BOOK OF ABSTRACTS

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

VERTIFARM 2024

Under the aegis of

SOI

Comune di Bologna

Farm

ISHS
International Society for Horticultural Science

FOOD2

MINISTERO DELL'AGRICOLTURA DELLA SOVRANITÀ ALIMENTARE E DELLE FORESTE

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

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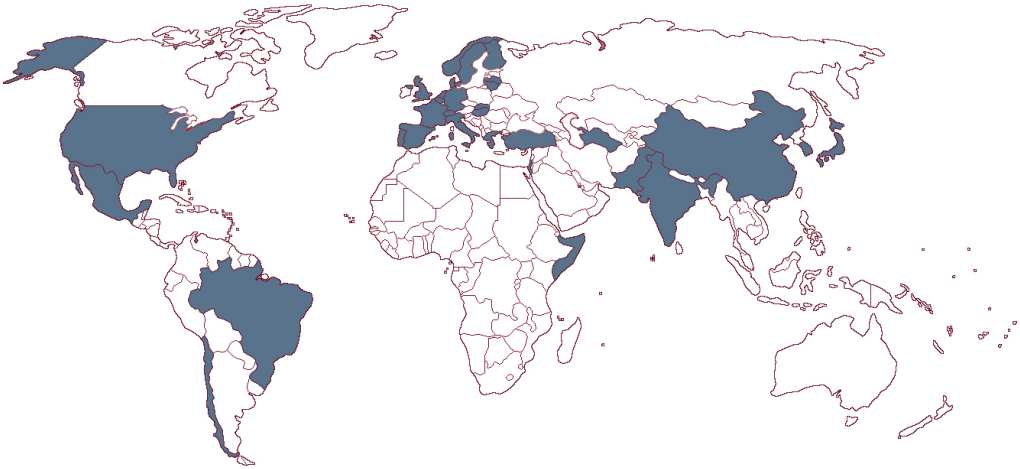
We thank our partners and sponsors for their support.



5
continents

31
countries

93
speakers

15
sponsors

VERTI FARM

2024

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Foreword

Vertical farming, growing plants on multiple layers or upright surfaces, in enclosed climate-controlled chambers and supplemented with artificial lighting technologies, is reshaping current agriculture. This revolutionary way of food production may substantially impact our knowledge on plant biology and physiology, cultivation systems and resource use. Beyond the hype toward this new sector, a clear need for successful cooperation between industry and research is pivotal to ensure feasibility and sustainability of the technology.

The International Workshop on Vertical Farming (abbreviated as VertiFarm from its 1st edition, in 2019, followed by a 2nd event in 2023) is a recurring workshop within the portfolio of scientific dissemination and communication events of the International Society for Horticultural Sciences (ISHS), the World's leading independent organization of horticulturists with a network of over 70,000 individuals, universities, governments, institutions, libraries and commercial companies.

At VertiFarm, experts from diversified World regions and with cross-disciplinary backgrounds encounter entrepreneurs, policy makers and investors to exchange on priorities and challenges of the sector. Its mission is to shed light on innovation technologies and pave the way for the future evolution of the sector.

The content of the 3rd International Workshop on Vertical Farming (#VertiFarm2024) is condensed into the following pages, where an effort was made to summarize the many diverse (though all significant) steps research and industry are advancing toward a viable vertical farming sector, ranging from the single technologies to the whole food system approach.

Thematic sessions, business panels, workshops, technical visits and a dense agenda of social and networking events constitute the solid framework of the workshop series, as clearly visible in the agenda of this VertiFarm2024 edition.

We sincerely hope you will enjoy the workshop and look forward to meet and exchange with you in the coming days,

The convenors
Giuseppina Pennisi and Francesco Orsini

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Support to organization and logistics was provided by:

PLANNING

Food Systems in European Cities (FoodE)

Scan Me

Scan Me

www.foode.eu

Led by the University of Bologna and financed under Horizon 2020*, FoodE brings together a highly qualified consortium of universities, research institutes, SMEs, NGOs, as well as city councils distributed across 8 EU countries.

The project aims to build and promote a "Think global, eat local" mindset with a view to accelerate the rise of City/Region Food Systems (CRFS) that are sustainable and resilient, thus able to guarantee food security while boosting local economies.

