57 t ha^{-1}, as compared to 63.5 t ha^{-1} for KNS). On the field with low SOC, ECOFERT recommended 165 kg N ha^{-1}, resulting in no yield loss (76.2 t ha^{-1}) but a 21% reduction of applied nitrogen and a 51% reduction of the residual soil nitrate (35.5 kg NO_3^- ha^{-1}). While the KNS system adviced 209 kg N ha^{-1} for a yield of 76 t ha^{-1} and a residual nitrate of 71.8 kg NO_3^- ha^{-1}.

This study showed that model-based fertilization could reduce N-input compared to the standard KNS advisory system. However, for specific soil conditions, this might lead to yield loss.

Keywords: ECOFERT, optimization of nitrogen fertilization, nitrogen leaching, leek.

OS22-03

Implementation of the circular economy concept in greenhouse production systems: microalgae and biofertiliser production using soilless crops' drainage nutrient solution

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The challenges to feed the world in 2050 are becoming more and more apparent. This calls for producing more with fewer inputs (most of them under scarcity), higher resource efficiency, minimum or zero effect on the environment, and higher sustainability. Therefore, increasing the circularity of production systems is highly significant for their sustainability. Protected horticulture offers opportunities for maximum resource efficiency across various levels within and between farms and at the regional level), high-quality production and contributes significantly to the nutrition security as part of the world food production. In greenhouses, closed soilless cultivation systems give the opportunity to increase the water and nutrients use efficiency and reduce the environmental impact of the cultivation system by the reuse of the drained water and nutrients. However, due to low quality of the water used in the Mediterranean countries, a completely closed systems is not feasible. Partial discharge of the drainage nutrient solution when the levels of electrical conductivity (EC) or of the toxic ions in the system are reached, is still a necessity. Thus, in the frame of the circular economy concept, this work presents the utilisation of the drainage solution of soilless cultivation systems for microalgae and of biofertilisers production. The system includes a greenhouse equipped with a soilless cultivation system, a drainage solution collection tank, a closed bioreactor for microalgae production and a biocatalysis tank. The bioreactor tested in the frame of this work includes two closed tube loops of a capacity of 1000 L each where, after the initial inoculation, the microalgae is developed using as growth medium the drainage solution collected from the greenhouse crops. The bioreactor includes light and temperature control while pH still is manually regulated. As soon as the microalgae culture reaches a certain density level, 20% of the culture is harvested and the culture system is refiled by drainage nutrient solution. The microalgae produced is going through a biocatalysis process which leads to the production of a rich to aminoacids (and nitrogen) biofertiliser. The produced biofertiliser is then used for the fertilisation of the greenhouse crops. The complete production cycle along with the effects of the biofertiliser produced in

crop growth and yield are presented and discussed in this manuscript. This work was carried out under the PestNu project that has received funding from the European Union's Horizon 2020 research and innovation programme under the Green Deal grant agreement No. 101037128 — PestNu.

Keywords: circular economy; drainage solution; microalgae; biofertiliser.

OS22-04

Electric fields influence lettuce plant growth and mineral uptake

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An electric field, a physical field that surrounds electric charges and exerts a force on charged particles, is a natural component of Earth. Hence, plants have adapted to live in electric fields, and the fields can influence growth and development. Several studies have reported increases in seed germination, plant biomass, and mineral uptake by applying external electric fields. However, the mechanisms responsible for these responses are still unclear, and there is a need for a systematic understanding of the effects. In this study, we investigated the influence of external electric fields on lettuces, considering directional influences on plants. Lettuce seedlings were grown under four conditions: zero, ambient, vertical, and horizontal electric field. Zero electric field was formed using a Faraday cage, which is a type of shield that blocks the electromagnetic field. The electric fields were generated continuously for four weeks using stainless steel mesh electrodes and a DC high voltage generator set to a strength of 5 kV m^{-1}. Timelapse videos were recorded to visualize the growth trends of the lettuce under electric fields. Both shoot and root fresh weights increased in the vertical and horizontal electric fields; however, the weights decreased in the zero-field compared to the ambient treatment. We found that the electric field directions modified the allometric relationship between shoot and root growth. In addition, mineral uptake was boosted in lettuce plants under electric field treatments compared to the ambient treatment. This suggests that electric fields may affect the relationship between plant development and the transport process of nutrients and provides a foundation for understanding the mechanisms of growth promotion. The vectorial consideration and quantification are required to address the knowledge gap of the electric field's relationships with plant physiology and production.

Keywords: Electro-culture, Electrical stimulation, Mineral uptake, Vertical electric field.

OS22-05

AI-Based Detection of Plant Stress: A Case Study on Fir Trees Under Bark Beetle Attack

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Plants are constantly exposed to a variety of abiotic (including drought, high salinity, extreme temperatures, and/or nutrient deficiency) and biotic stressors (includes attacks by pathogens and herbivores) in their environment. These stressors can negatively impact plant growth, development, and overall fitness. To survive and adapt to these challenges, plants have evolved intricate molecular mechanisms to sense and respond to stress. Among these mechanisms, the emission of volatile organic compounds (VOCs) plays a crucial role in plant stress responses. Various sensing technologies, such as gas chromatography-mass spectrometry (GC-MS) and electronic noses (e-noses), can be used to capture VOC emissions and detect plant stress at early stages.

In Austria bark beetles (Scolytinae) pose a significant threat to fir trees, causing substantial damage and mortality in forests. Early detection of bark beetle infestation is crucial for effective management and mitigation strategies. However, early detection of the bark beetle has so far been unsuccessful. With the advent of artificial intelligence (AI) technologies, novel approaches have emerged to automate and enhance the process of plant detection and identification. Additionally, AI techniques have been combined with other data sources, such as hyperspectral imaging and LiDAR data, to extract more detailed information about plants and trees. The integration of AI techniques with VOC analysis provides a powerful approach for the detection and identification of stress-induced VOCs emitted by plants. This technology can significantly improve our understanding of plant stress responses, facilitating early detection of stress conditions, and developing targeted interventions for sustainable plant health management. Our research group uses AI technology to detect and analyze VOCs emitted by stressed fir trees and pheromones emitted by bark beetles, offering a novel approach for early detection of tree stress and monitoring of bark beetle infestation in fir forests.

Keywords: plant stress management, fir tree, bark beetle, volatile organic compounds (VOCs), pest management, artificial intelligence (AI), deep learning, gas chromatography-mass spectrometry (GC-MS), electronic nose (e-nose).

ORAL SESSION 23 / Lighting technology III

OS23-01

Intra-canopy lighting in tomato and cucumber crops

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Supplementary lighting in greenhouses is usually applied on top of the crop. Light emitting diodes (LEDs) make it possible to provide light in between the plants, so called intra-canopy lighting (ICL). In this presentation we aim to explore and quantify the effects of intra-canopy lighting on yield, growth and physiology of the high-wire crops tomato and cucumber. Using Functional-structural plant models we showed that a combination of 50% intra-canopy and 50% top lighting, compared to only top lighting at the same total DLI increased the spatial uniformity of light distribution in the canopy as well as the total fraction of light absorbed by the canopy. Several winter experiments with tomato and cucumber showed that replacing part of the top light by intra-canopy light increased yield by 10 to 24%. However, when top lighting was completely replaced by intra-canopy lighting in a spring-summer experiment, no significant difference in tomato yield was observed. The positive effect of intra-canopy light on yield in the winter experiments was larger when higher total intensities of light were used. Yield component analysis revealed that the increased yield was primarily due to an increase in dry matter production of the plants, but in some cases also an increase in the fraction of dry matter partitioned to the fruits contributed to the yield increase. Positioning of the LEDs had no effect on the photosynthetic light response curves of upper leaves in tomato. However, in lower leaves these curves raised to a higher level. In tomato intra-canopy light did not substantially affect fruit quality while in cucumber this led to fruits with a darker green colour.

Keywords: tomato, cucumber, LED light, yield, dry matter partitioning, photosynthesis.

OS23-02

Effect of light intensity and air temperature on morphology, specialized metabolism, and photosynthesis of medical cannabis (*Cannabis sativa* L.)

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The use of cannabis (*Cannabis sativa* L) as a medical treatment has propelled interest and research within the rapidly expanding cannabis industry. Developments in the medical cannabis industry are made by regulating, controlling, and monitoring the production of medical cannabis and its derivatives. Improving and standardizing production is required to develop uniform medical products. This research aims to study the effect of light intensity

and air temperature on the morphology, yield, and specialized metabolism of *C. sativa*. Plants were grown in climate-controlled rooms without solar light, where light intensities of 600, 900, and 1200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ were applied in the generative stage. The experiment was conducted four times, i.e., four growing cycles. The growing cycles (n=4) were done with a relatively low temperature (25/21 °C, n=2) and with a high temperature (31/27 °C, n=2). Plant morphology, flower development, carbohydrates, and specialized metabolites in the upper and lower located inflorescences, such as cannabinoids and terpenes (gas chromatography-mass spectrometry), have been measured. Photosynthetic traits such as operational photosynthesis, Fv/Fm, J_{max}, V_{cmax}, and TPU were determined by measuring gas exchange (LI6800, Licor). Disentangling the treatment effects on the formerly mentioned parameters explained how yield components, such as inflorescence weight, inflorescence density, and specialized metabolite concentrations, were affected by carbohydrate concentration and biomass partitioning.

Keywords: medical cannabis (*Cannabis sativa* L.), light intensity, air temperature, specialized metabolites, carbohydrates, morphology, photosynthesis.

OS23-03

Interactions between photon spectra and temperature in lettuce and basil grown under sole-source lighting

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Understanding the effects of temperature and photon spectra on plant growth, quality, and operational costs is needed to support the emerging indoor farming sector of agriculture. The similarities in plant responses to high temperature and shading, such as low blue (B, 400–500 nm) photon flux density (PFD, $\mu mol \cdot m^{-2} \cdot s^{-1}$) and low red (R, 600–700 nm) to far-red (FR, 700–800 nm) light ratio (R:FR), suggest the existence of shared regulatory pathways. We hypothesized that the R:FR and B-PFD interact with air temperature to regulate plant growth and morphology. We grew lettuce 'Rouxai' and basil 'Prospera' under six sole-source lighting treatments with three R:FR (4:0, 4:1, or 4:2) and two B-PFD (40 or 100 $\mu mol \cdot m^{-2} \cdot s^{-1}$) at air temperatures of 19 and 24°. The lower R:FR and B-PFD and higher temperature increased the shoot fresh weight, dry weight, and leaf size of lettuce. Response trends in basil were similar, but the influence of B-PFD was less notable. The effects of the low R:FR on increasing shoot fresh and dry weight of both crops was greater at the higher air temperature; however, the higher B-PFD attenuated this synergistic interaction. Lettuce leaf expansion was promoted by the low R:FR, higher temperature, and their interaction and suppressed by the higher B-PFD. In contrast, there was no notable interaction between photon spectra and air temperature in regulating leaf length and width in basil. We conclude that photon spectra and temperature interact to regulate plant growth and morphology, with the extent

of interaction varying by plant species. In particular, the higher air temperature amplified responses to shading signals (low R:FR and B-PFD), while cues for high light (high R:FR and B-PFD) negated the effects of high temperature. Thus, integrated environmental control, which combines photon spectra and temperature, is needed to precisely manage plant morphology and growth.

Keywords: Blue light, Far-red light, Phytochrome, Photomorphogensis, Shade-avoidance response, Thermomorphogenesis, Vertical farming

OS23-04

The effect of photoperiod and light spectra on greenhouse eggplant production

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The use of supplemental lighting in greenhouse vegetable production has become a common practice over the last decade. Unlike during sunlight-abundant summer months, supplemental lighting is a necessary component of winter production to maintain adequate crop growth and yield. Light-emitting diodes (LEDs) are energy-efficient options that allow for tailored spectral output used to optimize plant growth. While the use of supplemental lighting has become popular for cucumber and tomato production, lit cultivation of eggplant (*Solanum melongena* L.) is uncommon, likely due to the lack of research and knowledge surrounding the crop. Here, we will discuss two experiments that examine the impact of both spectral quality and photoperiod on greenhouse production of eggplant. Both experiments were run at the Harrow Research and Development Centre in Harrow, Ontario, Canada during the winter months. Our first experiment assessed the impact of four overhead supplemental lighting treatments with various percentages of green light. It was found that eggplant supplied with a red + blue spectrum without green light provided a yield advantage during early growth, which persisted throughout the growth cycle and contributed to an increase in overall plant production. We also observed no correlation between an increase in supplemental green light percentage and light penetration through the canopy. The second experiment examined the impact of 16h, 20h, and dynamic 24h (16 hours of white light followed by 8 hours of blue light) photoperiods at the same DLI on greenhouse eggplant production. A higher yield was recorded in all treatments when compared to a no-light control, further alluding to the importance of supplemental lighting for greenhouse vining crops. The implications of extended photoperiods using a reduced light intensity as it pertains to electricity usage will also be discussed.

Keywords: Eggplant, LED, Greenhouse, 24h Lighting, Light Spectrum.

OS23-05

Evaluations of Dim Nighttime Blue Lighting and Downward Airflow to Manage Tipburn in Indoor Farm Lettuce

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Indoor vertical farms (IF) have gained popularity in the US within the last decade. Lettuce is the most produced crop in these systems, but often suffer from the calcium (Ca) deficiency called tipburn due to poor airflow causing low transpiration of young leaves near the meristem. Prevention methods (e.g., foliar calcium sprays, vertical air flow, and slowing growth rate) exist but are not ideal in IF facilities. Therefore, new methods are needed to prevent the common deficiency. In the first experiment, we assessed the application of dim (30 $\mu mol \cdot m^{-2} \cdot s^{-1}$ PPFD) nighttime lighting to enhance transpiration and thus xylem-driven transport of Ca to mitigate tipburn. Dim light of 100% blue, blue/red (4:1), or darkness were applied to 'Klee' and 'Rex' lettuce plants starting 14 days after transplant (DAT). Blue light alone was shown to increase nighttime leaf conductance by more than 50% and transpiration by 25% but did not reduce tipburn severity (% of leaves with tipburn) at harvest (28 DAT) likely due to the high boundary layer created in our tipburn-inducing growing conditions. Of interest, blue/red light were less effective than 100% blue light and showed no differences in stomatal conductance compared with the control treatment. In the second experiment, we examined downward vertical fans (0.4 $m \cdot s^{-1}$) or no added fans with 100% blue light or darkness. Nighttime leaf conductance and transpiration were enhanced by nighttime lighting but tipburn was not reduced. Vertical downward airflow eliminated tipburn entirely as expected. Downward vertical airflow remains the most effective tipburn prevention mechanism for IFs.

Keywords: Indoor farms, lettuce, tipburn, nighttime lighting, blue light effect, gas exchange

OS23-06

Effects of different supplemental lighting directions and intensities on leaf photosynthetic characteristics and fruit yield of strawberry (*Fragaria×ananassa*)

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Strawberry fruit is loved by consumers for providing a wide range of sensory stimulation and health benefits, including its flavor, aroma and nutritional value. Seasonal low light intensity and short photoperiod in winter lead to decreased fruit yield and quality. With the extensive application of facility agriculture in crop production, supplemental lighting using light-emitting diodes (LEDs) could overcome such problems. However, most studies have focused on light intensity or quality but not on direction. In this study, we demonstrated changes in leaf photosynthetic capacity, chlorophyll fluorescence, as well as fruit yield and quality of strawberry under different supplemental lighting directions and intensities. The

plant morphology, fruit yield and quality of strawberry were significantly different under different treatments, and closely related to the adaptation of the plant to light direction and intensity. Even though, compared with the un-treatment control, supplementary lighting significantly improved leaf photosynthetic characteristics, single fruit weight and yield, as well as soluble sugar, protein and solids contents. Among those, fruit yield was significantly positively related to photosynthesis-related parameters, such as Asat, SD, AQY, ACE, Tr, gm, phips II, ETR and qP, but was not significant with Chl a, Chl b, NPQ, and Fv/Fm. Besides, there was no significant difference in fruit yield and quality between the treatments with medium intensity (< 180 μmol/m^2/s) supplemental upward lighting and high intensity (270μmol/m^2/s) supplemental downward lighting. However, photoinhibition of the leaf, caused by the high intensity of supplemental upward lighting significantly reduced the fruit yield and quality. Hence, supplemental abaxial upward lighting can generate greater economic benefits in a way that consumes less energy. This study provides a theoretical basis for utilizing the photosynthesis potential of the abaxial leaf and improving unit leaf productivity to promote fruit yield and quality of strawberry.

Keywords: Strawberry; Supplemental downward/upward lighting; leaf photosynthetic characteristics; Fruit yield.

OS23-07

Response of greenhouse tomato to continuous LED lighting varies with lighting placement

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The improvement in plant growth and yield by supplemental lighting in greenhouse vegetable production is directly related to the total amount of light supplemented during a day (daily light integral (DLI) – intensity × photoperiod). It is more economical to achieve the desired DLIs with long photoperiods of low intensity light such as continuous lighting (CL, 24h) because it reduces light fixture costs. Furthermore, long photoperiods of lighting can reduce energy costs because the heat released by the light fixtures (a by-product without additional cost) can reduce heating demand during the otherwise dark night period and electricity price is lower during the night than daytime in many jurisdictions around the world. However, lighting > 16-17 hours causes photo-injury such as leaf chlorosis and limits the yield increase in greenhouse tomatoes. In our previous study, we have discovered that dynamic CL lighting with monochromatic red or blue light up to 95μmol·m^{-2}·s^{-1}during the night can eliminate photo-injury and does not compromise fruit production. However, the purple LED light (red and blue) is not good for workers to see the plants. Therefore, we expanded the study to broad/white LED light. Intra-canopy LED lighting (placed inside middle to bottom canopy) can be used to improve vertical light distribution in greenhouse tomatoes for increasing whole plant photosynthesis, in addition to top lighting placed above crop canopy. Four CL treatments, consisting of 2 photoperiods (16 h or 24 h/CL) and 2 lighting

placements (100% top lighting or 50% top lighting and 50% intra-canopy lighting) were investigated. All 4 lighting treatments achieved the same DLI by adjusting top light intensities. The 24 h/CL top lighting resulted in severe leaf chlorosis and reduction in leaf photosynthesis and fruit yield. There was no leaf chlorosis or photosynthesis or yield reduction in the lighting treatment with 16 h top lighting and 24 h/CL intra-canopy lighting. Therefore, CL or 24 h intra-canopy LED lighting can be used in greenhouse tomato production to reduce light fixture and energy costs, without compromising fruit production.

Keywords: *Solanum lycopersicum*, light spectrum, leaf chlorosis, photoperiod, continuous light, light placement, vertical distribution.

ORAL SESSION 24 / Greenhouse crops management

OS24-01

Effects of vertical air velocity on growth, morphology, and acclimatization of tomato seedlings

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Plant physiology, morphology, and growth can be affected by air velocity through effects on transpiration and thigmomorphogenesis. The objective of this study is to investigate vertical air flow as a tool to manipulate seedlings grown in indoor growing systems. Tomato seedlings were used for this experiment. Plants were grown in a growth chamber at a density of 1000 plants·m^{-2}. Air velocity treatments included: 0.5 m·s^{-1} (control), 1.0 m·s^{-1} (S1), 2.0 m·s^{-1} (S2), and 4.0 m·s^{-1} (S4). In addition, four dynamic treatments were also delivered: (D1) hourly alternating between 0.5 and 4.0 m·s^{-1} from day 10 to 21. (D2) 0.5 m s^{-1} from day 10 to 17, followed by hourly alternating between 0.5 and 4.0 m·s^{-1} from day 18 to 21. (D3) 0.5 m·s^{-1} from day 10 to 14, followed by 4.0 m·s^{-1} from day 15 to 21. (D4) 0.5 m·s^{-1} from day 10 to 17, followed by 4.0 m·s^{-1} from day 18 to 21. On day 21, morphology and growth were measured in a subsample of plants. In addition, two more subsamples were moved into a growth chamber with radiation 1519 µmol·m^{-2}·s^{-1} and into a greenhouse to monitor growth rate for an additional week. On day 21, increasing air velocity from 0.5 m·s^{-1} to 4.0 m·s^{-1} decreased plant height, leaf area, and shoot dry mass of tomato seedlings by 50%, 47%, and 20%, respectively. Increasing air velocity from 0.5 to 4.0 m·s^{-1} increased transpiration rate and stomatal conductance by 115% and 132%, respectively; however, no changes in net photosynthetic rate were observed. After 1-week from treatments, dry mass was 30% lower for plants treated with the 4 m·s^{-1} when compared to plants in the 0.5 m·s^{-1} treatment. However, the leaf area growth rate from day 21 to day 28 increased linearly with the increase of the air velocity treatments.

Keywords: air movement, propagation, vertical farms, thigmomorphogenesis.

OS24-02

Study on the mechanism of different soil-rotation irrigation with brackish and fresh water coordinately regulate cucumber development

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We have valid the hypothesize that the soil-irrigation cooperative regulation in rootzone can reduce the limitation of a single practice, complement each other's advantages and benefits the sustainable utilization of saline water resources. The results indicate soil available water content has increased by 5%~8% after vermicomposting with flue gas desulfurization gypsum (FGD gypsum). Similarly, the pH and EC have improved. Both vermicomposting and vermicomposting with FGD gypsum can increase the content of soil organic matter, available nitrogen, available phosphorus and available potassium. Furthermore, we also found the soil quality index (SQI) is significant positive related to the yield of cucumber. Compared with the CK, the yield of cucumber was 5508kg/667m^2 (increased by 12.1%) after applied with vermicomposting with FGD gypsum. Above research results would be important for illuminating the potential mechanisms of the soil-irrigation cooperative regulation in rootzone and exploring the comprehensive response of soil-crop system to saline water irrigation, and would provide a scientific basis for the sustainable utilization of saline water in the safety production of greenhouse vegetables in Ningxia and other regions having similar problems.

Keywords: soil-irrigation cooperative regulation, sustainable utilization, secondary salinization, greenhouse cucumber.