Cities and Regions represent the scale at which ecological, social, and economic interconnections may be fostered through co-governance and active involvement of urban and regional institutions and players, such as:

- Citizens;
- Food system start-ups and small businesses operating in the urban food landscape;
- Cities and regional authorities;
- Academia;
- Schools.

By increasing the relationships and interlinkages between the different actors of the food chains, FoodE will pave the way for job creation, enhance local economies, and enable local communities to contribute to the United Nations Sustainable Development Goals.

* The European Union Research and Innovation Framework Programme (2014-2020)

VFarm

VFarm is a Research Project of National Interest (PRIN), funded by the Italian Ministry for Research and Education, aiming to implement a virtuous process to facilitate the rapid development of vertical farming in Italy. This objective is pursued through interdisciplinary research that combines strategies for crop diversification and experimentation related to vertical farming technologies.

The generated experimental data aim to contribute to defining sustainability indicators and will allow the design of typologies and strategic tools specifically adapted to the Italian context. A strong link between research and innovation is expected, thanks to the creation of collaborations between academia and the private sector for a rapid diffusion of the developed technologies.

VFarm will promote Italian scientific excellence, cooperation between research, business and civil society, the creation of guidelines and policies for the promotion of a sustainable society, the promotion of gender equality in science and the recruitment of young researchers, in line with the strategies of the European Union and towards achieving the SDGs.

Scan Me

GENERAL INFORMATION

CONGRESS VENUE INFORMATION
Palazzo Re Enzo
Piazza del Nettuno, 1/C, Bologna - Italy
Tel. +39 051 6583111
https://www.palazzoreenzo.com/

Palazzo Re Enzo is located in the main square of Bologna (Piazza del Nettuno 1, Bologna), therefore very close to many accommodations. Palazzo Re Enzo is 1.5 km from Bologna Centrale train station, 9 km from Guglielmo Marconi Airport and 3 km from the Bologna motorway exit.

On foot: Palazzo Re Enzo can be easily reached with a 20 minutes' walk by the central station.
With public transport: from both the train and bus stations several bus lines can get very close to the conference venue. The closest bus stops are "Rizzoli" and "San Pietro".
For more information on getting around Bologna city by car, bus, taxi and bike please visit the website of Bologna Welcome:
www.bolognawelcome.com/en/information/plan-your-trip?tab=Get%20around

REGISTRATION AND INFORMATION DESK OPENING HOURS
All participants are required to register at the Registration and Information Desk, which is located on the 1st floor of Palazzo Re Enzo. All participants will receive a badge with their name and QR codes to scan showing the workshop program and the book of abstract, as well as the workshop gadget kit.

Registration hours:
January 16th: **10.00-19.00**
January 17th: **8.00-19.00**
January 18th: **8.00-16.30**

During the opening hours the Workshop Secretariat can be contacted at:
Mobile Phone +39 346 3676568
Contact person: Claudia Magrì

IDENTIFICATION BADGE
All participants should wear their identification badge while attending the scientific sessions, social events and technical visits. Entrance to the sessions is limited to badge holders only.

WORKSHOP LANGUAGE
The official language for the event is English.

ON-SITE REGISTRATION
On-site registration will be processed on a first-come, first-serve basis. Priority will be given to pre-registered participants. Please note that depending on the number of on-site registered delegates, availability of congress material may be limited.

On-Site Registration
- Student: € 820
- ISHS and SOI member: € 940
- Non-ISHS and non-SOI member: € 1160

REGISTRATION FEE COVERS
- Welcome ceremony
- Admission to all oral and poster sessions
- Admission to workshops and roundtable
- Coffee breaks and lunches
- Welcome cocktail on January 16th
- Social dinner on January 17th
- Closing ceremony, awards and farewell cocktail on January 18th
- Technical visits, including transport
- Workshop kit
- Digital Book of Abstracts

PROGRAMME CHANGES
The organisers cannot assume liability for any changes in the congress programme due to external or unforeseen circumstances.

WIFI:
As a courtesy to all participants WiFi will be available at the venue:
Network: Vertifarm2024
Password: Vertifarm2024

CERTIFICATE OF ATTENDANCE
All participants will obtain a digital certificate of attendance. The certificate of attendance will be sent to the email used for registration.

TOURIST INFORMATION AND ASSISTANCE
Tourist information offices are located in the arrivals area of the international airport "G. Marconi" and in the city center, at Piazza Maggiore.