OS24-03

Pre-harvest Nitrogen Limitation and Continuous Lighting Improve the Quality and Flavor of Lettuce (*Lactuca sativa* L.) under Hydroponic Conditions in Greenhouse

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Lettuce is one of the most in-demand ready-to-eat vegetable salads worldwide because of its freshness, nutritional properties, and health benefits. However, the nitrate accumulation and perceived bitterness in hydroponically cultivated lettuce could be potentially detrimental to human health and reduce its consumption. A greenhouse trial was conducted to address

this issue. Two nitrate levels (with and without nitrogen) and three light quality ratios (red/blue = 3:1, 1:1, and 1:3) were applied individually and in combination to butterhead and red oak leaf lettuce for 1, 2, or 3 days before harvest to assess their effects on improving the nutritional value and sweet taste and reducing nitrate content and bitterness of lettuce. The results suggested that a 3-day nitrogen limitation combined with continuous lighting reduced the lettuce content of nitrate and sesquiterpene lactones and improved the quantities of soluble sugar, soluble protein, anthocyanins, and phenolic compounds without reducing the fresh weight of lettuce. In addition, in vitro simulated digestion results suggested that the 3-day nitrogen limitation combined with continuous lighting significantly improved the sweetness and reduced the bitterness of lettuce compared to the control. In conclusion, nitrogen limitation combined with continuous lighting for three days before harvest effectively enhanced the quality and taste of lettuce, showing great potential for its use in hydroponic lettuce production.

Keywords: flavonoids, phenolic compounds, sesquiterpene lactones, LED lighting, greenhouse, lettuce taste.

OS24-04

Can extreme light diffusion still increase crop growth in greenhouses?

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Research has largely proved the benefits of diffuse light above direct light for many horticultural crop species. The diffusiveness of a greenhouse cover can be characterized by the hortiscatter parameter (NEN2675) from 0 (no diffusiveness) to 1 (perfect Lambertian diffuser). However, the effect of hortiscatter larger than 50% on the crop is not studied yet. To investigate the effects of very high hortiscatter on crop light interception, photosynthesis and growth, an experiment was performed within the PPP proect "Smart Materials" by Wageningen UR Greenhouse Horticulture with a lenticular material which was able to generate extreme light diffusion (hortiscatter=0.9) without light loss. Three levels of light diffusion were compared: very high diffusion (hortiscatter=0.9), medium diffusion (hortiscatter= 0.65) and no diffusion (hortiscatter~0). Young tomato plants were placed on elevated growing tables and grown until the stage of first truss flowering at a high density to simulate the high LAI values of a grown-up crop. The materials allowing for the differences in light diffusion were placed on metal frames above the plants. Each material was used on two tables. Despite a careful set up, the PAR sum was not equal for all tables due to position effects in the greenhouse as well as small differences in light transmission of the covering materials. When both diffusion factor and PAR sum are considered in the statistical analysis, the plants grown under the very high diffusing material showed more leaf area and higher fresh and dry weight than the other two treatments. The photosynthesis as well as the light

use efficiency, expressed as grams of dry matter produced per mol PAR, increased with increasing Hortiscatter. In a follow-up a larger trial in separate compartments would need to verify these results in real growing conditions and evaluate the effects on fruit production during a longer experiment.

Keywords: Hortiscatter, lenticular material, light interception, photosynthesis, Smart Materials, tomato.

OS24-05

UVA1 radiation induced a rapid "leaf-blade flattening" response and promoted growth of tomato plants

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Plants adjust their morphology in response to the light environment by sensing an array of light cues. Though the wavelengths of ultraviolet-A1 radiation (UVA1, 350–400 nm) are close to those of blue light (B, 400–500 nm), it remains poorly understood how responses to UVA1 could differ from those to B. We initially transferred white-light-grown tomato plants to monochromatic red light (R) peaking at 660 nm, used as the control condition, and subsequently transferred treated plants to four dichromatic light environments adding ~20 μmol·m^{-2}·s^{-1} of UVA1, peaking at 370 nm (UVA_{370}) or at 400 nm (UVA_{400}), or B (peaking at 450nm, at ~20 or 1.5 μmol·m^{-2}·s^{-1}). PAR photon irradiance was the same in all treatments at ~200 μmol·m^{-2}·s^{-1}. We showed that UVA_{370} was the treatment most effective in inducing leaf flattening, resulting in larger leaf area and more shoot biomass accumulation. In contrast, UVA_{370} triggered weaker and later transcriptome-wide responses than B. Thus, the difference between responses to UVA_{370} and blue light was qualitative rather than quantitative. Mechanistically, UVA_{370}-promoted leaf-blade flattening was apparent in less than 12 h and appeared as very weakly related to gene transcript abundances. Thus, the observed leaf-blade flattening response likely depended on the transport of auxin and the regulation of cell wall acidification that were observed. Most importantly, the comparison of different wavelengths revealed wavelength-specific responses within the blue/UVA region challenging usual assumptions about the role of blue/UVA photoreceptors in different wavelengths.

Keywords: UVA radiation, blue light, leaf-blade flattening, transcriptome, auxin, cell wall acidification.

OS24-06

Implementation of wind-solar hybrid systems in solar dryers through a mathematical model and the analysis of the ventilation rate

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To install renewable energy systems in solar dryers it is essential to determine the electrical energy demanded. For the most part, solar dryers require the use of exhaust fans (which are the most considerable electrical loads) for two reasons: 1) to control the air temperature, since normally a temperature above 60°C could spoil the products, and 2) decrease dehydration time. In this work, a stable state mathematical model is presented that calculates the indoor air temperature of solar dryers. A direct type model solar dryer of 2.2 m3 volume was built in the central region of México to obtain experimental data, which is ventilated by exhaust fans and has a polycarbonate cover. Based on the air temperature results, an analysis of the ventilation rate was carried out and the air flow required by the model solar dryer was obtained to reduce unwanted temperatures. Subsequently, an average operating time of the extraction fans of 4.2 hours per day was taken as a basis and proceeded to the sizing and installation of an autonomous wind-solar hybrid system that is capable of supplying the energy required by the solar dryer. The system consists of one wind turbine of 400 W, two solar panels of 80 W, one battery of 2 kWh. Results of hybrid energy systems are shown for larger capacity solar dryers. System operation tests were carried out, the feasibility of installing renewable energy systems in solar dryers was demonstrated.

Keywords: Renewable energy, sustainable solar dryers, covering material.

GreenSys 2023

International Symposium on New Technologies for Sustainable Greenhouse Systems

Poster presentations

Poster presentations

PS01: Poster presentations: Monday October 23, 2023

PS01-01

Indoor growing of tomato with LED lamps and FR bulbs

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The indoor hydroponic growing of plants requires the use of different LED lamps, to provide the needed Photosynthetically Active Radiation (PAR); and the crops more efficiently produced with this technology are the leafy vegetables and herbs; however, there is a growing interest to produce other important crops like tomato and other fruiting crops under these conditions. Because there is some information that plants also respond to Far-Red light (FR) with increased size, increased biomass and more flowering; the objective of this research was to evaluate the growth and fruit production of tomato under indoor conditions with LED lamps and FR bulbs. Tomato plants cv. Rio Grande were established in NFT systems using a nutrient solution recommended for hydroponic vine crops, under 3 different (12 hours) lighting conditions: LED lamps only (control), LED lamps + FR (during day), and LED lamps + FR (during night). We had 3 replicates (NFT systems with 2 plants each) per treatment, arranged in a completely random design. Two months later we recorded plant height, leaf length and width, shoot and root fresh weight, and immature fruits per plant. We found the best results in the treatment with LED lamps + FR bulbs (during the day), in terms of plant height (111 cm), leaf length (31.5 cm), leaf width (32.5 cm) and shoot fresh weight (190 gr); compared to the control and treatment with LED lamps + FR bulbs (during the night); however, with regard to the number of fruits per plant, the plants with only LED lamps presented the best results (2.5 fruits), followed by those with LED lamps + FR bulbs (during the night) (1.5 fruits), and lastly the plants with LED lamps + FR bulbs (during the day)(0.5 fruits).

Keywords: Artificial Lighting, NFT system, *Solanum lycopersicum.*

PS01-02

Estimation of a thermal time in individual cucumber (*Cucumis sativus* L.) fruit under Japanese greenhouse production

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Cucumbers (*Cucumis sativus* L.) can have growth imbalances among individual fruits, which are derived from the duration of fruit growth and fruit abortion, and these phenomena are influenced

by environmental factors and sink organs. Although it is difficult to predict sink organs that is constantly fluctuating, we assumed that when immature fruits are harvested, as in Japanese cucumber cultivation, the sink is stable and the duration of fruit growth is easy to estimate. Effect of temperature, solar radiation during fruit development, and number of fruits at the anthesis on the thermal time from anthesis to harvest in greenhouse cultivation were investigated. The number of fruits set fluctuated until about 2000°C day after transplanting, after which it showed a stable trend. The thermal time was highly negatively correlated with mean temperature ($p < 0.01$) and mean cumulative solar radiation ($p < 0.01$), but not with the number of fruits (p=0.72). Then, an equation was developed based on the average daily temperature and the daily cumulative solar radiation to estimate the thermal time and evaluated. Validation based on the equation showed good correlations (r=0.99, $p < 0.01$) between observed and estimated results for the fruits at 31–60 node (1700–3600 °C day after transplanting). These results indicated that temperature and solar radiation were the important factors to predict the duration of cucumber fruit development under stable fruit set.

Keywords: fruit development, hydroponics, fruit set, environmental control, cumulative temperature

PS01-03

Growth and Flowering Characteristics of Strawberry Affected by Application of Various Light Quality

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This study was conducted to examine the growth and flowering characteristics effect on the strawberry (*Fragaria* × *ananassa* Duch.) by different light quality using a light emitting diode (LED). The cultivar of strawberry 'Kuemsil' was planted in a pot filled with coir medium and placed in a closed-type plant production system (CPPS). The light treatments were set in White (100% white), Red (100% red), Green (100% green), Blue (100% blue), R5B5 (red:blue = 50:50), B5G5 (blue:green = 50:50), and R5G5 (red:green = 50:50) LEDs. The experiment was conducted from September 23, 2022 to January 16, 2023 (127 days). White was set as the control. All treatments were provided 12 hours a day with a light intensity of 50 ± 10 $\mu mol \cdot m^{-2} \cdot s^{-1}$ photosynthetic photon flux density. The daily light integral (DLI) was 2.16 $mol \cdot m^{-2} \cdot d^{-1}$ in all treatments. The flowering was the fastest in Blue and R5B5 at the first flower bud stage. However, the second and third flowering was the fastest in White, Red, and R5B5. The light quality without Red and Blue showed the latest flowering at all stages. Petiole length was the longest in Red and Green and the shortest in R5B5. Leaf length, leaf width, number of leaves, crown diameter, fresh and dry weights, and leaf area tended to be lower in the treatment with green light, such as Green, B5G5, and R5G5. Conversely, White, which is

mixed light, tended to be higher in leaf width, number of leaves, crown diameter, dry weight, and leaf area. Through this study, it was possible to confirm the flowering and growth characteristics of strawberries affected by each light quality. Based on this, additional research can be conducted to control the flowering or vegetative growth of strawberries by adjusting the light intensity, photoperiod, and application timing that reflect growth stages.

This work was carried out with the support of "Cooperative Research Program for Agriculture Science and Technology Development (Project No. PJ01707201)" Rural Development Administration, Republic of Korea.

Keywords: closed-type plant production system, daily light integral, flower bud, light emitting diode

PS01-04

Air quality monitoring system in agricultural areas to identify the generation characteristics

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About 80% of the total ammonia are emitted from the agricultural sector in Korea. Since 2021, Korean government has been developing technologies and policies for reducing fine dust and promoting carbon neutral in the agricultural sector. To this end, it is necessary to make basic data for understanding air quality and ammonia generation in agricultural sector in Korea. Among 600 air quality monitoring stations, there are no monitoring system for specifying to agricultural air quality. To reduce fine dust and achieve carbon neutral in the agricultural sector, it is necessary to know the amount of air pollutants emitted including ammonia through air quality monitoring in the agricultural sector. In this study, an air quality monitoring system was established by selecting 8 agricultural fields by consideration of crops and spatial distribution in Korea. We have established standards for installing air quality monitoring systems in agricultural sector. The installation location was determined according by selection criteria, and a stable system was built by installing monitoring equipment certified by the Ministry of Environment of Korea for measuring equipment. Through the established measurement network, the concentration of air pollutant in agricultural area was identified. The generation characteristics of fine dust according to various factors such as seasons, crops, and farming activities were analyzed.

Keywords: Air quality, Agricultural area, Ammonia, Monitoring system.

PS01-05

Searching for environmental conditions that increase vindoline and catharanthine concentrations in *Catharanthus roseus* leaves during early nutritional growth

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The anticancer alkaloids vinblastine (VLB) are contained in the leaves of *Catharanthus roseus*. The VLB is synthesized by condensing the monomeric alkaloids vindoline (VDL) and catharanthine (CAT). It has been shown that UV-A light irradiation to the leaves promotes the condensation of VDL and CAT. Our group has reported that continuous irradiation of UV-A light in the range of 365 nm to 385 nm with 5 W m^{-2} for 5 d maximizes the concentration of vinblastine in the leaves. To produce VLB efficiently by UV-A irradiation in a plant factory using artificial lighting, we have tried to cultivate *C. roseus* with high concentrations of VDL and CAT, the precursors of VLB.

When the seedlings grown under white fluorescent light for one month were cultivated under different light quality environments such as white fluorescent light, red light, blue light, and mixtures of red and blue light for about one month, the accumulation of VDL and CAT in the leaves of *C. roseus* cultivated under red light irradiation was the highest. Considering the profitability of the PFAL, it is necessary to shorten the growth period. Therefore, we studied for environmental conditions to improve VDL and CAT concentrations in the leaves of *C. roseus* during the seedling-raising period. 1) red light irradiation during the early growth stage, 2) Combined treatment with red light irradiation and high CO_2 concentration, and 3) Combined treatment with red light irradiation and high temperature. We will report the results of the analysis on these three themes.

Keywords: plant factory, high CO_2, alkaloid, vegetative growth, *Catharanthus roseus.*

PS01-06

Growth and flower characteristics of calendula under different light spectra in a controlled environment

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Healthy food is getting more and more attention. Edible flowers are enriched in phytochemicals and are considered one of the sources of nutrient foods. Since farming has benefited from the development of environmental control technologies, high-quality crop production with high efficiency become possible. This research investigates how

calendula plants' growth and flower characteristics respond to different light spectra. Two calendula varieties were grown hydroponically under a controlled environment (plant factory). At the flower initiation stage, plants were exposed to four different light spectra, including white (W), 50% blue (B), 50% red (R), and 50% far-red (FR). Plant growth parameters and flower characteristics were recorded 78 days after sowing, while the number of flowers was recorded every two days after transplanting. The results show that plants grown under FR tend to be highest in plant height, and contrastingly, the chlorophyll content of leaves tends to be lowest. Interestingly, both R and FR influence calendula flower characteristics. The days from the sowing date to the first flower bud occurrence were shortened by R and FR, compared with W or B. In addition, the total number of flowers and total flower weight per plant also increased by RD and FR. However, there is no significant difference in the characteristics of individual flowers under different light spectra. These results demonstrate that the light spectrum can control plant growth and flowering of calendula.

Keywords: pot marigold, edible flower, LEDs, light quality, artificial lighting.

PS01-07

Optimal Irrigation Prediction Model for Advanced Wild Ginseng in Smart Farm for Sustainability based on Deep Learning Technology with Xgboost

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We use smart farms to grow high-value-added crops to improve farm income, as well as to reduce the crop loss rate and increase survival rates. GREC LAB in Seoul National University develops and grows advanced wild ginseng in Smart Farm. This advanced wild ginseng aims to secure a field by increasing the survival rate of wild ginseng, which has been neglected in nature for more than seven years. It is essential to control the temperature, humidity, and amount of light in the smart farm. Among them, humidity can be controlled through irrigation, but we still control moisture after looking at people's experiences, know-how, and crop conditions. We wanted to develop a model that can predict the optimal irrigation timing of advanced wild ginseng using deep learning technology. We implemented deep learning technology based on XGboost. By doing so, we detect the color of the surface soil of the pot to estimate the moisture content of the current state and predict the optimal irrigation time and amount.

Keywords: wild ginseng, XGboost, Sustainability, smart farm.

PS01-08

Effect of plant density and light intensity on growth and yield of green perilla in plant factory with artificial lighting

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Plant morphological and physiological characteristics are affected by cultivation methods and environment. The number of plants per area is essential for plant production in plant factories because it directly affects space use efficiency. Moreover, optimizing light intensity is critical for maximizing plant productivity. Green perilla (*Perilla frutescens* var. *crispa*) is a popular plant in Asia countries and has high nutritional and medical value. This experiment aimed to determine the optimal plant densities and light intensities to maximize the productivity of green perilla cultivated in a plant factory. Three plant densities (440, 733, and 1,465 plants/m^2) combined with two light intensities (200 and 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$) were applied to perilla seedlings for three weeks after transplanting. The results demonstrated that the highest fresh weights, biomass, SPAD, leaf no., leaf area, and leaf weight ratio were observed in the lowest plant density treatment. In contrast, plant height and leaf area index were increased by increasing plant density. In addition, plant height and specific leaf area were highest under lower light-intensity conditions. Thus, 440 plants/m^2 and 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ are considered the optimal combination for maximizing space use efficiency and productivity of green perilla in this study.

Keywords: Shiso, medicinal plant, PPFD, plant density, leaf area.

PS01-09

Effect of light quality environment on nutrient uptake in several plant species grown in plant factories with artificial lighting

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This study aimed to clarify the effects of light quality on plant nutrient uptake and to suggest suitable fertilizer management by controlling light quality for reducing fertilizer costs in a plant factory with artificial lighting (PFAL). The seedlings of the komatsuna (*Brassica rapa var. perviridis*) and the leaf lettuce (*Lactuca sativa*) were grown for 14 d, and the spinach (*Spinacia oleracea* L.) for 35 d under red light irradiation (control) and blue light irradiation. Each organ's concentrations of N, P, K, Ca, Mg, Fe, Mn, Zn, and Na at harvest were measured. And the effects of light quality on the concentrations of the minerals in each organ were analyzed using principal component analysis. Principal component analysis showed that the effects of light quality differed among the plant species. In komatsuna, N, Ca, Mg, and Na

concentrations increased under blue light than under red light. The concentrations of Ca and Na increased under blue light compared with red light in the leaf lettuce. On the other hand, the concentrations of P, Ca, Mn, and Zn decreased in spinach leaf blades under blue light than under red light. Transpiration may have significant effects on changes in element concentrations and the delivery of elements to each organ as light quality changes. Therefore, the transpiration rate of komatsuna leaves is measured under different light qualities. We will also report the results of the elemental concentrations of kidney beans and potherb mustard.

Keywords: blue light, mineral concentration, plant factory with artificial lighting, red light.

PS01-10

Yield and quality of cherry tomato at different harvest timing determined by cumulative temperature in plant factory

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Recently, consumers have been willing to pay more for good quality products, while harvest timing is one of the essential factors affecting the quality of cherry tomatoes. As tomato ripening status correlates with cumulative temperature and the temperature inside plant factories with artificial lighting (PFAL) can be easily controlled, the cumulative temperature can be used to determine the harvest day. In this research, cherry tomatoes were harvested based on cumulative temperature to investigate the variation of yield and quality of each fruit. The objective is to determine the right time to harvest cherry tomatoes grown in a PFAL based on cumulative temperature. Cherry tomato plants were grown until they produced two fruit clusters each. Accumulated temperatures were counted from the day of each flower blooming till the day of harvesting in the range of 900 °C to 1300 °C (levels were set every 100 °C). The parameters evaluated in this research are fruit weight, fruit hardness, sugar content (Brix%), acid, and the ratio of sugar and acid. The results show that cumulative temperature affected the fruit hardness level and sugar content of cherry tomato fruits. Cherry tomato fruits harvested at lower cumulative temperatures showed higher hardness levels. The fruits from cluster 1 showed the highest hardness level at 900 °C and the lowest level at 1300 °C, while the ones from cluster 2 showed the highest level at 900 °C and the lowest level at 1200 °C. However, the sugar content of fruits showed the opposite tendencies to that of hardness. Therefore, this study shows that the fruit quality (such as the sugar content) of cherry tomatoes is affected by the cumulative temperature. Producers can use the cumulative temperature as an index to determine the harvest time to optimize the profit of tomato production.

Keywords: daily mean temperature, sugar content, mini tomato, plant factory with artificial lighting

PS01–11

A new technique of LED light irradiation for green leek production in plant factory

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Green leek (*Allium fistulosum* L.) plays an important role as a seasoning in many Japanese dishes. A new light irradiation method was investigated to increase the production efficiency of green leek in plant factory. Normally, the lighting for cultivation is installed above the plants in plant factory using artificial light. Therefore, plants are illuminated from top to bottom. However, with long grass plants like green leek, installing lighting above the plants wastes a lot of growing space and light energy during the growing process. Therefore, we compared the growth of two green leeks using a method in which LEDs were installed at the base of green leek plants and light was irradiated to the sheath base of green leek plants from the lateral direction (sideways irradiation) with a conventional method in which light is irradiated from the top of the green leek plants (conventional method) in this study. The green leek varieties used in the experiment were 'White Star' and 'Fukuchi-Negi'. Fourteen days after sowing, seedlings were transplanted into containers with a hydroponic system using a deep flow technique. Philips LED GreenPower Production Modules made by Signify (formerly Philips Lighting) were used as light sources. The plants were harvested 43 days after cultivation under the two irradiation methods. The results showed that top fresh weight of 'White Star' and 'Fukuichi-Negi' grown under sideways irradiation were 1.5 times and 1.3 times higher than those by conventional method, respectively. Furthermore, there was also the advantage that the leaf scorch that occurs when the upper part of green leek approaches the light source does not occur under sideways irradiation. We found that the growth of green leek was better under the sideways irradiation than the conventional downward one when the sheath base of green leek is irradiated directly with the same light intensity.

Keywords: environmental controls, hydroponics, irradiation method, monocotyledon, sideways irradiation, vertical farming.

PS01–12

Agronomically & Economically profitability of a shifted-tomato-cultivation in greenhouse under a Semi-Continental with Meridional Influence Climate

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Soilless tomato production in greenhouses is practiced in many countries with a particular focus on energy-saving costs due to heating and artificial lighting. Today, energy is the second most important cost (about 30%), after labor costs, in a greenhouse farm. In Europe, tomato cultivation in greenhouses can be carried out from December (pre-planting) to November (plant removal), or it can be "shifted" with pre-planting in August and final plant removal the following July. This second cultivation method, essentially practiced in the north of Europe, is

characterized by a higher energy demand (heating and lighting) compared to non-shifted cultivation. In Switzerland, the climate "semi-continental with meridional character" differs greatly from that of the countries of northern Europe, "temperate or temperate oceanic climate". As a result, the energy requirements cannot be transposed between the two climatic regions. In the present study, we compared a shifted with a non-shifted crop of tomato and carried out the energy, agronomic and economic balances over a period of 3 years (2019-2022). Two complete 11-month cultures were conducted for each of the two cropping modes. The study used cherry tomatoes grown on a coco substrate. The yields obtained were relatively similar in the non-shifted (19 to 25 kg/m^2) and shifted (18 to 23kg/m^2) systems. In terms of energy consumption, 245 kWh/m^2 and 478 kWh/m^2 were respectively required for the non-shifted and the shifted culture (i.e., a consumption surplus of 95% in shifted culture). More precisely, lighting required +82% additional energy and heating +99%. Therefore, in the context of rising energy costs, we concluded that shifted cultivation was not profitable in Switzerland or in a continental climate with meridional influence.

Keywords: Shifted-crop, Greenhouse, Energy, Heating, Artificial light

PS01-13

The impact of sequential harvesting and irradiation methods on tuber yield in long-day conditions using temporary light interruption treatment in potato

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Potato tubers are typically formed under short-day conditions, but it has been found that they can also be induced under long-day conditions using a temporary interruption of light treatment. This treatment, known as a temporary light interruption, aims to suppress the expression of *StCOL1* by exposing the plants to a period of darkness and far-red light at one hour after the start of the light period. Potatoes grown under this treatment will continue to form tubers while maintaining their shoot growth. This has led to the development of "sequential harvesting," a method in which tubers are continuously harvested as they reach maturity. This study investigated the impact of different harvesting methods on tubers. Results showed that the number of tubers was greater when using the sequential harvest method than the batch harvesting method. Additionally, the weight of the tubers was higher in the short-day treatment than in the temporary light interruption treatment, regardless of the harvesting method used. Previous research has shown that blue monochromatic light can promote earlier tuber formation and increase the amount of assimilates in tubers under short-day conditions. Furthermore, alternating blue and red light irradiation has increased tuber yield. The current study investigates the effects of different irradiation methods on increasing tuber yield in long-day conditions using the temporary light interruption treatment and will be reported in the meeting.

Keywords: LED, vartical farming, seed potato, einvironmental control, carbohydrates.

PS01–14

The cultivation technology for high quality spinach by controlling light environment in plant factory

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It has recently become possible to cultivate various vegetables by plant factory using artificial lighting (PFAL). Spinach, which is a vegetable much expected to be cultivated in PFAL, has few examples to cultivate there. Reasons for this include the decline in quality due to the occurrence of bolting and the difficulty in securing profits due to the high cost of the product. Therefore, it is necessary to develop cultivation methods that reduce spinach bolting. Additionally, this experiment increased the content of carotenoids in spinach to achieve higher quality spinach. The first experiment investigated the effects of light quality and light intensity on the growth and carotenoid content of spinach. After 3-week-old spinach plants were cultivated for two weeks under red and blue LEDs (red:blue=1:1) of 150 $\mu mol \cdot m^{-2} \cdot s^{-1}$ using hydroponic systems, they were cultivated more 1 week under 4 combinations of 2 levels of PPFD (300 or 400 $\mu mol \cdot m^{-2} \cdot s^{-1}$) with two light spectra (only blue and red:blue =1:1). Compared to red-blue mix light; blue light tended to have a higher plant height. There was no significant difference in the shoot fresh weight in any treatment. Lutein and β-carotene contents tended to increase in the blue light of 300 $\mu mol \cdot m^{-2} \cdot s^{-1}$ treatment. The second experiment looked at the effect of different day lengths on spinach bolting. Spinach was grown under various conditions of day length in addition to long-day conditions of 16 h light and short-day conditions of 8 h light. Spinach bolting occurred in all plants under long-day conditions, but not under short-day conditions. Spinach bolting was not observed in the treatment with 7 h of light and 5 h of dark. However, *FT* gene expression was lower in this treatment than in the other treatments in which bolting was observed.

Keywords: Bolting, Carotenoid, City farm, Light emitting diode, Light quality.

PS01–15

Predicting Stomatal Conductance in Controlled Environment Through Non-Parametric Machine Learning

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Stomatal conductance (gs) is a key leaf-level function controlling water, carbon, and energy exchange between vegetation and the surrounding environment. Stomata play a central role in the regulation of leaf and plant water status and transport, drought sensitivity and tolerance. Conventionally, empirical and semi-empirical models have been used to model gs, but these models are difficult to parameterize and require re-parameterization as ecosystems undergo phenological changes throughout the growing season. Machine learning (ML) offers a potential path to overcome this problem through the development of more flexible, data driven models. The development of ML models however requires care as these approaches can be plagued by

over- fitting to limited data and have been criticized for lacking transparency and interpretability. Here we explore the use of several ML approaches to develop flexible and robust models of stomatal conductance for plants grown in controlled environments.

In this work we have utilized an explainable machine learning (eXML) approach to interpret the outcomes of the ML models using a popular eXML algorithm SHapley Additive exPlanations (SHAP). The eXML aims to provide an understanding of ML model outputs, allowing users to understand and trust ML models' decision-making processes and to peer inside what is often considered the ML black box. Here we contrasted extreme gradient boosting (XGBoost) to predict the gs response of vegetation to its environment. We developed and tested models with predictor sets composed of compositions of environment forcing and physiological response variables including leaf surface CO_2 concentration, photosynthetically active radiation, leaf temperature, vapor pressure deficit, and net photosynthesis. We quantified the performance of two predictors, and various combinations of predictors organized around typical use cases (i.e., available weather data or environmental remote sensing), as well as the performance of models composed of all predictor variables taken together.

Here we summarize the results of our stomtal conductance model developments and performance across a range of growth and sampling conditions. We discuss the value of SHAP values in understanding the importance of each predictor variable in predicting gs responses to environment. This work demonstrates how ML models can flexibly integrate information on multiple environmental conditions and physiological plant characteristics to model stomatal dynamics, allowing for more accurate simulation of plant function.

Keywords: stomatal conductance, machine learning, plant water use.

PS01-16

Dynamic analysis of leaf and air temperatures in a greenhouse canopy: which measurement to use for greenhouse climate control?

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Currently, in medium tech passive tunnel and multi-span greenhouses, the measurements used in the greenhouse to manage the climate are generally taken at 1.5 m above ground level. However If the ventilation of the shelter of the sensors is insufficient, the measured temperature can differ greatly from the actual temperature, especially during the day in summer. In addition, the climatic conditions at 1m50 can be very different from those at the level of the canopy. From a physiological point of view, it is the temperature of the leaves that

plays a major role in the development of the plant. Having a temperature close to the leaf temperature and easy to measure would thus be relevant to better control the climate in medium tech greenhouse. The proposed study is based on the comparison of leaf temperatures with air temperature measurements carried out at several levels in and above the canopy, in ventilated or unventilated shelters, or even with unsheltered sensors. The experimentation was carried out in tunnel greenhouses at the ASTREDHOR station in Brindas, France. Results reveal that the air temperature measurements closest to those of the leaves are those measured with unsheltered sensors positioned inside the canopy, under the leaves protected from direct solar radiation. Typically for a Chrysanthemum production, during a sunny day with 600 W/m² radiation, the average difference between the leaf temperature and air temperatures inside the canopy is 1.6 °C. It reaches 4.1°C when compared with the air temperature measured inside a ventilated box at 1m50. This measurement could be integrated in algorithms of climate control of greenhouses, which would allow to bring a "high tech" climate control to "medium tech" greenhouses.

Keywords: microclimate, sensor, ornamental crop, climate heterogeneity

PS01–17

Conditions and Directions to Distribute the Rooftop Greenhouse in Korea

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Humanity is facing all-round changes due to climate change. Changes in the weather environment due to global warming lead to changes in the cultivation environment and production of agriculture. Various studies have suggested countermeasures to climate change facing rural and urban areas at the same time. Among several countermeasures, urban agriculture is becoming promising method. The urban agriculture can reduce greenhouse gases emitted in the entire process of production and consumption by reducing distance between production area and consumption area. And the urban agriculture can attribute to promote urban amenity. In Korea, urban agriculture was introduced around 2010, and it is developing in the direction of utilizing building rooftops and vacant lots. Since 2020, many studies about rooftop greenhouses are being conducted as an alternative to a sustainable urban agricultural environment. However, in Korea, there are no laws and regulations on the combination of buildings and greenhouses. Previous studies in Europe suggested advantages of rooftop greenhouses such as agricultural production, the use of surplus thermal energy, rainwater storage, and rainwater utilize, and securing economic, emotional activities. The purpose of this study is to find a way to apply these advantages to Korea. In order to establish a new political system or modify the existing system in Korean, the evidence of universal interests is necessary. Therefore, this research suggests the concept that rooftop greenhouses can be of universal benefit to a large number of citizens. At the same time, the study also deals with solutions to safety, firefighting, landscapes, and conflicts with agricultural producers that may arise from installing greenhouses on rooftops.

Ultimately, this study analyzes the positive value and negative conditions of rooftop greenhouses, and to suggest rooftop greenhouses as an alternative to settle on urban horticulture and agriculture in Korea.

Keywords: Climate change, Urban agriculture, Korea society, Building regulation, Universal values

PS01-18

Deep learning-based phenotyping data fusion approach for effective detection of drought stress responses in basil

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Basil is a versatile plant that is commonly used for culinary and medicinal purposes, as well as being a valuable greenhouse crop. However, limited water availability caused by environmental factors in the greenhouse can have a significant impact on production. Phenotyping have been developed to detect stress in crops, but single parameters have limitations of application in greenhouses due to variations in crops, varieties, and stress types. This study aimed to obtain a more effective parameter for detecting drought stress responses in basil by deep learning-based data fusion approach. Four treatments were applied to sweet basil (*Ocimum basilicum* L.) for three weeks, and phenotypic parameters were measured daily using chlorophyll fluorescence imaging, RGB-D imaging, and infrared imaging. The phenotypic data were reconstructed into 3D data and analyzed using a CNN-based algorithm, resulting in a more effective fusion parameter for detecting drought stress responses in basil than single phenotypic data. Fusion parameters can be a useful indicator for the production and breeding of basil, and this deep learning method can be applied to build parameters for other stress responses in variable crops.

Keywords: Phenotyping, Drought stress, Data fusion, Greenhouse crop, Chlorophyll fluorescence imaging, RGB-D imaging

PS01-19

Profiling of individual desulfo-glucosinolates and sugar content among cabbage germplasm and selection of multi-functional genotypes for commercial breedin

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The criteria to evaluate the core functionality of cabbages include leaf color, glucosinolate, and sugar content, and it is necessary to select genetic resources that consider these

comprehensive functionalities. This study aimed to select promising resources with complex functionality by quantitatively analyzing desulfo-glucosinolates and sugar content in the leaf parts of 70 cabbage genetic resources, combining their commercial morphological value. A total of 16 types of glucosinolates were identified, and variations in key substances, such as glucoraphanin and glucobrassicin, have been confirmed. Among the analyzed sugar components, glucose had the highest proportion, followed by fructose and sucrose. The graphical distribution of target functional substances depending on the leaf parts was presented, combined with principal component analysis. This study provides the extensive functional information and selection methodology to expand the multi-functional germplasm selections for the commercial breeding program of cabbage. [This research study was supported by the National Agrobiodiversity Center, National Institute of Agricultural Sciences, Rural Development Administration, Korea (PJ0142552023) and the Basic Science Research Program through the National Research Foundation of Korea (NRF) by the Ministry of Education (No. 2019R1A6A1A09031717).]

Keywords: cabbage; commercial breeding program; desulfo-glucosinolates; sugar

PS01-20

Evaluation of energy and light use efficiency in *Valerianella locusta* growing in indoor vertical farms

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Nowadays, one of the main challenges is to bring safe, fresh and nutritious food in the rapidly growing urban areas. Vertical Farms (VFs) is a pioneering agricultural method that can significantly contribute to the partial solution of this challenge. Due to the sophisticated controlled-environment agriculture practices, the fully insulated installations and the application of multiple stacked growing layers, VFs can maximize yield production per unit area. However, one of the challenges of VFs is the high electricity demand for lighting operation and consequently high operational cost for maximum biomass production in a year-round basis. The aim of this study is to examine and determine the optimum duration, quality and quantity of the indoor lighting operation in *Valerianella locusta* plants under different operational schemes and evaluate the energy and light use efficiency of the system. Two different light qualities have been tested, a) white (W) and b) blue, red and NIR-infrared (B-R-NIR). The three tested treatments under each spectra combination had a photoperiod of 16 h d^{-1} of light and 3 different PPFD (150, 250, 350 μmol $m-^{2}s^{-1}$), resulting in different daily light integrals, DLI of 8.6, 14.4 and 20.2 mol $m^{-2}d^{-1}$, respectively. Plants were cultivated at 25°C and 500 μmol mol^{-1} CO_2 and 60 RH%. From results, it is observed a progressive increase of biomass production of plants along with higher PPFD at DLI 14.4 mol/m^2d. However, energy use efficiency is maximized under lower PPFD and DLI values at lamp lettuces' plants. Effects of the spectrum quality relate to differentiations in the leaf coloring and the chlorophyll content

of the plants. This study shows that under reduced PPFD and DLI values, *Valerianella locusta* plants can present optimized yield and resources use efficiency for indoor cultivation contributing to significant improvements on the sustainability performance of the system.

Keywords: Vertical Farming, light in horticulture, energy use efficiency, light use efficiency, plant physiology, daily light integral, *Valerianella locusta*.

PS01-21

Physiological Disorder Analysis of Strawberry Leaves using Hyperspectral Imaging and Deep Learning Algorithm

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Development of smart agricultural analysis technology using convergence technology is required to increase agricultural competitiveness in response to rapidly changing climate conditions and to ensure stable production of crops. As the securing of core technology becomes important and the analysis of complex quality characteristics has become possible, the importance of plant phenomics as a research field that covers the phenotype such as physiological, morphological, biochemical characteristics of crops is emerging. In phenotypic analysis of crop quality, predicting and early detection of physiological disorders plays an important role in crop growth and production. In this study, hyperspectral imaging and deep learning were used to analyze the nutritional conditions and stress of crop leaves. Strawberry seedlings were used as experimental crops to induce physiological disorders through artificial treatment, and several hyperspectral leaf images for normal, predicted, and appearance of symptom were acquired. For the acquired hyperspectral image, analysis was attempted using various deep learning algorithms without any spectral preprocessing. Various deep learning models and hyperparameter tuning were performed to determine the optimal model. This result was compared with the conventional spectroscopy method and showed better performance. This showed a novel possibility of using hyperspectral imaging to perform precise non-destructive analysis of crop characteristics for various physiological disorders.

Keywords: strawberry leaf, hyperspectral image, deep learning, physiological disorder, early diagnosis, phenotyping

PS01-22

Changes in the growth and isoflavone content of soybean plants according to the R/FR ratio

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Soybean is one of the largest sources of isoflavones and is a major crop worldwide for human nutrition and nutraceutical. The objective of this study was to observe the changing pattern of

isoflavone contents in each part of soybean by R/FR ratio in a vertical farm. Soybean seeds were grown on an Oasis medium using a deep flow technology (DFT) hydroponic system. In a vertical farm, growth conditions were set at a temperature of 25°C, a humidity of 60%, and a photoperiod of 12/12 (day/night). The soybean plants were subjected to the light condition of each R/FR ratio during the growth period in a vertical farm. The PPFD of white-LED lighting and the treatment groups was the same at 210 ± 10 μmol·m^{-2}·s^{-1}. The R/FR ratio was controlled with the supplemental light of far-red. This experiment was constructed with white-LED lighting (control), high R/FR (R/FR ratio of 4.6), normal R/FR (R/FR ratio of 1.2), and low R/FR (R/FR ratio of 0.7). Twelve types of isoflavones were analyzed by HPLC. As a result of the morphological analysis of soybean plants, the length was significantly increased in the low R/FR treatment compared to the control. Also, fresh weight, dry weight, and leaf area of soybean plants showed the same results as above. Based on the results of this study, the R/FR ratio composition through supplemental light of far-red positively affected the overall growth of soybean plants, such as biomass and leaf area. In addition, it was confirmed that the R/FR ratio composition had a positive/negative effect on individual isoflavone concentrations. These results suggest that in vertical farms, effective production of each isoflavone from soybean plants is workable depending on the conditions of the R/FR ratio composition.

Keywords: soybean, isoflavones, vertical farms, hydroponic system, Far-red, R/FR ratio.

PS01-23

Enhancement of isoflavone contents in soybean plants by pre-harvest UV-B irradiation

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Soybean (*Glycine max* L.) contains isoflavones which are recognized for their health benefits such as antioxidant, anticancer, anti-inflammatory activities and menopausal women. This study aimed to determine the changing patterns of isoflavone contents in each part of soybeans by UV-B treatment before harvest in a vertical farm. The growth conditions of a vertical farm were controlled at a temperature of 25°C, a humidity of 60%, a light intensity of 210 ± 10 μmol·m^{-2}·s^{-1}, and a photoperiod of 12/12 h (day/night) during the cultivation. The soybean plants were subjected to UV-B treatments after two weeks after sowing. The energy of UV-B LED (peak wavelength; 305 nm) was maintained at 0.33 ± 0.07 W·m^{-2}·s^{-1} for 24 hours at each treatment. The harvesting time of the control and treatment groups was the same, and the UV-B treatments consisted of UV 1, UV 2, and UV 3, meaning 24-hour treatment one, two, and three days before harvest, respectively. As a result, there are no significant differences in the fresh and dry weights in each UV-B treatment. The UV 1 treatment increased the content of total glycosides and aglycones in roots compared with the control by about 1.45 and 1.65 times, respectively. On the other hand, in the leaves, the total glycoside and the total aglycone contents were increased through the UV 2 treatment compared with the control by about 2.24 and 1.61 times, respectively. Based on the results of this study, isoflavone accumulation patterns were different depending on the presence or absence of a recovery

period after UV-B treatment for each part of soybean plants. In addition, the appropriate UV-B treatment before harvest positively affected the isoflavone contents of soybean plants, suggesting that the efficient production of individual isoflavones from soybean leaves and roots is possible.

Keywords: Soybean, UV-B, Isoflavones, Secondary metabolites, Environmental stress, Vertical farms

PS01-24

Blue and UV-A light wavelengths positively affected the accumulation of healthy compound profiles in pakchoi

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Pakchoi, a major leafy vegetable cultivated worldwide, is rich in healthy functional compounds, including vitamin C, carotenoids, flavonoids and glucosinolates. LED light become an important strategy to regulate vegetable growth and quality in controlled greenhouse or plant factory. However, many studies have focused on the plant response to radiation increase and light quality transform, and we know less about different blue and UV-A light wavelengths. In this study, we found that the different blue and UV-A light wavelength treatments could significantly increase the fresh and dry weight of green-leaf and red-leaf pakchoi, and the content of soluble protein was higher compared with those of CK. The contents of total phenolics, flavonoids and anthocyanins increased significantly under supplementary blue and UV-A light in green-leaf pakchoi. Besides, supplementary blue light could enhance the contents of glucoalyssin, glucobrassicin, glucobrassicanapin, gluconapin and total glucosinolates in varying degrees, and also promote the expression of key transcription factors and genes of glucosinolate biosynthesis pathway in two cultivars pakchoi. Therefore, Blue and UV-A light wavelengths could positively affect the accumulation of phytochemical profiles in pakchoi, which is benefit for cultivate high-value and potentially healthy functional vegetables in controlled environment.

Keywords: light wavelength, healthy compound, pakchoi, vegetable, controlled environment

PS01-25

Production of faba bean (*Vicia faba* L.) inside a Mediterranean naturally ventilated solar greenhouse

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Faba bean (*Vicia faba* L.) is an olden crop that is widely used around the world for both human and animal food. In Spain its commercialization is carried out in the form of fresh pods, for the consumption of grains, such as dried and fried or roasted grains and more broadly as fresh frozen grains. There is a fourth form of consumption, which are the tender beans to eat cooked

with pod, mainly fried. However, this form of consumption is little known today and its use is limited to farmers in southern areas and the Mediterranean coast, without commercialization. Given the current lack of fiber and vegetable proteins in the diet of Europeans, and the need to diversify crops in the greenhouses of Almeria, the idea arose to analyze the possibility of growing faba beans for the production of tender fresh pods. With this objective, the cv. '*Reina Mora*' was sowed on October 4 in 2022 in sand mulched soil "*arenado*" inside a solar greenhouse in Almeria, without cover in one of its two spans. During the development of the crop, no phytosanitary treatment was carried out nor were beneficial insects of integrated control directly applied. Three planting densities were analyzed, D1=1.6 plants/m^2, D2=2.1 plants/m^2 and D3=3.9 plants/m^2. The highest production was obtained at the end of the crop in the highest density, with a tender fresh pods production of 1.75 kg/m^2 (D3), followed by the intermediate density with 1.38 kg/m^2 (D2), and 1.09 kg/m^2 for the lowest density (D1). The plants reached in mid-March, after 164 days from sowing, heights of 147.2 cm (D1), 164.0 cm (D2) and 164.5 cm (D3). No statistically significant differences were observed in pod length (13.7±2.2 cm), pod weight (8.4±2.7 g), pod width (11.4±1.8 mm) and number of grains (5.6±1.0).

Keywords: Faba bean; tender pods; solar greenhouse; natural ventilation; sand mulched soil.

PS01-26

Effect of UV-B irradiation on the concentrations of rosmarinic acid in different leaf positions of red perilla

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Red perilla (*Perilla frutescens* (L.) Britton) from the Lamiaceae family is an aromatic herb used as food, flavoring, coloring agent, and traditional medicine. The leaves contain high concentrations of bioactive compounds such as rosmarinic acid (RA). We have previously reported that 3 days of UV-B irradiation under a 16 h light period increases the concentration of RA in red perilla leaves. However, the degree of increments in RA concentrations may differ depending on the intensity of UV-B irradiation at different leaf positions. Therefore, in this study, red perilla seedlings were cultivated under UV-B irradiation at 0 (control) and 6 W m^{-2} in a controlled-environmental chamber for 3 days. Thereafter, RA concentrations at each different leaf position (from the fourth to seventh leaf nodes, from bottom to top) were measured. Leaves from the first to third leaf nodes were not analyzed as they are smaller than the leaves above the fourth node and do not contribute to the total amount of RA in a plant. At all leaf positions, the concentrations of RA were higher in leaves irradiated with UV-B compared to those in the control. In particular, the concentrations of RA were 2.5 times higher in the irradiated leaves at the sixth and seventh nodes compared to those in the non-irradiated leaves. In addition, the concentrations of RA in the leaves of the sixth and seventh nodes in the irradiated leaves were 1.6 times higher than those in the leaves of the fourth and fifth nodes of

the same treatment. These results indicate that 3 days of UV-B irradiation significantly increased the concentrations of RA in the upper leaves compared to those in the lower leaves as well as the total amount of RA in a plant.

Keywords: antioxidant, bioactive compound, medicinal plants, phytochemical, plant factory.

PS01-27

An organic fertilization system to sustain plastic-ho use soil health

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Plastic-house soils are estimated to be approx. 4 million ha, mainly for horticulture production by smallholder farmers in China, and the areas keep increasing worldwide. However, soil management is not sustainable due to vast amounts of chemical fertilizer input to counteract environmental stresses, such as low temperatures in winter and accumulated soil toxins, leading to severe soil degradation and environmental pollution. The use of organic amendments and bio-stimulants shapes farmers' focus on enhancing bioavailability rather than the total amount of soil nutrients. Here, we summarize and design an organic fertilization system that includes basal application of organic amendments during fallow period, in conjunction with applying soluble carbon sources and/or bio-stimulants via fertigation. This organic approach facilitates bio-stimulant production by harnessing the *in-situ* soil microbial decomposition, and accelerates soil toxin degradation, thus demonstrating its effectiveness in promoting sustainable soil management practices. Future studies should focus on screening effective organic carbon sources to produce bio-stimulants, and to degrade soil toxins, and increase their effectiveness in enhancing nutrient bioavailability of a specific plant and sustainable management of various horticulture soils.

Keywords: Bio-stimulants, fertigation, in situ, organic amendments, soil toxins

PS01-28

Optimal leaf temperature for photosynthesis in melon plants predicted by stomatal conductance under soilless cultivation

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High-speed leaf-level measurements of stomatal conductance in ambient conditions allow for faster response to crop physiology and stress responses compared to gas exchange system in controlled environments. Photosynthesis is a highly temperature-sensitive process, exhibiting a sharp increase with increasing in net photosynthetic rate (A_{net}) up to an

optimal temperature (T_{opt}), making in challenging to measure rapidly changing environment. Thus, photosynthetic rates and stomatal conductance are significantly affected by thermal conditions within leaves; however, crop-specific analyses of these relationships remain scarce. Melon, a crop that frequently encounters high-temperature conditions in cultivation environments, was selected as the target crop for this research. This study aims to investigate the response of photosynthesis and stomatal conductance in melon to varying temperatures in order to determine the optimal photosynthetic rate, leaf temperature, and stomatal conductance using a portable gas exchange system. Furthermore, the study seeks to elucidate the interrelationships among these factors through the FvCB biochemical model of photosynthesis. We measured net CO_2 assimilation across a range of leaf intercellular CO_2 concentration (A-C_i curves) nested within a range of 10 different ambient CO_2 concentrations and 10 different leaf temperatures using a portable gas exchange system. Our model selection process, which evaluated the single best predictor of A_{net} across leaf temperatures and at T_{opt}, revealed that stomatal conductance was the most accurate predictor of A_{net} for melon plants. Our findings are in accord with those of previous studies, especially in the C3 plants, that have identified stomatal conductance to be the most important factor limiting A_{net} and an indicator of real-time crop physiological responses to rapidly changing environment.

This work was supported by Korea Institute of Planning and Evaluation for Technology in Food, Agriculture and Forestry (IPET) and Korea Smart Farm R&D Foundation (KosFarm) through Smart Farm Innovation Technology Development Program, funded by Ministry of Agriculture, Food and Rural Affairs (MAFRA), Ministry of Science and ICT (MSIT), and Rural Development Administration (RDA) (421001-03, PJ016439202206).

Keywords: Leaf temperature, Photosynthesis, Stomatal conductance, FvCB model, Thermal optimum.

PS01-29

Total evapotranspiration estimation in multi-crop layers of indoor vertical farms for energy savings

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Energy for the climatization of indoor farming contributes to the highest fraction of total energy use. Staggering different crop varieties at different growth stages makes optimizing the entire growing space possible. But even more relevant, it is to reduce the maximum capacity of the equipment for dehumidification loads.

The optimal multi-crop combination can be identified by modeling the evapotranspiration of different overlapping growth cycles and crop varieties. This work focuses on short-cycle crops using previously validated models of two varieties of lettuces (green leaf cv 'Aquino' and red leaf lettuce 'Barlach') and one variety of leafy greens (Italian Basil). Additionally, blue

and white LED light treatments are compared in their influence on cooling loads. The model estimation aims to include crop-specific stomatal conductance values reflecting the differences in transpiration rates. The targeted results are to minimize space and dehumidification loads by combining growth cycles of lettuces and herbs.

Keywords: evapotranspiration; vertical farming; energy savings; multicrop layers

PS01-30

Blue Light, Higher Humidity, and Horticultural Substrate Promote the Adventitious Root Development of Hemp (*Cannabis sativa* L.) Cuttings

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Cannabis sativa is a widely known annual herbaceous plant that has been cultivated as a medicinal plant since 2800 BCE. It can be classified into two types based on its Δ9-tetrahydrocannabinol (Δ9-THC) content: hemp (medical, < 0.3%) and marijuana (recreational drug). The legalization of hemp in the United States in 2018 has increased its market value. Among the various propagation methods for *Cannabis sativa*, cuttings are preferred by cultivators as they provide genetically uniform plants with consistent growth rates at a low cost. In this study, we evaluated the effects of several environmental factors on the adventitious rooting of the hemp (*Cannabis sativa* L. 'V4') cuttings. The environmental factors included (*i*) light quality (white, blue, red, and green) with PPFD of 80 $\mu mol \cdot m^{-2} \cdot s^{-1}$, (*ii*) relative humidity (30%, 50%, 70%, and 90%), (*iii*) substrate composition (Rockwool and horticultural soil: vermiculite ((25: 75, 50: 50, and 75: 25) (v:v)). The cuttings were evaluated for the rooting rate, number of adventitious root (ARN), total root length (TRL), average root length (ARL), longest root length (LRL), and root fresh weight (RFW) after being placed in a growth chamber at 24° for 21 days. Watering was done every two days with sub-irrigation method. Red light appeared to affect the length growth of stem cuttings, while blue light appeared to affect the development of the adventitious root primordium. At the relative humidity of 90%, the rooting rate was 100%, and the adventitious rooting degree decreased as the humidity decreased. Interestingly, adventitious rooting degree of the cuttings in the mixed substrate of horticultural soil and vermiculite (50: 50, v:v) was higher than that of the rockwool. For the development of adventitious roots of hemp cuttings, the conditions of blue light, high humidity, and mixed horticultural media was most effective. Ultimately, optimum environmental controls can make the better adventitious rooting of hemp cuttings with for mass propagation of cannabis.

This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government (MSIT) (No.RS-2022-00155857, Artificial Intelligence Convergence Innovation Human Resources Development (Chungnam National University).

Keywords: root system growth, Artificial Lighting, Growing media.

PS01-31

Shading by solar panels influences growth and crop characteristics of kimchi cabbage in an agrivoltaic system

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Agrivoltaics (AV) or agrophotovoltaics is the simultaneous cultivation of crops and the production of electricity by installing solar panels on farmland and planting crops beneath them. In this study, changes in microclimates, crop growth and quality were investigated under the AV panels for kimchi cabbage (*Brassica rapa* ssp. *pekinensis*). On September 3, 2022, young seedlings of kimchi cabbage 'Bulam No. 3' was planted in the soil under AV panels at a farmland in Gyeongsan, South Korea and at the open field for the control and managed in a conventional growing method. In the microclimates during the experiment period, there was no difference in temperature, relative humidity and vapor pressure deficit, but daily light integral under AV panels was about 72% of the control group and the average geothermal temperature was 17.5% lower than that of the control group. After 15 weeks, plants under the AV panel had greater head shape index due to smaller width, and softener heads than the control. Plants under the AV panel had more glucose, K, Ca, Fe, but less sucrose and N contents compared to the control. Fresh weight of marketable heads decreased 10% by the AV panels. In conclusion, AV panels changed the amount of light and the microclimate including soil temperature, and this change created a relatively good environment in the early crop stage, which is a high light and hot season, but it had a negative effect in the latter period and also made plants overgrown. This work was supported by Korea Institute of Planning and Evaluation for Technology in Food, Agriculture and Forestry (IPET) through Agri-Food Export Business Model Development Program, funded by Ministry of Agriculture, Food and Rural Affairs (MAFRA) (322005-02).

Keywords: agrophotovoltaics, Chinese cabbage, head formation, microclimate, plant shape index.

PS01-32

Reduction effect of fugitive dust by crop cultivation in reclaimed land

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The reclaimed land has a salt-containing dry surface and has a low vegetation cover compared to other areas. In Saemangeum reclaimed land in Korea, there are few buildings and exposed land to the air resulting in a high possibility of fugitive dust. Fugitive dust from reclaimed land can affect crop cultivation and human health. Chemical and mechanical treatments could not be useful considering the vast land area. This study monitored the fugitive dust reduction rate using various crop cultivations in Saemangeum reclaimed land. The experimental site cultivated green barley, potato, and triticale with each 0.5 ha. The concentration of fugitive dust was monitored according to crop growth and wind directions. The OPCs (optical particle counter) were installed upwind, downwind, and inside the field to monitor the fugitive dust generation rates. The results

showed that the crop covering could reduce the concentration of scattering dust according to the crop canopy. The fugitive dust generation was reduced by 0.1800 kg/ha/hr of PM10 with green barely, 0.1584 kg/ha/hr with triticale, and 0.1080 kg/ha/hr with potato, respectively.

Keywords: Fine dust, Fodder crops, PM-10.

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PS02-01

Dynamic irrigation control under evapotranspiration uncertainty

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Growing demands in agricultural and industrial produce make water scarcity a threatening environmental challenge of the 21st century. Water scarcity is further intensified by the effects of climate change, such as an increase in intense droughts. This study evaluated a dynamic irrigation control scheme to reduce water use and drainage while maintaining zero drought exposure compared to fixed dosages. It also evaluated the effect of sources of uncertainty on the control scheme predictions of water use, drainage, and drought exposure. The results showed that the control scheme improved water use and reduced drainage while maintaining zero drought exposure compared to fixed dosages. Water use and drainage were reduced by 26% and 69%, respectively. An optimal ratio of irrigation and evapotranspiration (1.1) was also found, which represents the additional ratio of irrigation required on top of the amount predicted by the cumulative evapotranspiration to maintain zero drought exposure. These results demonstrate the potential of dynamic irrigation control schemes to optimize water use and reduce drainage in crops while avoiding drought exposure. The findings of this study are significant for growers looking to optimize their irrigation strategies and for policymakers working to improve water use efficiency.

Keywords: Irrigation, Monte Carlo, Uncertainty, Optimal control.

PS02-02

Seed priming improves yield attributes of tomato under salt stress in greenhouse conditions

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Tomato (*Solanum lycopersicum*) is grown worldwide with immense economic importance. Biotic and abiotic stress factors are huge concerns for tomato producers around the globe. It is estimated that by the year 2050, salt stress alone will cause a 50 % loss in the yield of lead-

consuming vegetables, including tomatoes, and will be a huge concern for developing countries in the tropics. Salt stress retards the growth of plants due to a decline in photosynthesis, which leads to a reduction in fruit size and total yield per plant. Plant roots become shorter, and the ability to absorb water and nutrients decreases under salinity. Moreover, in the case of growth, it has been reported that tomato plants under salinity stress have shorter plant heights and lower leaf areas. High salt accumulation decreases the fruit quality due to disruption in photosynthetic activity. Researchers mostly worked on enhancing tolerance at the seedling stage under stress conditions, but there are limited studies about the effects of seed priming on plant yield and yield attributes. The study was carried out with the objective of evaluating the effects of seed priming with polyethylene glycol, a polymer with a molecular weight of 6000, on tomato yield attributes under salt stress conditions. The experiment was conducted at the Tokyo University of Agriculture (Setagaya campus, Tokyo, Japan) in 2022. Tomato seeds were primed using polyethylene glycol (PEG6000) for 36 hours. The priming treatments were a. control (0 MPa), b. 0.4 MPa, c. 0.8 MPa, and 1.2 MPa. This experiment was set in a factorial design with six replications in each treatment, and a total number of 120 plants were used in this experiment. Yield attributes such as fruit weight (g), fruit size (mm), number of fruits per plant, and total fruit yield per plant (g) were recorded. It was observed that salinity decreased the fruit weight (g), fruit size (mm), fruits per plant, and total fruit yield per plant compared to control conditions. Salt-stressed plants produced fruits of lightweight and small sizes. Seed priming could enhance stress tolerance and improve yield attributes. Under no salt stress (0 mM), there were no significant differences in fruit weight between primed and none-primed plants, but in the case of fruit size, 0.8 MPa treatment gave bigger fruits than others (Table 1). Under 50 mM salinity, all priming treatments gave bigger and heavier fruits compared to none-primed ones. While in 100 mM salinity, 0.4 MPa gave heavier fruits but 1.2 MPa gave bigger fruits. Furthermore, in high salt stress conditions (150 mM, and 200 mM), all priming treatments showed higher performance compared to the control (0 MPa). The number of fruits per plant was negatively affected by salt stress. However, seed priming could alleviate such damages under each salinity level (Fig.1). Final yield, which was the important focus of the current study, was significantly decreased by salt stress. Stressed plants produced lower fruit yields compared to healthy ones. Seed priming was not effective for yield per plant under ambient conditions, while under salty conditions, it could significantly improve yield per plant, and primed plants resulted in higher yield compared to none-primed ones.

Keywords: Tomato, yield attributes, seed priming, salt stress.

PS02-03

Development of a system using acceleration sensor for automatic collection of work records in a greenhouse

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To reduce the labor required for recording work in greenhouses, we created a system that uses the acceleration of a work trolley to estimate the work status and automatically records

work time in detail. The system includes a commercial electric pipe rail trolley, a smartphone with a built-in acceleration sensor, and a custom-developed work data collection application. The trolley and smartphone are not remodeled. The laborers launch the application on the smartphone, which is mounted on the trolley, and then proceed with their work, such as harvesting. The smartphone's built-in acceleration sensor measures the trolley's acceleration in three directions (X, Y, Z). It uses this data to estimate the current work status (trolley driving, lifting the trolley's platform, working on the trolley's platform, stopping). This information is recorded every 10 ms, both internally and online, and can be sorted by cultivation area or laborer. This data is expected to assist in efficient labor management, such as in identifying growth variations between areas and determining differences in technical skills among laborers. In a field test, laborers used the trolley equipped with the developed system and simulated harvesting paprika fruits placed in high positions in a greenhouse. The measured time was highly accurate, and the differences in work procedures among laborers were almost accurately identified.

Keywords: farm work time, labor management, low cost, pipe rail trolley, smartphone.

PS02-04

A main stem-based operation method for a cultivation management robot system in greenhouse horticulture

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In large-scale greenhouse horticulture facilities, robot systems are required for harvesting and cultivation management to reduce labor effort and time, and some researchers have developed such systems with a focus on harvesting. These conventional robot systems are operated based on image processing results, and a robot manipulator directly approaches target objects such as fruits and leaves. However, this method does not always work well when plants are thriving due to false identification of targets, changes in target location during the approach, instability of targets during operation, etc.

To solve these issues, we propose a new robot system that manages cultivation based on the main stem of the target plant. In this proposed system, the robot manipulator first approaches the main stem of the target plant, which is easier to recognize than target objects. The manipulator moves closer to the target objects along the main stem with a steady approach. Finally, the manipulator stably attends to the target objects while holding the main stem.

To achieve the proposed system, we have developed a prototype finger gripper that allows the robot to catch, trace, and grip the main stem of the target plant. In this study, we especially aimed to develop a de-leafing robot for tomatoes that perform based on our

proposed method with the gripper. We have conducted fundamental de-leafing experiments with the developed gripper, and our results suggest the potential and effectiveness of our proposed system.

Keywords: cultivation robot, main stem, deleafing, finger gripper.

PS02-05

Detection of tomato main-stem skeleton using point cloud segmentation

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Horticulture requires considerable human labor; therefore, saving labor by employing robotic systems is necessary. Research has focused mainly on robots for harvesting. To robotize the harvesting process, it is necessary to "deleaf" (cut leaves) in advance so that the robot can easily recognize the fruit. Deleafing is the second-most labor-intensive task after harvesting; thus, demand for the robotization of deleafing is expected to increase. To achieve deleafing using a manipulator, path planning is performed based on the main-stem position. This study devised a method to detect the tomato plant's main stem from a 3D point cloud acquired by an RGB-D camera. This method consists of two parts. The first is using the PointNet++ deep-neural-network model for segmenting the point cloud into main stems, leaves, and growing beds of tomatoes. The second is extracting the main-stem skeleton from the segmentation results through postprocessing, entailing the clustering and linearity evaluation of the point cloud. To train PointNet++, a dataset of 100 point clouds generated from RGB-D images of tomatoes at the same growth stage in a single greenhouse was created. The dataset was divided into training, validation, and test sets in proportions of 60%, 20%, and 20%, respectively. As a result of the proposed method, the average intersection-over-union values of each class (main stem, leaves, cultivation bed, and others) for point cloud segmentation were 0.64, 0.94, 0.91, and 0.53, respectively. The average precision and recall were 87.33% and 87.31%, respectively, for detecting main-stem skeletons within 1.7 m from the camera in each shooting scene.

Keywords: Tomato main-stem, Deep learning, Point cloud segmentation, Deleafing.

PS02-06

Design of Intelligent Tomato Disease Image Classification System Based on Complex Environmental Information

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This paper uses a KS standard-based artificial intelligence complex environment information system. In the automatically acquired crop image data, the environmental information inside the greenhouse is used to predict the occurrence of diseases. In addition, using light

environment information such as insolation, light transmittance, and scattered light, crop diseases that were difficult to detect in the greenhouse demonstration environment were solved by applying pre-processing techniques such as image conversion enhancement techniques and fine parameter adjustment. As a result, the disease detection rate, which was 92.5% in 2020 in the existing demonstration environment, was raised to 95.2%. This was improved by more than 6.2% compared with the 89% maximum detection accuracy of the deep learning disease prediction model using Keras. In other words, considering that unseen data acquired from an external environment rather than an environment controlled by a laboratory is used (Practical outcome), it can be said that the disease classification accuracy is very high.

Keywords: Smart Agriculture, Data Preprocessing, Artificial Intelligence, Plant Disease forecasting.

PS02-07

Urban smart farms: architectural approach and system design

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Greenhouses are built to control the natural elements of the agricultural environment. For efficiency and functionality of farming, forms of the greenhouse that create indoor environments were very limited. It can also be considered a typical form. This study focused on urban smart farms, which are in the paradigm shift of greenhouse system design. The purpose of the research is to explore the possibility that smart farms in urban areas can be expanded and supplied together with some of the buildings at this time when urban agriculture is being activated worldwide. The research methods are case studies and analysis of plan alternatives. Through case studies, it will be revealed how smart farms in greenhouses according to urban areas by land use can be installed in conjunction with buildings. Develop greenhouse system design alternatives in the actual site, conduct SWOT and expert interviews in the fields of horticulture, agriculture, and environment for each alternative, and present alternatives as results. Urban smart farm has not only the social value of urban agriculture but also spatial and place value in an urban area, so it is necessary to diagnose the relationship with other buildings and morphological possibility. The outcomes of the study are based on an architectural approach but require multidisciplinary discussion and will contribute to the spread of supply in the city in a very diverse form of the urban smart farm in the future.

Keywords: urban farm, smart farm, greenhouse type, architectural perspective.

PS02-08

Counting the number of cherry tomato fruits by using a hanging-type imaging robot: the relationship between the width of image analysis and the fruit number per plant

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The speaking plant approach (SPA) is regarded as a sophisticated concept for environmental control in current greenhouses. It is based on the paradigm that the optimization of crop cultivation conditions should be based on measurements of the plant's physiological status. A hanging-type imaging robot developed by our previous study enabled us to capture a color image of dozens of meters wide tomato canopy in a commercial greenhouse automatically. In this study, we applied robot imaging to the entire cherry tomato plant canopy of 56-meter width, which comprises more than a hundred plants, on a single cultivation lane. And the obtained color images were analyzed by a deep learning-based object detection algorithm YOLOv3 to count the number of tomato fruits. The average number of tomato fruits on a plant (F/P) is 18.7±3.9(S.D.) fruits/plant for the entire tomato canopy of 56m width. However, the F/P varies from 18.5 to 20.2 fruits/plant when the image analysis unit is at 30m, and the extent of the variation of F/P increased to 17.4-20.7 fruits/plant at 20m and 15.6-20.8 fruits/plant at 10m. The results implied that the 20m width for the imaging is enough to obtain the value of F/P at an accuracy of ± 10%.

Keywords: deep learning, growth monitoring, object detection, plant diagnosis, yield forecast.

PS02-09

Influence of the growing media on phytochemical composition of six salad rocket (*Eruca sativa*) accessions

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Compost from agricultural and agri-food industry wastes is an alternative to peat that can be used as a component of growing media to cultivate rocket salad, which is an important vegetable for the ready-to-eat sector. However, the chemical and physical characteristics of the compost may not be suitable for plant cultivation. The aim of this study was to compare commercial and non-commercial rocket salad genotypes emergence and subsequent growth in pots filled with three growing media and how these combinations affected the glucosinolates and phenolic content in the plants. One commercial variety 'Rocket Sky' and five local accessions were grown in pots (Ø 10 cm diameter) filled with a mix of peat: and

compost with the following percentages (w:w): 0:100, 50:50, and 100:0. Plants were cultivated in a growth chamber with the following parameters: temperature 20 °C, photoperiod 12/12 h (light/dark), relative humidity of 55% and photosynthetic photon flux density (PPFD) of 180 $\mu mol \cdot m^{-2} \cdot s^{-1}$, resulting in a daily light integral (DLI) of 7 $mol \cdot day^{-1}$. Compost produced a 3-5 days delay in the emergence percentage of plants compared to peat. The commercial variety produced similar emergence percentages in the three mixes, while the highest emergence percentages were observed in genotypes #184, #248, and #254 and in the commercial variety grown in peat. Once the plantlets were transferred to pots, mixing compost and peat (50:50) resulted in significant differences in each growth parameter (leaf size, leaf area, fresh and dry weight) compared to compost or peat. The assessment of the rocket salad varieties on the phytochemicals profile evidenced the presence of glucosinolates (GSL) and phenolic compounds. Growing plants in compost and peat-compost mixtures increased the referred values by the average percentages of 80.1 and 136.1%, respectively, except for 4-(β-D-Glucopyranosuldisulfanyl)-butyl-GSL that reduced its concentration by 32.3 and 65.6%, correspondingly, relative to plants grown in peat. Concerning (poly)phenols, it was found the presence of 6 individual compounds in concentrations higher than the limit of quantification. When using a compost or compost-peat mixture for growing rocket salad, the concentration of phenolics decreased between 18.2 and 96.2%, depending on the individual compound considered, relative to plants grown in peat. However, a minor effect of the accession considered was retrieved from the present study.

Keywords: compost, peat, phenols, glucosinates.

PS02-10

Design and implementation of Wireless sensor and control network for Deep Flow Technique (DFT) in Hydroponic Systems

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In this work, the design and implementation for monitoring and controlling deep-water crop system, based on ESP32 and raspberry pi devices, is presented. The proposed system is a low-cost alternative for experimental studies in academic research that allows remote monitoring and automatic controlling. This work is focused on the development of the system, where the raspberry pi is used as a database and web server for storage and consults the acquired data in the sensors which, using an ESP32 microcontroller, send the lectures through a Wi-Fi local network. The data includes temperature, conductance, pH, and, using an ESP32cam, image captures. The physic system structure for mounting the sensors and controllers is presented as a prototype where manufacturing technologies such as 3d printing and laser-cut are used. The obtained prototype in this work could be replicated for an agriculture experimental design platform where the effects on the plant growth of the controlled variables can be studied through experimental factorial designs.

Keywords: 3D printing, laser-cut, local network.

PS02-11

Load cell-based automated irrigation system for efficient irrigation management of plug production

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With the increasing importance of efficient water management in recent horticultural production, various sensor-based automated irrigation systems have been implemented. However, the current soil moisture sensor technology for measuring moisture levels of media in plug trays for young plant production is limited by the size of soil moisture sensors and the number of cells. To address this, this study was conducted to develop an automated irrigation system for plug production that monitors and controls the weight of the plug tray via a load cell. The hydrophysical properties of the medium in the plug tray and plant growth changes were considered, and the weight of the plug tray was calculated into substrate volumetric water content (VWC) value. This automated irrigation system used load cells, a data logger, and solenoid valves to irrigate when the substrate VWC dropped below a certain irrigation threshold level. To calibrate the VWC from the weight changes, this system continuously changed the set weight at saturation with an irrigation event, ensuring accurate VWC calculation that also considered plant growth. This system precisely monitored and controlled the substrate VWC of the plug tray, and efficient irrigation for young plants with a certain threshold VWC levels could be provided. In a trial test, basil seedlings irrigated with threshold VWC at 0.60 m3·m−3 used 23% less water than the control group that irrigated the tray every morning, without significant differences in shoot dry weight. However, when irrigated at threshold VWC at 0.30 or 0.45 m3·m−3, the irrigation efficiency was greater than the control group, but the growth of basil seedlings was reduced compared to the control group. In conclusion, this load cell-based automated irrigation system can be effectively applied to plug production for efficient irrigation management of young plants.

Keywords: automated irrigation, efficient irrigation, load cell, plug production, volumetric water content, young plants.

PS02-12

Development of a high-precision, non-destructive technique for estimating individual and plug tray unit plant height and leaf area in red pepper seedlings using Plant Image Measurement System (PIMS)

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Image-based non-destructive measurement techniques to determine plant growth and physiological disorders have been receiving increasing attention in agricultural science. This

study presents the correlation analysis results between destructive and non-destructive measurements to enhance the accuracy and efficiency in measuring the major growth parameters of both individual and plug tray units of red pepper seedlings depending on the growth stages. The red pepper seedlings ('Kalatan') were grown under two different environmental conditions to diversify the variation in seedling growth. The environmental conditions at each site were simultaneously recorded using a data logger. Plant height (PH) and leaf area (LA) were measured at 14, 28, 39, 57, and 75 days after sowing using both destructive and non-destructive methods, with the Plant Image Measurement System (PIMS) equipped with RGB, multi-spectral camera, and LiDAR sensor. The changes in seedling PH and LA under two different environmental conditions were separately plotted as a graphical tracking method to determine a potential standard growth curve of PH and LA in healthy seedlings. The R^2 values of PH in individual units varied from 0.2029 to 0.9676 depending on the growth stages, and the highest correlation coefficient (0.9676) was found during the entire growth period. The R^2 values of LA in individual units ranged from 0.2807 to 0.9983, and the highest correlation (0.9983) was found at 39 days after sowing before leaf overlapping. In the plug tray unit, the average R^2values were 0.9183 in the PH and 0.7992 in the LA, respectively. The high correlation observed in the individual seedling unit, as compared to the plug tray unit, might be presumably due to the low degree of leaf overlapping. This study established preliminary ranges for graphical tracking curves and developed an image-based rapid measurement technique for two major growth parameters in red pepper seedlings before the leaf overlapping stage. Our future research will focus on correcting the underestimated image-based values of PH and LA due to leaf overlapping, as well as detecting physiological disorders in red pepper seedlings. This study was supported by the National Institute of Horticultural and Herbal Science, Rural Development Administration, Korea (PJ017040012023) and the Basic Science Research Program through the National Research Foundation of Korea (NRF) by the Ministry of Education (No. 2019R1A6A1A09031717). T. +82-63-270-2578, jungu@jbnu.ac.kr

Keywords: Graphical tracking, Image-based measurement, Non-destructive measurement, Seedlings, Plant Image Measurement System (PIMS).

PS02-13

AstroPlant: a novel IT infrastructure and network of plant growth chambers

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MELiSSA (Micro-Ecological Life Support System Alternative) is the European Space Agency (ESA) project of circular life support system that was established to gain knowledge on regenerative system, aiming for the highest degree of autonomy in Space missions. Plants are the most promising biological regenerators in life support systems as they renew air through

photosynthesis, recover purified water through transpiration, and recycle waste products through mineral nutrition while providing fresh food for the crew's diet. The design and development of growth chambers are critical to characterize the plant performance within Biological Life Support Systems for long-term manned missions in Space. The AstroPlant project aims to develop a distributed network of simple, instrumented, and standardized plant growth chambers or experimental kits for researchers in the field of closed-loop artificial ecosystems and circular systems as well as engage and connect citizens, scientists, students, and schools in this research. The focus of this project is on validating this objective within the context of the MELiSSA project. Indeed, a challenge of plant production in Space is the lack of data on plant growth in closed environments. Data generation on plant growth behavior under varying and non-standard environmental conditions can be accelerated by developing simple plant growth facilities like AstroPlant and deploying a high number of them. Several MELiSSA partners received the kit in 2020 to participate in the scientific validation of the system, among them the Department of Agricultural Sciences of the University of Naples (UNINA). The activities carried out at UNINA focused on developing specific cultivation protocols for growing microgreens in AstroPlant, testing different environmental conditions in terms of light intensity and spectrum, and airflow velocity, to be disseminated to the global project community. However, AstroPlant can also be a wonderful educational tool, as well as be used for big data generation.

Keywords: Life Support System, educational tool, school engagement, cultivation protocols, microgreens.

PS02-14

Substrate comparison for tomato propagation under different irrigation protocols

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Greenhouse tomato production has multiple challenges including the excessive use of nonrenewable substrates that are difficult to dispose after their use. Most growers currently propagate tomato in rockwool but the demand for sustainable media is increasing. The objective of this research was to evaluate sustainable and organic alternatives to use in greenhouse propagation of tomato seedlings intended for high wire production. Different organic and inorganic substrates were evaluated in three different trials. The nutrient solution used was composed of a complete water-soluble fertilizer. Germination and growth parameters including height, leaf area, stem diameter, shoot fresh and dry weight, and foliar chlorophyll levels (SPAD) were measured. In the first trial with both overhead and subirrigation, rockwool, coir, wood fiber and coir mix, medium grade pine bark, pine bark screened to < 0.64 cm, and pine bark screened to < 0.32 cm were evaluated. Tomato germination was faster and at higher percentages with fine grade pine bark (< 0.32 cm).

However, rockwool had the highest height and shoot dry weight, and coir had the highest SPAD, sped diameter and leaf area. For the second trial with subirrigation, rockwool, coir, wood fiber and coir mix, fine grade pine bark, and peat were evaluated in different container heights. Peat resulted in greater growth across all the parameters followed by wood fiber in all the container heights, while pine bark had the least growth across all measured parameters. For the third trial with overhead irrigation, rockwool, wood fiber and coir mix, fine pine bark, and a commercial formulation of peat:perlite were evaluated under different fertilizer rates (electrical conductivity 1.1 $mS \cdot cm^{-1}$ or 2.2 $mS \cdot cm^{-1}$). Wood fiber and coir mix, and rockwool were the substrates with highest values for all the evaluated parameters. While all the organic substrates showed potential for use in tomato propagation pine bark, and wood fiber and coir mix provided the best media for germination rate. Moreover, wood fiber and coir mix showed the best combination of seedling growth, and it showed potential to be used as substitute for rockwool.

Keywords: coir, organic substrate, rockwool, peat, pine bark, wood fiber.

PS02-15

Novel Greenhouse Cooling Technology Using Natural Cold Energy in Winter

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It is necessary to develop eco-friendly greenhouse cooling technology to cope with rapid climate change. The current greenhouse cooling system has not reached the level that can improve greenhouse productivity. The seasonal cold energy storage is a high-efficient and environmental-friendly technology that uses the stored natural cold energy in winter for free-cooling in summer without any power consumption for cold energy production. This study first presented the demonstration experiment on the novel natural cold energy production based on the oscillating heat pipe under natural cold ambient in winter. The oscillating heat pipe module for cold energy production was made of copper meandering capillary tube charged with R-134a refrigerant and represented very small thermal resistance below 0.02 K/W which shows superior thermal performance. The present demonstration experiment could obtain instantaneous cold energy production rate of 885 W and total accumulated cold energy production of 82.4 kWh. This study also developed the theoretical model for prediction of cold energy production rate of the present oscillating heat pipe system and suggested the guidance for improved cold energy production performance.

Keywords: Greenhouse cooling, Natural cold energy, Cold energy storage, Oscillating Heat Pipe.

PS02-16

Use of 'double roof' with photoconversion films to improve yield and photosynthetic activity in Mediterranean greenhouses

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Enhancing the sunlight spectrum can increase crop photosynthesis and yields, reduce pests and diseases incidence. The French company CASCADE developed the 'LIGHT CASCADE®' (LC®) technology that shifts and adapts the sunlight spectrum closer to plant needs. LC® technology dispersed into plastic foils absorbs UV and Green wavelengths in the sunlight spectrum and reemits into respectively Blue (400-500 nm) and Red (600-700 nm) wavelengths. The aim of this work was to analyse the effect on cucumber (*Cucumis sativus* L.) crop of two sunlight spectrum photoconverter films used as double roof inside greenhouses. The effect on photosynthesis and yield was analysed in 2 fertigation modalities (standard and 25% reduced). The trial was carried out during autumn-winter 2020 season in two multispan greenhouses located in Almería (Spain). Every greenhouse was divided in four parts, two with a double roofs with blue (greenhouse 1) and pink photoconversion LC® films (greenhouse 2) and two with a double roof with standard colourless film. In greenhouse 1, photosynthetic activity measured in plant leaves was 3.2 % higher under the blue photoconversion LC® double roof (12.6 µmol CO_2 $m^{-2}{\cdot}s^{-1}$) compared to the standard film (12.2 µmol CO_2 $m^{-2}{\cdot}s^{-1}$). In the case of greenhouse 2, photosynthetic activity was 3.8% higher in plants with double roof with pink photoconversion LC® double roof (13.3 µmol CO_2 $m^{-2}{\cdot}s^{-1}$) compared to the standard colourless film (12.8 µmol CO_2 $m^{-2}{\cdot}s^{-1}$). Cumulative marketable yield of the cucumber crop increased 0.36 kg/m^2 (5.3%) with the blue film and 0.25 kg/m^2 (3.0 %) with the pink spectrum photoconverter film in classic fertigation. For the treatment with a 25% of reduction in fertigation, the increase in marketable production was 0.08 kg/m² (1.2%) with the blue spectrum photoconverter film and 0.42 kg/m² (5.1%) with the pink film, compared with the standard colourless film.

Keywords: protected crop, market production, photosynthesis, spectrum conversion film, cucumber.

PS02-17

Evaluation of Decision Tree-based Ion-Specific Dosing Algorithm for Closed Hydroponics

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When dealing with closed hydroponic solutions, the maintenance of ion balances in nutrient solutions is fundamental not only to ensure the productivity and quality of crops, but to elongate the recycling period of the nutrient solution for reducing the water and nutrient discharge,

thereby allowing more economic and environmental benefits. However, it is still difficult to conduct the ion-specific management for all nutrient ions using the ion sensors because several nutrient salts are injected with the coupled ions which are not required for the replenishment. A simplex algorithm, which calculate the injection volumes of stock solutions simultaneously with a set of given constraints, has been used in several studies. However, the calculation is limited in actual because it requires information on all nutrient ions in the hydroponic solution. As the result, the simplex method has been limitedly used for specific ions. Therefore, it is essential to consider the ion coupling issue for more efficient fertilizer dosage in closed hydroponic solutions. In this study, a decision tree-based dosing algorithm was developed considering a monitoring system with NO_3, K, and Ca ion selective electrodes for recycled nutrient solution. Then, it determines the proper amount of fertilizers while minimizing the coupled injection of the nutrient ions. To compare the performance of the algorithm with the conventional simplex algorithm, a dosing simulation test was conducted with an automated individual nutrient dosing system. The test was conducted by a five stepwise management test and the replenishments for the given target concentrations were evaluated. From the results, the over-injections of the NO_3 ions were observed in both methods due to the coupling of the NO_3 with the Ca. However, the amounts were slightly higher in the simplex method. In case of K ions, the decision tree method made more accurate control for the K ions than the simplex method. Specifically, the decision tree method was about 87.2% lower compared to the simplex method in terms of the total input amount of fertilizer. The results proved the developed dosing algorithm could effectively control the individual ion concentrations by calculating the optimal injection volumes of the seven kinds of fertilizer salts for the given target ion concentrations.

Keywords: Closed hydroponics, Ion-specific dosing algorithm, Individual fertilizer, Ion selective electrode.

PS02-18

Assessment of nutritional properties of *Valerianella locusta* plants growing in indoor vertical farms under different lighting conditions

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Vertical farms (VFs) are controlled indoor growing systems that facilitate the cultivation of leafy vegetables in urban areas, maximizing yield per square meter. Plants are usually hydroponically cultivated in VFs, reducing irrigation needs, but on the other hand, VFs have high energy demands for lighting operation. Thus, it is valuable to specify the light conditions that offer desirable traits to the plants while the VFs are energy efficient. The aim of this study was to evaluate biochemical factors of corn salad (*Valerianella locusta*) plants, such

as ascorbic acid, total polyphenol content, antioxidants and nitrate content under different lighting conditions. Two different light qualities were tested; a) white and b) blue, red and NIR-infrared (B-R-NIR) parts of the spectrum. The tested treatments under each spectra combination had a PPFD of 250 µmol $m^{-2}s^{-1}$ and 3 different photoperiods of 16, 14 and 12 h d^{-1} of light, resulting in different daily light integrals, DLI of 14.4, 12.6 and 10.8 mol $m^{-2}d^{-1}$, respectively. Results showed that ascorbic acid concentration reached maximum levels at 14 hours daylight, under white light, and under all conditions in B-R-NIR light. Total polyphenols were at the highest concentration under 16 hours of daylight at both light qualities, while antioxidant activity reached its peak at 12 hours of white light and 16 hours B-R-NIR light. Nitrate content was lowest at maximum daylight. As a conclusion, optimal biochemical characteristics of the plants, like high ascorbic acid, polyphenols and antioxidants but low nitrate content, were observed under the condition of 16 hours of light per day, under B-R-NIR light quality, while the second-best condition was 14 hours of B-R-NIR light. Energy consumption was doubled at 16 hours compared to 14 hours of daylight, thus the second condition was considered optimal.

Keywords: Vertical farming, biochemical analysis, nutritional properties, nitrate, antioxidants, daily light integral, *Valerianella locusta*..

PS02-19

Optimization of nutrient solution concentration improves plant growth and secondary metabolites of *Cannabis sativa* L. in hydroponics

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This study aimed to find the optimal electrical conductivity (EC) of nutrient solution in an indoor growing farm system to improve plant growth and secondary metabolites in *Cannabis sativa* L. We investigated the effects of 4 EC treatments (1.0, 2.0, 4.0, and 8.0 $dS{\cdot}m^{-1}$) on plant growth and the secondary metabolites in *Cannabis sativa* L. plants. Plant growth parameters and physiological activities were measured three weeks after transplanting for the vegetative growth analysis and six weeks after reproductive growth. The results showed that plant growth parameters were increased under medium EC treatments (2.0 and 4.0 $dS{\cdot}m^{-1}$) and decreased under lower EC (1.0 $dS{\cdot}m^{-1}$) and higher EC (8.0 $dS{\cdot}m^{-1}$) because of nutrient deficiency and salt stress, respectively. The activities of antioxidant enzymes, such as catalase and superoxide dismutase, and the higher proline contents were increased at higher EC levels (8.0 $dS{\cdot}m^{-1}$) compared with remaining treatments which may be a response to the oxidative stress caused by salt stress. However, guaiacol peroxidase activity was reduced under higher EC levels. Total chlorophyll content in leaves was the highest at EC 2.0 $dS{\cdot}m^{-1}$ and decreased at higher EC levels (4.0 and 8.0 $dS{\cdot}m^{-1}$). Likewise, total phenolic content and antioxidant capacity were decreased at higher EC levels. Total flavonoid content under 8.0 $dS{\cdot}m^{-1}$ was 37.1% lower than those of 2.0 $dS{\cdot}m^{-1}$. Total CBD and total Δ9-THC contents in flowers were significantly higher at lower EC

treatments (1.0 and 2.0 dS·m^{-1}) than those of higher EC treatments (4.0 and 8.0 dS·m^{-1}). The results of this study suggest that 2.0 dS·m^{-1} successfully improved the secondary metabolites, CBD and Δ9-THC of hemps with no adverse influence on plant growth or yield productivity. This work was supported by Institute of Information & communications Technology Planning & Evaluation (IITP) grant funded by the Korea government(MSIT) (No.RS-2022-00155857, Artificial Intelligence Convergence Innovation Human Resources Development (Chungnam National University).

Keywords: secondary metabolites, electrical conductivity, *Cannabis sativa* L.

PS02-20

Calibration and evaluation of a simplified dynamic model for lettuce grown in a mini plant factory

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Mathematical models allow to forecast plant responses to environmental factors and crop management. In the literature several dynamic lettuce growth models have been reported; however, only few investigations have been done on plant factories with artificial lighting (PFALs). The aim of the current work was to calibrate and evaluate a recently proposed simplified mathematical model for biomass accumulation of lettuces (*Lactuca sativa* L.) grown in a mini-PFAL built in Chapingo, México. Two growing experiments were performed with lettuce type butter using the NFT technique. The environmental variables: temperature, CO_2, and LED light intensity as well as lettuce dry weight were recorded at regular intervals. To determine the most influential model parameters on the accumulated biomass, a global sensitivity (SA) analysis was carried out with the Sobol method. The SA analysis involved the eight parameters of the model. The influential parameters turned out to be only four: two of them related to the effect of temperature on the CO_2 diffusion in the leaves, the yield factor and the LED light use efficiency. Only the yield factor and the light used efficiency parameters were estimated from measurements. The model calibration was carried out using the standard differential evolution algorithm, with the data from the first experiment. The objective function to be minimized was the error between the measured and simulated crop biomass. The model evaluation was done with the data coming from the second experiment. According with the fitting indices, mean relative error (MRA), root mean squared error (RMSE) and model efficiency (EF) both the calibrated (MRE = 9.53, RMSE = 0.0041 kg m^{-2}, EF = 0.99) and evaluated (MRE = 34.31, RMSE = 0.0066 kg m^{-2}, EF = 0.97) models acceptably predict the dynamics of accumulated biomass of the lettuce crop grown in a mini PFAL.

Keywords: Nutrient film technique, biomass, LED light, Latin hypercube sampling, global sensitivity, differential evolution.

PS02-21

Change in physicochemical properties of coconut coir during five cultivation cycles of blueberry (*Vaccinium spp*.) cv biloxi

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The increase in demand for blueberries (*Vaccinium spp*.) worldwide has benefited Mexican producers, since large areas of agricultural production of this crop have been established in the last 10 years, mainly in the central region of the country. In some productive areas, the physical and chemical properties of soil have not been optimal in all scenarios, therefore, the soil has been replaced by different types of substrates for better production. However, it is necessary to understand the change in the physicochemical properties of the substrate, as well as the root development of the blueberry plant over time. In this study, the objective was to compare the physicochemical properties of coconut coir and root development of blueberry plants during five cultivation cycles. A sampling was carried out in a production unit with plants of two, three, four and five years of cultivation with blueberry (Biloxi) in Ciudad Guzmán, Jalisco. Within the four plants of each year of cultivation, two diseased plants and two healthy plants were selected. For diseased plants, with "tip wilt" as the most common symptom (commonly associated with the *Pestalotiopsis spp.* Pathogen) were sought. The De Boodt methodology was followed for the evaluation of the physical properties, and for the chemical properties, titration, spectrophotometry, colorimetry and atomic absorption techniques were applied. The obtained results were subjected to statistical analyses of variance and mean comparisons (Fisher p≤0.05). The physical properties that showed significant differences were: bulk density, water holding capacity, total porosity, air capacity, easily available water, reserve water, total available water and not available water. The chemical properties that presented significant variations were: pH, electrical conductivity, NO_3-N, NH_4-N, P, K, Ca, Mg, Fe, Mn, Zn, Cu and B. Differences in volume, fresh and dry weight of the roots, both in the fine and medium roots were observed along the cultivation cycles.

Keywords: blueberry, substrate, physicochemical properties, root development.

PS02-22

Dynamic lettuce growth model for temporal spectral changes

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The crop model is a versatile tool for abstracting plant responses to the environmental conditions. Light is an environmental factor that can significantly influence plant growth and morphology across a broad spectrum. In many cases, the light factor in crop models has been concerned quantitatively as intensity or its accumulation. However, since lighting strategies have been advanced in crop production using artificial lighting, various light stimuli, such as

spectral distribution, light quality, need to be considered as environmental factors inducing plant response variances. Light has a cumulative effect and a combination effect in plants, which are living organisms. This study aimed to model the dynamic influence of the light spectrum based on the NICOLET model. Three different spectral ranges were adopted in photosynthetically active radiation in this study. The light response was supposed in two ways of photosynthesis and photomorphogenesis, along with their interaction in time series. Experimental data were obtained from the growth characteristics of lettuce plants treated with various light spectrums, which temporally changed at two, four and six weeks after sowing. By modifying the carbon concentration fluxes of vacuoles and structures, our model accurately simulated plant growth throughout the cultivation period. The model reflecting the photosynthesis and photomorphogenesis induced by temporal spectral changes can improve the cultivation technology using artificial lighting and expand connection with other environmental conditions.

This research was supported by the MSIT under the Grand Information Technology Research Center support program (IITP-2020-0-01489) supervised by the IITP.)

Keywords: Artificial lighting, Lighting strategies, Light quality, NICOLET.

PS02-23

Simplified greenhouse climate and crop model predicts yield using Bayesian inference

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Greenhouse crop simulation models are a great tool to evaluate, *in silico*, new technologies and greenhouse control strategies. Greenhouse climatic and crop simulation models are based on ordinary differential equations (ODE) models with multiple sate variables and flows. The state variables at any given time are calculated based on the flows associated with them. In turn, flows are calculated with a variety of approaches ranging from thermodynamic equations as well as biochemical and empirical sub models. In all cases, an important number of parameters are needed to calculate these flows. Obtaining these parameters for a new greenhouse type, construction material, location and/or crop cultivar is a severe limitation to the extensive use of greenhouse crop simulation models in practice. This is because the experiments to infer the parameters require special equipment, are expensive and/or could take a full growing season. Here, we present a procedure to parametrize an ODE greenhouse climatic and crop simulation model using Bayesian inference and posterior sampling resorting to Markov Chain Monte Carlo algorithms. The procedure takes only about two hours of calculations using only a personal computer and two days of simple climate data and historical yield. In this way, we can predict state variables, flows and yield for the next 30 days. We show

an example of the procedure on data collected from a cucumber crop cultivated in a high-tech, Venlo type greenhouse. We discuss the use of this procedure to accurately predict greenhouse crop yield in any greenhouse without the need of traditional parametrization.

Keywords: greenhouse, modeling, Bayesian inference, uncertainty quantification, cucumber, MCMC, Markov chain Monte Carlo.

PS02-24

Growth evaluation of the tomato root system cultivated in two hydroponic systems

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Modeling nutrient uptake in crops requires an understanding of root growth dynamics. The present trial was carried out to obtain some root growth parameters in tomato plants cv. Aguamiel. The plants were grown in two hydroponic systems: nutrient film technique (NFT) and modified 'new growing system' (NGS). Root sampling was carried out at 44, 95 and 107 days after planting (DAP), classifying the roots according to their diameter, medium-sized roots (MR), fine-sized roots (FR) and roots hairs (RH). Measurements of quantity, length, fresh weight and dry weight of the above structures were taken; with the data obtained, total root system length (TRL), root system growth rate (RGR), root surface area (RSA) were estimated. The amount of the medium-sized roots per plant in NGS was 13.3, 19.7 and 17.7 at 44, 95 and 107 DAP respectively, while for the NFT system it was 21.3, 42 and 23 at the same sampling dates respectively. The quantity of fine roots per plant in NGS was 190, 275 and 331 at 44, 95 and 107 DAP respectively, and for NFT the amounts were 363, 337 and 356 for the aforementioned dates. The estimated number of RH in NGS was 11 465, 14 506 and 40 790 at 44, 95 and 107 DAP respectively, while in the NFT system 21 578, 32 796 and 35 908 absorbing hairs were estimated at 44, 95 and 107 DAP. At 107 DAP, RGR was 328.3 cm/d in NGS and 336.1 cm/d in NFT; no significant differences were found between hydroponic systems for this variable.

Keywords: soilless system, Lycopersicon esculentum.

PS02-25

Machine Learning image classifier: autonomous fertilization management of indoor-grown lettuce for baby leaf production

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The automation and optimization of input, such as nutrition, for crop plant development is becoming increasingly urgent for ecosystem sustainability and natural resource management.

Information from digital images can be automatically collected and analyzed using computer vision (CV) technologies, which is closely related to sophisticated machine learning (ML) techniques that can solve complex information processing problems through self-learning.

The main objective of this study was the creation and validation of a ML algorithm to obtain a digital RGB image classifier for lettuce leaves. The algorithm was meant to classify the lettuce images according to three nutritional classes, related to the fertilization treatments applied. In commercial application, the classifier could enable to remotely guide fertilization in order to avoid or remediate nutritional deficiencies.

The experiment involved the indoor growth of *Lactuca sativa* L. (cv. 'Romana'), for 32 days after sowing. The study was conducted at the University of Bologna, inside a climatic cell(temperature ranging 21:18°C – day:night, and RH of 60-70%, CO2 of 410 ppm) equipped with light insulated compartments where the Photosynthetically Active Radiation (PAR) was provided by LED lamps featuring red (peak 660 nm) and blue (peak 440 nm) spectrum in a RB ratio of 3, photosynthetic photon flux density (PPFD) of 250 mmol $m^{-2} \cdot s^{-1}$ and a photoperiod of 16:8 hours (day:night).

During the growth cycle, three nutritional regimes were applied, by consecutive dilutions of the standard nutrient solution (EC in mS cm-1: 2.2, 1.5, 0.5) and the experimental scheme used was randomized blocks.Images were taken daily with a Nikon D7000 and processed with MATLAB software.The classification algorithm architecture involved the implementation of 7 interconnected layers with a total of 9.8 million parameters that the network learns for each image. The entire data set includes 405 images, the algorithm was trained for 150 epochs and 2 iterations per epoch, with a learning rate of 0.001. The performance was encouraging, with an accuracy rate of 81.8% and a loss rate of 0.05. The obtained results are promising, also considering the discrete number of images in the dataset and the few epochs with which the classifier has been trained and validated.

Keywords: Computer vision, Machine Learning, Image classifier, Autonomous nutrition.

PS02-26

Rosa 'Bonica 82' cuttings in aeroponic system: optimization of light spectrum for adventitious root formation

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Rosa 'Bonica 82' is a cultivar selected in France by Marie-Louise Meilland in 1982. It is a re-flowering shrub that produces pale-pink or white flowers depending on the temperature. This experiment aimed at evaluating the influence of additional doses of far-red light intensity on a red and blue ratio of 3 spectrum on rooting of rose cuttings . The cuttings were placed on a aeroponic system within the experimental vertical farm of Bologna University at controlled

environmental parameters (temperatures of 24/21°C and relative humidity of 65%/75%, day/night, and CO_2 concentration of 850 ppm). To prevent dehydration, cuttings were watered periodically with a nutrient solution but, to evaluate only the light effect on rooting, no rooting hormones were used. All cuttings were exposed to the same photoperiod of 16 hours of light and 8 hours of dark. Identical photosynthetic photon flux density (PPFD) of 100 µmol $m^{-2}s^{-1}$ and spectrum with a red and blue ratio of 3 was used. Four light treatments with increasing amount of far-red light were tested: 0 µmol $m^{-2}s^{-1}$ (as control), 30 µmol $m^{-2}s^{-1}$, 50 µmol $m^{-2}s^{-1}$ and 70 µmol $m^{-2}s^{-1}$ (resulting in Photon Flux Density, PFD, 100, 130, 150 and 170 µmol $m^{-2}s^{-1}$). Cuttings treated with additive far-red light presented a significant increase on root callus production between 10 and 15 days after the beginning of the treatments, as compared with control plants. The effect of additional far-red was validated through counting of the root callus production and the assessment of effective rooted cuttings.

Keywords: Rose, controlled environment agriculture (CEA), vertical farming, light spectrum, far-red.

PS02-27

Architectural design based on light performance of urban rooftop smart farm

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Climate change is causing a food crisis, and urban smart farms are a promising solution. Smart farms can reduce carbon emissions from buildings and produce self-sufficient food. Carbon dioxide and heat from the building's gas generator are introduced into the rooftop smart farm to be used for crop production and to reduce the cooling and heating load of the building. Fresh crops produced in the building can be provided at an affordable price, and this can also contribute to revitalizing the local economy and community by hiring local residents. Despite the advantages of rooftop smart farms, there is less architectural design or performance standard, so only simple glass greenhouses are installed. This study examines the environmental issues related to the expanded glass greenhouse on the rooftop and derives the optimal form of a smart farm for plant growth. The study utilizes the Rhino-based Plug-In, the Ladybug, for environmental performance simulations from the perspective of solar radiation. Based on the same area and volume of the building, simulations were conducted to determine the optimal shape in terms of floor shape ratio, growth bed arrangement, and louver shape. The study resulted in deriving the optimal smart farm form considering the solar environment. As a follow-up study, it is necessary to consider environmental factors such as airflow, heat, and humidity.

Keywords: Architectural design, light performance, rooftop, smart farm, evidence design.

PS02-28

Conditions and Directions to Distribute the Rooftop Greenhouse in Korea

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Humanity is facing all-round changes due to climate change. Changes in the weather environment due to global warming lead to changes in the cultivation environment and production of agriculture. Various studies have suggested countermeasures to climate change facing rural and urban areas at the same time. Among several countermeasures, urban agriculture is becoming promising method. The urban agriculture can reduce greenhouse gases emitted in the entire process of production and consumption by reducing distance between production area and consumption area. And the urban agriculture can attribute to promote urban amenity. In Korea, urban agriculture was introduced around 2010, and it is developing in the direction of utilizing building rooftops and vacant lots. Since 2020, many studies about rooftop greenhouses are being conducted as an alternative to a sustainable urban agricultural environment. However, in Korea, there are no laws and regulations on the combination of buildings and greenhouses. Previous studies in Europe suggested advantages of rooftop greenhouses such as agricultural production, the use of surplus thermal energy, rainwater storage, and rainwater utilize, and securing economic, emotional activities. The purpose of this study is to find a way to apply these advantages to Korea. In order to establish a new political system or modify the existing system in Korean, the evidence of universal interests is necessary. Therefore, this research suggests the concept that rooftop greenhouses can be of universal benefit to a large number of citizens. At the same time, the study also deals with solutions to safety, firefighting, landscapes, and conflicts with agricultural producers that may arise from installing greenhouses on rooftops. Ultimately, this study analyzes the positive value and negative conditions of rooftop greenhouses, and to suggest rooftop greenhouses as an alternative to settle on urban horticulture and agriculture in Korea.

Keywords: Climate change, Urban agriculture, Korea society, Building regulation, Universal values

PS02-29

Technology transfer from aquaculture to horticulture: rectangular sedimentation filter does not meet efficacy thresholds set for closed horticultural cropping systems

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Potentially propelled by the increasing interest in aquaponics, there is a growing interest in technology transfer from aquaculture to horticulture with respect to disinfestation of recycling nutrient solution. We tested the capacity of a rectangular sedimentation filter,

developed for aquaculture, to remove microconidia of *Fusarium oxysporum* f.sp. *cyclaminis* (*Focy*), zoospores of *Pythium aphanidermatum* (*Pa*) and vegetative cells of *Xanthomonas hortorum* pv. *pelargonii (Xhp)* in a plantless system. The filters were run at two flow rates (600 L h^{-1}, 6000 L h^{-1}). Efficacies were calculated after the first passage through the filter and 2 h, 4 h, 6 h and 24 h after introduction of the target organisms. Irrespective of flow rate, the filter's efficacy to remove zoospores of *Pa* was low (86–89% after 24 h) and did not meet the threshold of 99.9%. For *Focy* and *Xhp*, removal of microconidia and vegetative cells, respectively, was initially more efficient when the filters were run at the lower flow rate. For these two organisms, peak efficacies were first reached after 24 h of filtration irrespective of flow rate. Rectangular sedimentation filters need substantial improvement before the technology can be transferred to horticulture.

Keywords: closed system; Fusarium oxysporum f.sp. cyclaminis; hydroponics; Pythium aphanidermatum; Xanthomonas hortorum pv. pelargonii; zeolite.

PS02-30

How can high tunnel coverings and an insect-proof barrier improve productivity and pest management in berry crops?

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High tunnels are commonly utilized in organic berry farming for a better climate control and insect exclusion. Many growers in northern climates rely on these structures to extend the harvest season, reduce the incidence of plant diseases, and increase marketable yield and berry quality. This study aimed to compare the effects of five different coverings with varying light transmission properties (ranging from 77 to 91% light transmission; diffuse light of 18 to 70%; UV transmission up to 50%; infrared transmission bellow 15% to thermal film, anti-fogging, anti-dripping) and the impact of an insect netting barrier (3.45 m in height; mesh size of 0.243 x 0.773 mm)on the crop microclimate (light, temperature and humidity), pest pressure (leafhoppers, thrips, aphids, and *Drosophila suzukii*), photosynthetic performance (SPAD, Fv/Fm, Pindex), productivity and berry quality of container-grown raspberry (*Rubus idaeus* L. cv Imara) and blueberry (*Vaccinium corymbosum* L. cv Reka, Topshelf et Liberty) plants using an organic peat-based growing medium over two growing seasons. The results of the study showed that the differences in spectral quality and temperatures measured under the various coverings were not significant enough to observe any significant differencesinplant agronomic performance, including yield and fruit quality. However, significant variations were observed in the abundance of major pests for both raspberry and blueberry crops. Coverings with high photosynthetically active radiation (PAR) transmittance and low transmission of diffuse light, UV, and infrared radiation favored the populations of certain pests, such as aphids and leafhoppers, in raspberries. On the other hand, the insect netting barrier significantly

reduced aphid and spotted wing drosophila populations, demonstrating its potential as a promising pest control practice for organic producers. By combining an optimized covering that improves agronomic parameters and minimizes pest populations with an insect netting barrier, a sustainable alternative is achievable to reduce the reliance on certified organic or synthetic pesticides in the production of berries, whether organic or conventional.

Keywords: High tunnel, covering materials, raspberries, blueberries, yield, pest control, insect exclusion, insect barrier

PS02-31

The spread of *Botrytis cinerea* in green leaf lettuce *in vitro*

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Grey mold caused by the fungal pathogen *B. cinerea* has been considered a primary disease in greenhouse lettuce. The studies are needed to minimize yield, post-harvest and economic loss. Therefore, we evaluated the spread of *B. cinerea* infection by different inoculation methods of greenhouse-grown green lettuce 'Little Gem'. The leaves of 14 days of lettuce were transferred to a Petri dish (one leaf each) with sterile filter paper and 5 mL of distilled water. The artificial inoculation of lettuce leaves with *B. cinerea* isolate was done in three ways: (1) injection of pathogen suspension to the midrib or (2) droplet of suspension on leaf surface near midrib (20 µL containing 104 conidia mL^{-1}), and (3) inoculation with a mycelial disc (7 mm) on the leaf blade. The Petri dishes were placed in the thermostat at 22°C in the dark. The spread of the pathogen infection was measured as the percentage of the damaged leaf area at 1, 3, 5, and 7 days after inoculation (DAI). The results showed that the inoculation method influenced the spread of infection on lettuce leaves. In leaves inoculated by mycelial disc, the infection spread consistently over time, and the lesion was almost 47% of the leaf area at 3 DAI. In comparison, the spread of the infection in leaves inoculated by a droplet of spore suspension was similar at 7 DAI. The inoculation with spore suspension in the mid vein led to a 90% damaged leaf area of lettuce at 7 DAI. According to the results, the most suitable method for the early detection of *B. cinerea* in green leaf lettuce is inoculation by the mycelial disc on the leaf blade. Acknowledgment: This research was funded by a grant (No. P-MIP-23-431) from the Research Council of Lithuania. The management of mineral nutrition to control the quality andsafety of post-harvest leafy vegetables (NutriSafe).

Keywords: Artificial inoculation, fungal disease, grey mold.

PS02-32

Determination of weight on index indicating seedling quality using AHP (Analytic Hierarchy Process) in tomato

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Seedling quality is a key to improve crop productivity as a starting point in agriculture. However, the standard about good quality including the index and the range remains to be studied, because it's difficult to prove the relationship between seedling quality and crop productivity due to the complexity of various factors and long cultivation period after seedling is planted. AHP (Analytic Hierarchy Process), a method for evaluating multi-criteria and aggregating subjective judgements, is used to determine the weight on the index of seedling quality in tomato. After selecting 10 main indexes used in nursery farm, 18 farmers were surveyed on the relative weight comparing the indexes one by one on the 1-9 scale. The average career of respondents as nursery farmers was 17.6 years, and 61.1 % of them majored in crop or horticulture science. Some answers that had inconsistency were corrected, and the geometric mean of the answers was used to calculate the weight of the index using AHP. As a result, consistency ratio was 0.0097, which meant the answers were consistent. To assess seedling quality, whether seedling is damaged or not by disease and insects (relative weight = 0.2733) was the most important in tomato. In order of importance, the weight of indexes was uniformity of seedling height in a tray (0.2005), age of seedling (0.1051), seedling height (0.0962), height of flowering node (0.0761), number of node (0.0689), stem diameter (0.0609), color of leaves (0.0444), number of leaves (0.0431), and leaf area (0.0315). Besides, the proper range for good seedling was also surveyed in tomato. If combining the weight of the index from this study with the proper range, it can digitize seedling quality and prescribe good quality objectively. Moreover, to develop an analyzing system for seedling quality, measuring seedling quality rapidly and conveniently using image with movable camera, the result can be standard of good seedling quality.

Keywords: Analytic Hierarchy Process, Seedling quality, Weight, Standard

PS02-33

Comparison of various crop models in greenhouse CFD model design: Porous medium model and 3-dimensional crop structure model

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Computational fluid dynamics (CFD) is a method of analyzing and solving problems with fluid flows using numerical analysis and data structures. CFD is applied in various industries, especially in agriculture, which is important in analyzing the internal environment of the greenhouse. The internal environment of the greenhouse appears by complex interaction of various factors such as crops, solar radiation, soil, ventilation and so on. In particular, the crop model is very important in the CFD model because the sensible heat, latent heat, and

transpiration depend on the crop, and the internal air flow is also affected by the shape of the crop. Many CFD studies on greenhouses have been conducted, and various models have been developed to realize greenhouses. Initially, it was simply implemented as a limitation of technology, but as software and hardware technologies developed, it became possible to reflect more details. However, until recently, in most greenhouse CFD models, crop models were designed as porous medium models. The porous medium is a state where there are many small holes on the surface or inside. It can be designed by simplifying a model with a complex internal shape. According to previous studies, the CFD model using the porous medium model was also able to simulate the temperature, humidity, and air flow of the greenhouse with high accuracy. However, the Porous medium model cannot implement the crop surface temperature which is important for crop growth, and there is a limit to the evaporation and transpiration amount. Also, it is difficult to analyze the degree of natural light and the air flow rate near the crops. Therefore, in this study, the difference was analyzed by designing a porous medium model and a 3-dimensional crop structure model for tomatoes that have been studied a lot based on previous research.

Keywords: Computational fluid dynamics (CFD), Crop model, Greenhouse, Porous medium, 3-dimensional crop structure.

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PS03-01

Performance of a home plants factory (easy) for indoor lettuce production using computational fluid dynamics

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It is estimated that 60% of the world's population lives in urban areas, and it is projected that by 2050 this will increase to 80%. In México, the population movement indicates that it can reach 150.8 million people. Meeting the needs of more people meant a great challenge for the ability to manage and restore the natural environment on which basic life processes depend. The question of how to feed future cities finds alternatives in urban agriculture. Plant factories, vertical farms, rooftops, and green walls are some of the agricultural production techniques with a substantial increase in this decade. The reintegration of food production in cities offers opportunities to meet the challenges. Urban agriculture is driven by the desire to reconnect food production and consumption. The objective of this work is the diffusion of urban agriculture as a consequence of a growing awareness of how food and agriculture can shape today's cities. Particular aspects are presented for the importation of indoor crops and their basic physiological, climatic, and management requirements.

Computational fluid dynamics (CFD) gave certainty about climatic requirements in a basic Plant Factory with Artificial Light to produce salad plants in a kitchen. This proposal is also called Home-PFAL. CFD simulations showed that temperature, humidity, and wind are within the range of crop requirements in a kitchen. The main factor for management is the photoperiod with LEDs lights.

Keywords: Climate control, horticulture, dynamic model, Smart cities.

PS03-02

Implementation of ventilation towers in a greenhouse at the end of a slope: Numerical approach to natural ventilation behavior

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In a low and medium-technology greenhouse, the internal temperature depends on the external climate, material, design, orientation, location, and crop type. The ideal temperature in a greenhouse varies depending on the crop and its phenological stages (the minimum temperature required for a tomato is 10 °C, while 30 °C could be the maximum temperature at which the plant develops naturally). The objective of this work is to evaluate the current conditions of the greenhouses and simulate the effect of the implementation of ventilation towers on temperature. The environmental variables were monitored by installing temperature and relative humidity sensors inside the greenhouse and a weather station outside. The record of environmental variables shows that during certain hours of the day, the temperature inside greenhouses is close to 40 °C. This increase is caused by the location and obstruction of greenhouse windows (the proximity of some buildings and the distance between greenhouses). For the simulations, a computational model based on Computational Fluid Dynamics (CFD) was built and used to analyze the thermal effect of the windows' obstruction and the greenhouse's location. In addition, the implementation of ventilation towers was proposed to reduce the thermal gradient between the exterior and interior, increasing the airflow to the interior of the greenhouses. The simulations' results show that the windows' obstruction and the greenhouses' location cause a thermal gradient between the exterior and interior of up to 10 °C, generating temperatures outside the maximum threshold for tomato cultivation.

Keywords: CFD, simulation, climate, warm period.

PS03-03

Cross-laminated timber wall design and energy consumption analysis

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Cross-laminated timber is considered one of the innovative ideas that can reduce carbon emissions and energy consumption. In addition, cross-laminated timber is an energy-intensive and environmentally friendly building material using wood. Cross-laminated timber is a wood material bonded by crossing wooden boards and shows excellent insulation and airtight performance. In addition, cross-laminated timber has high strength and rigidity to construct high-rise wooden structures. Cross-laminated timber is continuously being researched and developed in construction as it can be used for walls, floors, and roofs. In this paper, cross-laminated wooden walls for mid-rise apartments proposed in ASHRAE 90.1 were designed. The energy consumption of the building to which it was applied was analyzed using building energy simulation. The wall design was constructed using four different insulation materials, including expanded polystyrene foam and glass wool, and the most energy-efficient wall was derived. The most energy-efficient wall was a wall with rock wool, and a cross-laminated timber building with rock wool and energy-saving technology could reduce energy consumption by about 14%. In particular, heating energy consumption in winter was reduced by up to about 36%, and it was confirmed that the cross-laminated timber walls had excellent insulation performance. Cross-laminated timber buildings can be an alternative to reducing energy consumption in the building sector.

Keywords: Cross-laminated timber; Energy simulation; Wall design; Energy consumption.

PS03-04

Proposal of revitalization plan through analysis of building greening technology trend and policy status in Korea

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In Korea, building greening is used as a term to collectively refer to gardening spaces that are installed on or connected to the exterior of a building, such as the roof or wall of a building. In particular, the reality of Korea, where the population is concentrated in cities (91.8% of the total population resides in urban areas, which occupy 16.7% of the country's land as of 2021), is a situation in which the introduction of natural elements in urban areas is urgently needed. Building greening is not only a practical countermeasure against urban heat islands and urban floods in modern cities that are being developed with high density but also serves as an urban architectural solution to respond to climate change, such as securing a carbon storage role in downtown areas, reducing fine dust, and increasing land use rates. It does an excellent job as an alternative. In addition, it is possible to secure the effects of ecological services, such as the expansion of contact with nature and the emotional stability of urban residents, and it can be said that it is a technology field whose role can be expanded to the aspect of securing food resources when linked with urban agriculture. In this study, despite

these positive effects, we tried to analyze the main reasons why building greening in Korea was not activated and to suggest alternatives through various analyses regarding technology and institutions (policies). At the same time as looking at the trend of changes in greening technology to adapt to Korea's climate environment, we analyzed success/failure cases of building greening vitalization policies based on regional characteristics at home and abroad and derived policy elements that can be used in common. Through this, we propose a direction in which Korea's building greening can be activated, suggest a development direction for element technologies necessary for this, and at the same time, suggest a plan to quantify various effects, which is a keyword that can revive Korea's building greening industry.

Keywords: Revitalization plan; greening technology; policy status.

PS03-05

Thermal behavior and leaf temperature in high pressure sodium lamp supplemented greenhouse

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High-pressure sodium (HPS) lamps have been widely used as a useful supplemental light source to emit sufficient photosynthetically active radiation and provide radiant heat, which contributes to the heat requirement in greenhouses. This study aims to analyze the thermal characteristics of HPS lamps and the thermal behavior in a supplemented greenhouse and evaluate the performance of a horizontal leaf temperature of sweet pepper plants using computational fluid dynamics (CFD) simulation. We simulated horizontal leaf temperature on the upper canopy according to three growth stage scenarios, which represented 1.0, 1.6, and 2.2 plant height, respectively. We also measured vertical leaf and air temperature accompanied by heat generation of HPS lamps. There was a large leaf-to-air temperature differential due to non-uniformity in temperature. In our numerical calculation, the thermal energy of HPS lamps contributed 50.1% of the total heat requirement on Dec. 2022. The CFD model was validated by comparing measured and simulated data at the same operating condition. The mean absolute error and root mean square error were below 0.5, which means the CFD simulation values were highly accurate. Our results about vertical leaf and air temperature can be used in decision-making for efficient thermal energy management and crop growth.

Keywords: computational fluid dynamics, conjugate heat transfer, temperature differential, Heat gain model, supplemental lighting.

PS03-06

Development of green building certification system for sustainable building-integrated greenhouse

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A building-integrated greenhouse can utilize the synergistic effect of a building and a greenhouse. Buildings can save energy through greenhouses, and greenhouses can reduce cultivation energy through energy left over from buildings. To reduce greenhouse gas emissions from buildings, a building-integrated greenhouse is becoming an alternative. The certification system for buildings is operating a system for each country worldwide. However, a program that can evaluate building-integrated greenhouses has not been activated. The purpose of this study is to analyze the application of sustainable greenhouses to the existing certification system and to develop a system that can evaluate them. The existing certification system targeted G-SEED (Green Standard for Energy and Environmental Design) operated in Korea, and the building certification system operated by each country was comprehensively analyzed. In order to apply to the existing operating system, first, a review of the operation system and second, a review of certification items should be conducted. Regarding the evaluation system, it can be reviewed as a method for establishing a new standard for the use of building-integrated greenhouses and a method for adding certification items to the existing system. New items that can be added as certification items include greenhouse characteristics and management plan, annual energy consumption, annual total waste, annual water consumption, impact on the environment around the greenhouse, heat island reduction, habitat protection, energy, water, and waste data tracking.

Keywords: green building certification, building-integrated greenhouse, G-SEED.

PS03-07

The performance of semi-transparent photovoltaics in the field of greenhouse systems

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By 2050, when the global population approaches 9 billion, agricultural production should increase by over 70%, according to the Food and Agriculture Organization of the United Nations. For addressing the particular circumstance, greenhouse systems, which may boost output even in off-season crops without losing quantity or quality, might be very convenient. On the other hand, it is impossible and unavoidable to ignore the enormous energy consumption of greenhouses, which may account for up to 50% of the cost of the product produced, whether for heating, cooling (during cold or hot seasons, respectively), and artificial lighting. At the same time, it is crucial that the energy used is produced from

environmentally friendly sources, such as solar energy, also known as Renewable Energy Sources (RES), given the severity of climate change caused by the use of fossil fuels for energy production. Simultaneously, with the demand for land constantly increasing, both spatial and economic issues are created. Thus, it is suggested that a very suitable alternative for the production of both energy and food is to put semi-transparent photovoltaics on the roof of each construction unit of a greenhouse in lieu of the current cover, resulting in a twofold use of the land. Regarding the proposed PV system, it consists of innovative semi-transparent photovoltaic glasses, which in contrast to conventional opaque photovoltaics, integrate energy production with the natural illumination of the greenhouse. The flexibility of these photovoltaics to let visible wavelengths (Photosynthetically Active Radiation, or PAR) enter the greenhouse environment gives significant advantages for plant growth as this region of light is employed during the biological process of photosynthesis. At the same time, bearing in mind the increased energy needs of a greenhouse, the need for energy autonomy, but also the uncertainty that characterizes RES, an MPPT solar charger has been chosen, which largely covers the above points, by maximizing the energy extraction as conditions vary.

Keywords: Solar energy, Renewable energy, greenhouse cover.

PS03-08

Analysis of Energy Load for Semi-closed Greenhouse with Hydrogen Fuel Cell Technology Based Trigeneration System using BES

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A semi-closed greenhouse is a greenhouse that creates a suitable cultivation environment for crops by combining the incoming outside air with the inside air that exists in an enclosed space, and the operation of air conditioning and heating devices is essential. About 92% of fossil energy is used as an energy source for the operation of the cooling and heating systems of these facilities. However, fossil fuels are being depleted worldwide. As a result, interest in renewable energy, which is an alternative resource, is increasing. In Korea, technologies for applying hydrogen energy utilization technology among new and renewable energy to agricultural facilities are being developed. In order to apply the hydrogen fuel cell to agricultural facilities, it is necessary to calculate the energy required for heating and cooling the greenhouse and calculate the appropriate capacity of the hydrogen fuel cell accordingly. Therefore, this study tried to calculate the appropriate cooling and heating capacity for the application of transportation fuel cells through dynamic energy load analysis for semi-closed greenhouses. The energy exchange and load of the greenhouse were dynamically analyzed using building energy simulation, and among several commercial programs, TRNSYS (Ver. 18, SEL, USA) was used. A dynamic energy exchange model was designed by realizing perfusion heat transfer, ventilation heat transfer, and ground heat

transfer in buildings and energy exchange in crops and soil. The crop for dynamic energy analysis is tomato and a 10-year cooling and heating load analysis was conducted in the Jeonju area using the designed model, and the dynamic energy load analysis of the target greenhouse was conducted.

Keywords: BES, semi-closed, greenhouse, energy load, Hydrogen Fuel Cell Technology Based Trigeneration System.

PS03-09

Optimized sunlight use in greenhouses with Agri-Photovoltaic

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Greenhouses' high energy consumption results in 2 issues: energy cost and carbon footprint. Photovoltaic (PV) solutions integrated on greenhouse surfaces tackle both issues. However, existing agrivoltaics solutions capture parts of the sun's incidence and transform it into electricity, which causes partial shading. This is incompatible with most greenhouse crops, as it reduces agricultural yield. The spectral splitting photovoltaic system of Voltiris is an innovative solution for energy production in greenhouses without affecting food production. Practically, the system filters spectrally sunlight: the light components required by plants to grow, i.e., the 'useful' colors, are left untouched and transmitted to the plants, while the other 'wasted' colors are focalized on a photovoltaic module to generate electricity. In this way, the entire light spectrum is utilized on existing greenhouse structures; the technology causes less than 10 % partial shading. Moreover, with continuous and dynamic tracking of the Sun, electricity production is optimized. In this study, a prototype was installed at Agroscope in Conthey (CH) and analyzed during the growing season in 2022. The impact of the solution has been quantified in terms of plants' growth, development, and yields of the different crops tested: tomato, bell pepper, basil, and salad. On all crops, no significant impact has been observed on plant growth, yield, and fruit quality. In addition, electrical measurements were realized to quantify the expected energy production and showed that the power output was two times higher than the standard PV panel oriented south. Greenhouse production must also undertake a transition to 'greener' energies. This innovative technology contributes to achieving the target of carbon-neutral greenhouses in Switzerland by 2050 by promoting the effective production of renewable energy.

Keywords: Agriphotovoltaic, greenhouse, tomato, basil, spectral filtering.

PS03-10

Analysis of High-temperature Air Environment of Wide Span Type & Semi-closed Greenhouses

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In recent years, abnormal climate phenomena have been getting worse all over the world. Abnormal weather conditions, such as extreme high temperatures in summer and cold waves in winter occur frequently, and damage to agriculture is also increasing. As the damage to agriculture increases due to abnormal climate, the importance of facility horticulture, which is less affected by the external environment, is gradually emerging. In the case of summer, vinyl houses and glass greenhouses have limitations in lowering the high temperature by methods such as ventilation, fog mist cooling systems, and shading curtains. Accordingly, wide span type greenhouses and semi-closed greenhouses are emerging as greenhouses to overcome high-temperature environments. However, an aerodynamic analysis is required to determine whether these greenhouses are suitable for high-temperature environments. Since airflow is invisible, it is difficult to predict through sensor measurement, but airflow simulations such as computational fluid dynamics can predict and visualize the aerodynamic flow of fluid by interpreting the laws of physics. Therefore, in this study, computational fluid dynamics was used to design a wide span type greenhouse and a semi-closed greenhouse, and analyze the air environment in the high-temperature period according to the ventilation method. For accurate analysis, based on meteorological data of the United Arab Emirates, which is a high-temperature environment, the external wind environment, sensible and latent heat equations of crops, and air resistance values of crops were investigated and entered as boundary conditions in CFD. For the ventilation method, natural ventilation and forced ventilation method using FCU and fog system were selected as simulation cases, and simulation analysis was conducted according to the ventilation method. Through the analysis of the high-temperature air environment of the wide span type greenhouse and the semi-closed greenhouse, it was possible to evaluate whether wide span type greenhouse and the semi-closed greenhouse were suitable for the high-temperature environment. It was judged that it would be possible to suggest an optimal operation plan for a greenhouse suitable for a high-temperature environment.

Keywords: CFD, wide span type, semi-closed, greenhouse, high-temperature.

PS03-11

CFD analysis of environmental uniformity in seedling factories

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Seedling factory is important to stably supply seedlings for large-scale greenhouse systems and smart farming. Appropriate environmental control can protect plant disease and save energy for improving thermal uniformity and suitability. It is difficult to control the internal environment

in the seedling factory with a multi-stage cultivation system due to invisible air flow pattern. Therefore, this study aims to analyze aerodynamic characteristics in the seedling factory by using computational fluid dynamics to improve the environmental control system in terms of uniformity. The seedling factory was operated by a mechanical ventilation system isolated from the outside. To analyze the thermal condition, multiple temperature and humidity sensors were installed in each stage vertically and horizontally. CFD model was designed and validated by the value of 0.84 using realizable k-e turbulence models, which showed the highest correlation. CFD simulation showed that the air conditioner interfered with the flow of the humidifier in the center of the plant factory, forming an uneven distribution pattern inside. The humidified air showed accumulation on the ceiling due to buoyancy. Through this study, a plan to improve the atmospheric environment inside the seedling plant was considered, and the validated model will be used as basic data to analyze the effect of the improved seedling plant.

Keywords: Aerodynamics, Greenhouse, Thermal uniformity, Seedling.

PS03-12

Greenhouse vegetable production from the point of view of climate change

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Greenhouse vegetable production has recently been increasingly popular to extend the growing season and improve crop yields and product quality. However, this method of plant cultivation has potential impacts on the climate. Here, we explore the relationship between greenhouse vegetable production and climate change, including this type's potential benefits and drawbacks. Protected cultivation could enhance energy efficiency and reduces carbon emissions from transportation, e.g., when situated in urban agriculture. Additionally, greenhouses can allow for more efficient irrigation systems, e.g., by using soilless culture systems, which can conserve water. On the other hand, greenhouses are typically heated with fossil fuels, which releases carbon dioxide and other greenhouse gases into the atmosphere. Additionally, synthetic fertilizers and pesticides can also contribute to greenhouse gas emissions. Therefore, renewable energy sources should be used to mitigate the climate impacts of greenhouse vegetable production. For instance, integrating novel photovoltaic systems in greenhouse production can significantly reduce carbon emissions and energy consumption by providing a sustainable energy source for heating and lighting. Additionally, reducing synthetic fertilizers and pesticides can decrease greenhouse gas emissions. In conclusion, protected cultivation production can mitigate the effects of climate change; however, it also can contribute to climate change. To minimize adverse effects on the climate, it is crucial to utilize renewable energy sources and implement sustainable farming practices such as integrated pest management and organic farming.

Further research is needed to fully understand the relationship between vegetable-protected cultivation and climate change and identify the most effective ways to decrease the climate impacts of this type of production.

Keywords: vegetable production; climate change, renewable energy sources, sustainable production systems.

PS03-13

CFD analysis of the effect of external obstructions on the natural ventilation of greenhouses

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Adequate natural ventilation in low and medium-technology greenhouses causes the thermal gradient between the outside and inside of the greenhouse to be minimal. A correct selection of materials, design, and orientation at the moment of the structure's construction is fundamental to taking advantage of the wind. However, there are areas where greenhouses are located very close to each other or where buildings obstruct ventilation. Studying these types of situations is necessary to develop actions to improve the greenhouse environment. The objective of this work is to evaluate the ventilation in greenhouses with obstacles around them. Wind direction and temperature behaviour were compared by simulating the presence of barriers at different distances and their absence. The results show that wind and temperature trajectories are modified by placing obstacles near the windows.

Keywords: Environment, temperature, comfort.

PS03-14

Impact of a rooftop greenhouse on building cooling and heating energy of a commercial building using building energy simulation (BES) model

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Climate change and urbanization have been weakening the conventional agriculture, thus the demand of new agricultural method such as urban agriculture, is recently increasing fast. Urban agriculture has diverse advantages such as the reduction of storage and shipping costs while increasing crop freshness. However, there are challenges in facilitating urban agriculture system. Cultivating in urban area inevitably increases energy consumption in the

city, and it is also difficult to secure enough space for farming. In this study, we are focusing on a rooftop greenhouse as a type of urban agriculture. The rooftop greenhouse utilizes empty rooftop space of city buildings, so additional land space is not required. Furthermore, thermal energy can be actively exchanged through rooftop surface of a building with the rooftop greenhouse. It can reduce required cultivating energy in the rooftop greenhouse, and can affect cooling and heating energy of the building.

In this study, the impact of a rooftop greenhouse on building's cooling and heating energy has been analyzed. Building energy simulation (BES) model was developed for an 8-story building including the rooftop greenhouse. Target building was modeled based on the existing building located in Seoul, South Korea. Using the developed model, the heat exchange patterns through the rooftop surface and the accompanying changes in energy consumption have been examined under various operating conditions and ambient weather conditions. The result can be used to suggest optimal operating strategy of the rooftop greenhouse in the aspect of saving energy consumption of the building and the greenhouse.

Keywords: Rooftop Greenhouse, Building Energy Simulation, Building Energy, Green Building.

PS03-15

Analysis of odor patterns in swine manure according to feed type

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The odor emitted from swine farms is a serious problem that causes great damage to nearby residents and hinders the development of the swine industry. It is very important to understand the chemical composition of the odor and the concentration of the odorous substance. Feed has a great influence on the composition of swine manure, which is the principal cause of odor. Therefore, the purpose of this study is to find a form of feed suitable for reducing odor by changing the processing and calorific composition of feed that directly affects the composition of swine manure. The experiment was conducted on 15 pigs from July to August 2021, and a total of three measurements were done. Three types of feed (A type: powder & general calorie feed, B type: pellet & general calorie feed, C type: pellet & low calorie feed) were evaluated in this study. The analysis items related to odor of swine manure are complex odor, ammonia, sulfur-based odors, and VOCs. In the case of complex odor, dilution multiples tended to decrease over time, except for type A feed. The concentration of ammonia in all types of feed decreased over time. Most sulfur-based odorous substances except hydrogen sulfide at the first measurement were not detected. Representatively, Decane, 2,6-Dimethylnonane, and 1-Methyl-3-propylcycolhexane were detected in VOCs generated from swine manure. The main substances affecting the degree of swine manure odor were initially ammonia and sulfur compounds. However, by four weeks, the ammonia and sulfur compounds disappeared and VOCs turned into major

odorous substances. In order to effectively reduce the odor caused by swine breeding activities, based on the results obtained from this study, it is advantageous to use low-calorie feed consisting of pellet-type, and it is considered that the manure in the swine farm should be treated before the second week of decomposition.

Keywords: complex oder, ammonia, sulphur-based odorous substances, vilatile organic compounds.

PS03-16

Evaluation of the effectiveness of disinfectants to reduce bacteria – focusing on meat processing

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Purpose: This study aims to evaluate the efficiency of disinfectants used in the Korea's meat processing industry to reduce bacterial exposure of Korean meat processing workers and use them as basic data for establishing work environment management measures.

Method: Disinfectants used by Korean meat processing workers were selected as evaluation targets. Thirteen types of disinfectents were selected to investigate the bacterial reduction effect. In order to compare the sterilization effect of the disinfectents, bacterial suspension and surface disinfection tests were conducted. Pork conductors, cutting boards, benches and conveyor belts have been selected for surface sterilization testing.

Results: As a result of the bacterial flotation experiment, the bacterial reduction efficiency of all disinfectants was more than 80%. Among them, chlorine disinfectants were found to have the highest bacterial reduction efficiency. As a result of the surface sterilization test of pork conductors, the reduction rate of disinfectants made of QAC (quaternary ammonium compound) was the highest. As a result of testing the plastic cutting board, chlorine disinfectants were found to have the best sterilization effect. As a result of the stainless steel bench experiment, chlorine dioxide and QACs disinfectants had the best bacterial reduction efficiency, and conveyor belts made of urethane had the best sterilization effect among QACs disinfectants.

Conclusion: In this study, the disinfection power of disinfectants against bacteria generated in Korea meat processing plants was evaluated. In the bacterial flotation experiment, all disinfectants were found to be effective, and in particular, chlorine disinfectants were found to be effective. In the surface sterilization experiment, the sterilizing agent containing QAC as the main component was excellent.

Keywords: Bioaerosol, bacteria, disinfectants, sterilization efficacy, livestock industry.

PS03-17

Effects of nutrient media and temperature on botrytis cinerea pers. Variability

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The contamination of leafy vegetables by fungal pathogens may occur from seed to edible plant parts. The Botrytis spp. is a fungi cosmopolite that infects leafy vegetables during growth, harvest, postharvest and logistics. Especially the conditions – relatively low temperatures and high relative humidity during postharvest and logistics, are suitable for spreading fungal pathogens. This study aimed to evaluate *Botrytis cinerea* variability on different nutrient media and temperatures. The B. cinerea variability was evaluated on various nutrient media: potato dextrose agar (PDA), universal beer agar (UBA), Czapek-Dox agar (CDA), pectin agar (PE) and plate count agar (PCA). The research was conducted in a growth chamber with controlled 10, 15, and 20 oC temperatures and 24 h dark or light period for 30 days and evaluated fungal colony growth (mm) and sclerotia formation time (days). The results showed morphological differences among the nutrient media, light/dark period, and different temperatures. The sclerotia did not form at 10 oC in both light/dark periods on PDA, CDA and UBA media. The best conditions for sclerotia formation were on PCA media in both light and dark at 20 °C and on PDA and PE at light at 20 °C. The lowest mycelium growth was after 4 DPI growth at 10 oC at various nutrient media. The highest growth was on UBA at light 15 oC and PDA at dark 20 oC. According to these results, it can be assumed that the temperature, nutrient media and light period affect B. cinerea variability. This research was funded by a grant (No. P-MIP-23-431) from the Research Council of Lithuania (LMTLT). The management of mineral nutrition to control the quality and safety of postharvest leafy vegetables (NutriSafe).

Keywords: Czapek-Dox agar, Grey mould, Mycelium, Potato dextrose agar, Sclerotia.

PS03-18

Effect of a high transmittance film cover on agronomic and microclimatic plant parameters in a greenhouse tomato crop

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The increase of transmittance to photosynthetically active radiation (PAR) of the greenhouse cover improves photosynthetic activity and consequently can enhance crop yields. The changes in the light reaching the crops could influence the microclimate inside the greenhouse and affect the development of the crop and some fungal diseases. The main objective of this study was to compare a standard film cover with a high transmittance

experimental film cover on growth, yield, fruit quality and microclimatic plant parameters of a tomato crop (*Lycopersicum esculentum* Mill.). The experiment trial was carried out inside a multispan greenhouse located in the Centre for Innovation and Technology Transfer "UAL-ANECOOP Foundation" in Almería (Spain). The naturally ventilated greenhouse (1800 m^2) was divided transversely by a polyethylene sheet, creating two isolated sectors. The experimental cover film (90% transmittance) was installed in the West sector while the standard film (85% transmittance) was located in the East sector. On 8 September 2021, a tomato crop of variety 'Ramyle' was transplanted with a density of 1.2 plants/m^2. The use of experimental film cover increased PAR radiation by 6% (not statistically significant). Leaf temperature increased by 5.4% in plants grown under the experimental film in comparison to the standard film, with statistically significant differences. The results of the tomato crop production show an increase in marketable and total yield of 0.21 kg/m^2 (+4.2%) and 0.15 kg/m^2 (+2.2%), respectively, in the West sector with experimental film cover. No significant differences were observed in any of the plant growth parameters (length and thickness of the stem, number of nodes and length of internodes) or fruit quality (weight, fruit diameter, firmness, soluble solids content, dry matter and colour parameters).

Keywords: protected crop, yield, PAR radiation, growth, fruit quality.

PS03-19

The energy balance in a mezcal process by analyzing the cooking system of "Pinia"

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Cooking the heart of agave (Pineapple) inside soil using wood as fuel is a traditional method that has been used for centuries in the mezcal process. To understand the energy balance involved in this process and ensure efficient cooking, an energy balance model with a mass balance goal is developed by recording data in different buried points. The model takes into account the inputs and outputs of the system, including the wood used as fuel, the material to be cooked, the heat generated by the combustion, and the heat transferred to the different system components. The energy content of the wood and the calorific value are used to calculate the energy generated by the combustion. As a result, the heat transferred to the food and soil is calculated using the specific heat capacity of the food and soil and the difference between their initial and final temperatures. The heat lost to the surroundings is calculated using the surface area of the system, the heat transfer coefficient, and the difference between the temperature of the system and the surroundings.

Keywords: Data recording, temperature, mass balance, heat, 3D geometry.

PS03-20

Biostimulants and inductors for the control of some stress variables in tomato (*Solanum lycopersicum* Mill)

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Tomato production in México and in the world has been affected by different stress factors, both biotic and abiotic, causing decreasing in volume, quality and economic value in production. In order to evaluate the effect of foliar application of biostimulants and resistance inducers on some biotic and abiotic stress, variables reflected in the blotchy ripening of the fruit in tomato (*Solanum lycopersicum* Mill), the severity of mildew (*Leveillula taurica*) and the incidence of *Clavibacter michiganensis* subsp. *Michiganensis*; six commercial products containing biostimulants and stress resistance inducers as active ingredients were evaluated, including a control (without application) in a greenhouse at the Chapingo Automous University, México in 2022.

The analysis of variance indicated that in the variable number of blotchy ripening fruits there was no significant difference between treatments, although the DEFENSE GR treatment at 3g/l + SUPA SILICA at 2 ml/l (P_2O_5 + amino acids + SiO_2 + K_2O) reduced in 10% the damage in relation to the control. The damage by *L. taurica* according to the Kruskal-Wallis test reported that the best treatment in relation to the control was DEFENSE GR at 3g/l + BARRIER at 7 ml/l (P_2O_5 + amino acids + CaO) with an average range of infection of 25.3% and 59.5%, respectively. The treatments with the lowest average number of dead plants due to *C. michiganensis* subsp. *michiganensis* was the one that contained acibensolar-s-methyl + silicon with 0.75 plants against 6.75 of the control.

Keywords: bio-stimulation, inducers, stress, silicon, systemic resistance, physiologic damage.

PS03-21

A Sustainable Greenhouse Business Model – A Way to Transform the agricultural landscape of Central Europe

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The Central European market is witnessing a growing need for sustainable agricultural practices to address environmental concerns, meet rising population demands, and adapt to the challenges posed by climate change. In this context, the greenhouse business model can emerge as a crucial solution to promote sustainable and efficient farming methods in the region. This abstract highlights the importance of the greenhouse business model and its significant role in transforming the agricultural landscape of Central Europe.

Greenhouses provide controlled environments that optimize crop production, resource efficiency, and environmental sustainability (Smith, 2020). By implementing techniques such as hydroponics and aeroponics, greenhouses offer favorable conditions for plant growth while minimizing water usage, fertilizer application, and pesticide reliance (Monzon et al., 2021). This model reduces the environmental impacts associated with traditional open-field agriculture, such as soil degradation, water pollution, and vulnerability to extreme weather events (Kumar et al., 2021).

The geographic location and climatic characteristics of Central Europe, characterized by seasonal variations and limited arable land availability, make greenhouses an ideal solution for year-round crop cultivation (Gulyás et al., 2020). Greenhouses enable farmers to extend growing seasons, protect crops from adverse weather conditions, and increase overall productivity (Körner et al., 2019). This advantage is particularly significant for high-value crops like fruits, vegetables, and herbs that are in high demand within the region (Malinowski, 2019).

Furthermore, the greenhouse business model aligns with Central Europe's commitment to sustainable development by reducing greenhouse gas emissions and conserving energy (Tóth et al., 2021). Integration of renewable energy sources, such as solar panels and geothermal systems, enables greenhouses to operate with a lower carbon footprint (Tsirogiannis et al., 2020). This is in line with Central Europe's sustainable development goals, environmental stewardship, and efforts to mitigate the impacts of climate change (Rizos et al., 2021).

The adoption of the greenhouse business model in the Central European market offers economic opportunities and benefits. Local production of fresh and high-quality crops reduces dependence on imports and supports domestic agricultural sectors (Mărcuş et al., 2021). Additionally, the demand for greenhouse technologies stimulates innovation, research, and development, fostering job creation, knowledge exchange, and economic growth within the region (Turek et al., 2021).

Addressing challenges such as initial investment costs, technical expertise, and market acceptance is crucial for the successful implementation of the greenhouse business model in Central Europe (Gajc-Wolska et al., 2022). Collaboration between governments, agricultural organizations, research institutions, and private sector stakeholders is essential to overcome these barriers and create an enabling environment for greenhouse farming (Tóth et al., 2021).

In conclusion, the greenhouse business model holds immense importance for the Central European market as a pathway to sustainable agriculture. By integrating advanced technologies, minimizing environmental impacts, and enhancing crop productivity, greenhouses offer a viable solution to meet the region's increasing demand for locally grown, high-quality produce. Embracing this model can lead to economic prosperity, environmental conservation, and improved food security, ultimately transforming the agricultural landscape of Central Europe.

Keywords: Greenhouse, Business Model, Sustainabile Greenhouse Business.

PS03-22

Influence of Silicon application on the agronomic and nutritional performance on container grown highbush blueberries

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PS03-23

Optimizing Nitrogen Availability for Organic Greenhouse Cultures: A Study on Various Organic Fertilizers and Growing Media

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In organic greenhouse farming, substantial amounts of nitrogen (N) are needed to fulfill the nutritional requirements of plants and achieve optimal yields. The process of mineralization plays a crucial role in converting the organic N found in organic fertilizers into inorganic forms, such as NH4 and NO3, through the activity of nitrifying bacteria present in the growing media (GM). However, the current understanding of N mineralization has primarily focused on field or greenhouse soil cultivation, with limited research conducted on soilless organic systems.

To address this gap, our project focused on studying the in vitro mineralization dynamics of organic fertilizers in different peat-based GM. We hypothesized that the addition of wood fiber to the GM would provide benefits due to its physicochemical and biological properties. We also assumed that a GM used for intensive soilless cultivation for 5 years would be less performant due to the loss of its properties. Furthermore, we presumed that plant-based organic fertilizers could exhibit efficient N mineralization rates and agronomic performance compared to animal-based organic fertilizers. To test these hypotheses, an in vitro experiment was conducted using three growing media (GM) with varying properties (1- peat mix control, 2-peat mix amended with wood fiber, and 3- 5-year-old peat-based GM) and ten commercial organic fertilizers. In vivo trials were also performed on pepper and cucumber crops to evaluate the agronomic performance of these three GM and three fertilization strategies (commercial fertilization, animal-based fertilization, and animal/plant-based fertilization) in terms of plant growth, nutrient levels, and microbial activity.

The in vitro results showed that for most fertilizers, N mineralization in the new peat-based GM peaked at day 14, while for the 5-year-old GM, the peak was generally observed at day 28. Fertilizers with the highest percentage of mineralized N were poultry pellets (80%), blood meal (61%), and soy protein hydrolysate (EZ-Gro 9-1.5-7; 53%) for the new GM, and the soy protein hydrolysate (EZ-Gro 13-0-0; 86%), shrimp meal (83%), blood meal and poultry

pellets (80%) for the 5-year-old GM. Although higher mineralization was often observed for the 5-year GM due to its residual fertilizer content compared to the new GM, lower microbial activity (FDA) was measured.

The in vivo trials showed that the yield of sweet pepper was lower in the 5-year-old GM compared with the new GM, while no significant difference was observed for the cucumber crops. Additionally, no significant difference was observed in the productivity of sweet pepper and cucumber when amended with animal-based fertilizers compared to a combination of plant- and animal-based fertilizers. Overall, this study emphasizes the importance of understanding mineralization rates and biological processes associated with the GM and organic fertilizers to promote sustainable agricultural practices.

Keywords: Organic farming, mineralization rate, organic amendements, cucumber, sweet pepper, productivity.

PS03-24

Optimizing electrical conductivity level improves plant growth and secondary metabolites of *Cannabis sativa* L.

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This study aimed to find the optimal electrical conductivity (EC) of nutrient solution in an indoor growing farm system to improve plant growth and secondary metabolites in *Cannabis sativa* L. We investigated the effects of 4 EC treatments (1.0, 2.0, 4.0, and 8.0 $dS{\cdot}m^{-1}$) on plant growth and the secondary metabolites in *Cannabis sativa* L. plants. Plant growth parameters and physiological activities were measured three weeks after transplanting for the vegetative growth analysis and six weeks after reproductive growth. The results showed that plant growth parameters were increased under medium EC treatments (2.0 and 4.0 $dS{\cdot}m^{-1}$) and decreased under lower EC (1.0 $dS{\cdot}m^{-1}$) and higher EC (8.0 $dS{\cdot}m^{-1}$) because of nutrient deficiency and salt stress, respectively. The activities of antioxidant enzymes, such as catalase and superoxide dismutase, and the higher proline contents were increased at higher EC levels (8.0 $dS{\cdot}m^{-1}$) compared with remaining treatments which may be a response to the oxidative stress caused by salt stress. However, guaiacol peroxidase activity was reduced under higher EC levels. Total chlorophyll content in leaves was the highest at EC 2.0 $dS{\cdot}m^{-1}$ and decreased at higher EC levels (4.0 and 8.0 $dS{\cdot}m^{-1}$). Likewise, total phenolic content and antioxidant capacity were decreased at higher EC levels. Total flavonoid content under 8.0 $dS{\cdot}m^{-1}$ was 37.1% lower than those of 2.0 $dS{\cdot}m^{-1}$. Total CBD and total Δ9-THC contents in flowers were significantly higher at lower EC treatments (1.0 and 2.0 $dS{\cdot}m^{-1}$)than those of higher EC treatments (4.0 and 8.0 $dS{\cdot}m^{-1}$). The results of this study suggest that 2.0 $dS{\cdot}m^{-1}$ successfully improved the secondary metabolites, CBD and Δ9-THC of hemps with no adverse influence on plant growth or yield productivity.

Keywords: secondary metabolites, electrical conductivity, *Cannabis sativa* L.

PS03-25

Nitrogen mineralization from organic fertilizers and water and oxygen content in growing media: How are they related?

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In organic horticulture, nitrogen is primarily applied to crops in its organic form. This organic nitrogen must undergo mineralization by bacterial and archaeal enzymes, through the successive processes of ammonification and nitrification, to become available to plants. These processes are influenced by various environmental factors such as temperature, C/N ratio, pH, fertilizer type, and water and oxygen availability. However, the impact of water and oxygen availability on the mineralization process, as well as their direct effects on microorganisms, have not yet been extensively studied in organic growing media (GM). A study was conducted during the winter of 2023 to evaluate the impact of water availability in growing media on oxygen availability and nitrogen ammonification and nitrification processes in different GMs. A randomized complete block experimental design with three replicates consisting of 60 L containers located in a greenhouse was conducted to compare four GMs with contrasting physical characteristics. A characterization of physical properties of each GM was performed, including water retention curves, saturated and unsaturated hydraulic conductivity, and gas diffusivity. An organic fertilizer blend consisting of blood meal and pelletized poultry manure was added at a rate of 400 mg N L^{-1} to each container. Three matric potentials (-1.5, -3.5, or -5 kPa), measured at mid-container height, were maintained for each GM. The CO_2 and N_2O emissions were monitored weekly at the GM surface while the O_2 concentration was taken at three depths within the containers over the 56-day period. These gas profiles and the physical characteristics of GMs were correlated with microbial diversity and genes related to nitrogen mineralization, as well as the total bacteria and fungi counts and available nutrients in the GM solution.

Keywords: Growing media, nitrogen mineralization, physical properties, water, oxygen, microbial diversity.

PS03-26

Assessment of two natural biostimulants for the production of organic vegetable seedlings in greenhouses

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The organic seedlings production is experiencing an unprecedented development, based on the potential effect of the vegetable growing activities on the environment awareness.

However, seedling production in an organic system requires a high level of knowledge combined with a deep mastery of the main technological links, mainly due to the numerous restrictions underpinning the regulations of organic agriculture.

The current paper aims to evaluate the effect of Etamin and Kerafol Evo, two commercial products with biostimulant action on the production of seedlings in three distinct vegetable species: sweet pepper (*Capsicum annuum* L.) "Dariana Bac" cultivar, celery (*Apium graveolens* L.) "Ina" cultivar and, respectively, cabbage (*Brassica oleracea* L. var. *capitata*) "Silviana" cultivar.

In this regard, their impact on the emergence and also a series of biometric parameters were assessed: hypocotyl height, cotyledon length and width, seedling total height and root length, total number of leaves, root/shoot ratio, seedling mass, as well as the content of chlorophyll and anthocyanins for each vegetable species. The results highlighted a beneficial effect of the two biostimulants use on most of the parameters studied when compared with the control, which entitles us to say that they might represent precursors for a future harmonious development of vegetable crops.

Keywords: environmental sustainability; plant emergence; seedling biometric; chlorophyll content; anthoscyanin content.

PS03–27

Effect of humic acids on the tomato production in soilless media

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The commercial hydroponic growing of tomato utilizes different substrates like rockwool, coir, peat moss and perlite; using different nutrient solution recipes with variable results, depending on the growing conditions such as the open field, macrotunnels or greenhouses. The humic acids are natural substances that can stimulate root growth and improve plant nutrition, and therefore it is important to test their effect in combination with the nutrient solution utilized in these systems. Based on this, the objective of this research was to evaluate the effect of humic acids on the production of tomato in soilless media, under open conditions. On May 5th, tomato plants cv. Rio Grande were established in 2.5 L plastic pots with a substrate of peat moss + coir + perlite (1:1:1, v/v), and during a period of 3 weeks the plants were watered with a 50% diluted nutrient solution, before applying the humic acids (0.2 g/L)(Commercial name: Ultra HumiMax, from CityMax), in combination with a nutrient solution which is recommended for the hydroponic growing of vine crops, applying 250 ml per pot three times a week. In the control we applied only the nutrient solution. We

had 10 plants (replicates) per treatment, arranged in a completely random design. We harvested tomatoes from July to September, recoding the number of mature fruits harvested per plant, the fruit weight, length, diameter, firmness and Brix; and the SPAD units of leaves. We did not find significant differences between the treatment and the control, with regard to the fruits harvested per plant, the fruit weight, diameter, and firmness and the SPAD units of leaves; however, we found that the plants treated with the humic acids presented fruits with higher weight (80.3 gr) and higher Brix (4.5), compared with the control, where we recorded values of 67.4 gr and 4.0 Brix, respectively.

Keywords: biostimulants, Growing media, *Solanum lycopersicum*.

PS03-28

Assessment of biofumigation with mustard or canola residues for controlling Rhizoctonia solani in greenhouse-grown cucumbers

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Soil biofumigation with brassica plant residues has shown significant potential for the control of soil-born plant disease, while offering the substantial benefit of reducing the reliance on chemical fumigants. Furthermore, the utilization of plant residues as green manure is highly recommended for agricultural systems, due to their capacity to enhance nutrient availability, although it depends on the specific material and Brassica species used. The goal of this study was to assess the effectiveness of brown mustard (*Brassica juncea*) and canola (*Brassica napus*) residues in suppressing *R. solani* under laboratory and greenhouse conditions. Additionally, the study aimed to investigate the impact of these Brassicaceae plant residues on the growth parameters of cucumber plants within a greenhouse environment. To achieve this, the infested growing media underwent various treatments, including brown mustard cv. Terminator and cv. Centennial, canola cv. Invigor L340PC, as well as two control treatments representing healthy soil and soil infested with *R. solani*. After a 14-day inoculation period, cucumber seedlings were harvested, and different parameters evaluated, including the presence of diseased plants, fresh and dry weights, and the lengths of surviving plants' shoots. Furthermore, soil chemical properties and microbial activity were examined. The results of this study indicated that both brown mustard and canola plant residues were effective in reducing *R. solani* mycelial growth, achieving a reduction of 40 and 12 %, respectively. The incorporation of mustard and canola residues significantly mitigated the severity of root rot disease in cucumber plants, when compared to the untreated control under greenhouse conditions. Among the treatments, mustard cv. Terminator exhibited the highest efficacy, with a remarkable 55% reduction in disease severity, followed by canola and mustard cv. Centennial, which achieved reductions of 40% and 11%, respectively. The decrease in root rot damage had a positive impact on cucumber growth parameters, resulting in increased plant height and fresh and dry weights per plant compared to the untreated control. These results suggested that the Brassica residues acted as a green manure, enhancing the structure and physicochemical properties of the growing media. In addition, the incorporation of *Brassica*

residues led to elevated microbial enzymatic activity, indicating an increase in populations of antagonistic bacteria and fungi. This microbial shift could contribute to the reduction in both the quantity and impact of *R. solani*, the pathogen responsible for root rot disease in cucumber plants.

Keywords: Biofumigation, Brassica, Rhizotonia solani, microbial activity, soil-born plant disease, growing media.

PS03-29

Effects of light spectrum on inflorescence development and specialized metabolism, at different light intensities in medical cannabis

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Recent research on the cultivation of *Cannabis sativa* L. for medical purposes has left several important questions unanswered, particularly regarding the impact of light spectra at increasing light intensities on growth, development, and inflorescence yield. This study aims to investigate the effects of a white and a red-dominant spectrum, at two light intensities on inflorescence development and yield, and content of specialized metabolites of *C. sativa*. Plants were grown in climate controlled rooms without solar light, where four light spectra were applied: two white spectra with a composition of 16% blue, 40% green, and 40% red, and two red-dominant spectra with a composition of 7% blue, 20% green, and 70% red. The two white spectra (16:40:40 BGR) differed in energy use efficiency, while the red-dominant spectra (7:20:70 BGR) varied in terms of red wavelengths, with one spectrum peaking at 660nm and the other peaking at 640 and 680nm. These spectra were applied at two intensities, namely 600 and 1200 µmol $m^{-2}{\cdot}s^{-1}$. The experiment was conducted twice. Plant morphology, flower development, and specialized metabolites such as cannabinoids and terpenes (analyzed using gas chromatography-mass spectrometry) were measured periodically. Photosynthetic traits, including operational photosynthesis, quantum yield, photosynthetic light use efficiency, and the light saturation point, were determined by measuring gas exchange (LI6800, Licor). This study elucidated how yield components, such as inflorescence weight, and concentrations of specialized metabolites, were influenced by a white or red spectrum, and their interaction with light intensity.

PS03-30

Investigations of auxins transport in Petunia hybrida caused by thigmomorphogenesis

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Thigmomorphogenesis (or mechanical stimulation - MS) is a term created by Jaffe (1973), meaning plant response to natural stimuli such as the blow of the wind, strong rain, or touch, resulting in a shorter stem length, but increased branching as well as increased activity of

axillary buds. The effect of MS on morphological characteristics of petunia is very well documented, but physiological processes controlling plant growth are not yet well investigated. In the current study, we tried to find an answer to the question if MS truly may affect auxin synthesis or transport in the early stage of plant growth, and which physiological factors may be responsible for growth blockage in *Petunia hybrida* plants. According to our results MS negatively affects plant growth, but does not block auxin transport from the apical bud. However, over the longer period MS blocks IAA and GA3 synthesis in MS-treated plants. In our study the main factor responsible for the thickening of cell walls, strengthening of vascular tissues and growth decrease, was peroxidase (POX) activity. A special attention should be also paid to AGPs as signaling molecules which also are directly involved in growth regulation as well as in cell wall modifications.

In the current research, we confirmed that mechanical stimulation of petunia plants negatively affects growth dynamics, and blocks auxin and gibberellins synthesis over a longer period of time.

Keywords: GA3 synthesis, IAA synthesis, Mechanical stimulation, Peroxidase activity, POX.

PS03-31

Analysis of Thermal Energy Loads of a Building-integrated Rooftop Greenhouse (BiRTG) for Urban Agriculture

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Energy management of a building-integrated rooftop greenhouse (BiRTG) is considered one of the important factors. Accordingly, the interest in energy simulation models has increased. Energy load computed from the simulation model can be used for appropriate capacity calculation and optimal operation of the environmental control system. In particular, because the thermal environment of greenhouses is sensitive to the external weather environment, dynamic energy simulations, such as building energy simulation (BES), play an essential role in understanding the complex mechanisms of heat transfer in greenhouses. Depending on the type and crop density, there is a significant difference in the thermal energy loads of greenhouses. Furthermore, ventilation is also an important factor affecting the energy input of the greenhouse. Therefore, this study aimed to analyse the energy-saving efficiency of BiRTGs using BES and computational fluid dynamics (CFD) techniques considering crop in a greenhouse. BES is a calculation method for analysing the heating and cooling loads of buildings; however, it was difficult to consider time-dependent changes in the ventilation characteristics in the BES model. CFD can be used to calculate more detailed ventilation characteristics of an experimental facility. Thus, CFD and the BES were combined to obtain more accurate BES-based data. The BES-computed annual energy load for a

single-span greenhouse in which tomatoes were grown was 490,128 MJ, whereas the annual energy load for growing tomatoes in a BiRTG resulted in a 5.2% reduction, on average (464,673 MJ). The energy-saving effects were positive from October to April.

Keywords: Building energy simulation (BES), Computational fluid dynamics (CFD), Greenhouse, Thermal energy loads, Urban agriculture.

PS03-32

Choosing light for a perfect date? Light spectra have different impacts on mating and developmental performances of the generalist beneficial *Orius insidiosus* (Say)

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Supplemental lighting (SL) is a powerful tool to both promote crop productivity and disrupt pest activity in greenhouses. However, SL optimization regarding beneficial insects remains overlooked. After screening various light spectra based on predation efficiency of *O. insidiosus*, we evaluated the impact of selected spectra on predator's life cycle, from mating to the new adult generation. Predators were exposed to daily light sequences via tunable LED devices. Mating behaviors were assessed from video recordings before couples were exposed to tested SL spectra to determine development-related parameters (fecundity, fertility, total development duration and adults' sex ratio). Surprisingly, spectra that increased the number of mating events didn't produce more offspring. Nevertheless, SL addition after a 12h exposure to solar light significantly improved the monitored developmental parameters. More specifically, we identified a Blue-Red light mix enhancing both *O. insidiosus* predation and developmental performances, thus paving the way towards SL-mediated biological control optimization.

Keywords: Biological control, Supplemental lighting, Spectral quality, Thrips, Orius insidiosus

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