To get a better experience in Bologna, we suggest downloading the app https://app.bolognawelcome.com/it on your mobile phone.

INSURANCE
The congress fee does not include insurance and all participants should arrange for their own insurance. Health and accident insurance is recommended and has to be purchased in your country of origin.

RECORDING
According to the European law, it is only permitted to record and to film lectures subject to the explicit consent of the lecturer. If the required consent was not given, we ask you to refrain from recording the lecture. Any infringements can have legal consequences.

PHOTOGRAPHS & VIDEO STREAMING
The organiser may without the further consent of the participants use and release pictures and videos taken during the congress for reports of the congress and/or in future marketing materials. By registering to this congress attendees agree that photographs or sound or video recordings taken during the congress that could include recognizable images or voices of those in attendance may be posted on the event website and related social media channels. All recordings are treated sensitively and discreetly. Names will not be published. The congress is held in a public space; therefore, we do not prohibit participants, exhibitors, sponsors, or news organisations from photographing, video or audio-taping some congress activities. The organiser reserves the right to use images taken at the congress with your photograph and/or likeness on social media and/or in future marketing materials. The organiser is NOT responsible for individual attendee's use of your image or likeness.

PRESENTATION GUIDELINES

SLIDES CENTER
The Slide Centre is located at the 1st floor of Palazzo Re Enzo.

The Slide Centre will be open at the following times:
January 16th: **10.00-18:00**
January 17th: **8.00-18.00**
January 18th: **8.00-15.30**

SLIDES
Authors are requested to prepare the presentation using Microsoft Powerpoint (2016 or latest version) or Portable Document Format (PDF). The organization is not responsible for problems caused by incompatibility issues with the software. Please bring your presentation file on a USB drive to the Speakers and Slide Center Room at latest 2 hours before your presentation will take place. Name your presentation using your full name and put it in the folder with the name of your session. Due to time and technical reasons we kindly ask not to use your own notebook. Technical staff will be glad to assist.
Please make sure you will reach the session room at least 20 minutes before your slot and no later than the beginning of your session. Due to time limitation, in case the speaker is late, the slot cannot be reallocated to another session, and the presentation will be cancelled.

ORAL KEYNOTE AND INVITED PRESENTATIONS
Timing allocated to each oral presentation is presented in the scientific program. Keynote presentations last 25' + 10' for Q&A. Invited lectures are presented in 15' + 5' of Q&A. Please strictly comply with allocated time schedule.

FAST TALKS (DIGITAL POSTER SESSION)
Attendees presenting in a fast talk (digital poster) are requested to prepare the presentation using the official template sent by email and available on the workshop website, without changing its size or the logo. The template can however be adjusted in order to allow the use of graphics from own institution.
Each poster fast talk consists in a 3' presentation followed by 2' questions. Please strictly comply with allocated time.
Only the abstracts presenting the symbol "☆" are eligible for the ISHS Young Ming award.

SOCIAL PROGRAM

WELCOME CEREMONY
All registered participants are welcome to join the opening ceremony, taking place at Salone del Podestà, Palazzo Re Enzo, on January 16th, 14.30-15.00.

WELCOME COCKTAIL
All registered participants are invited to the complementary Welcome cocktail, taking place at: Salone del Podestà, Palazzo Re Enzo, on January 16th, 19.00-21.00.

CLOSING CEREMONY, AWARDS AND FAREWELL COCKTAIL
All registered participants are invited to the complementary Closing ceremony, including the announcement of the winner for the ISHS young mind awards and a farewell cocktail, at: Salone del Podestà, Palazzo Re Enzo, on January 18th, 16.20-18.30.

COFFEE BREAKS AND LUNCHES
Coffee breaks and Lunches are included in the registration fee and will take place in the Sala degli Atti and Sala Re Enzo.

SOCIAL DINNER
The social dinner is included in the registration fee, and will take place at Sala degli Atti and Sala Re Enzo, Palazzo Re Enzo, on January 17th, 20.00-24.00

CLOAKROOM
A cloakroom is available at the Registration and Information Desk on the 1st floor.

TECHNICAL TOURS

Technical visits are open to all registered participants and transport is included in the workshop fee. All technical tours will take place on January 19th and attendees may choose between the following activities:

Option 1.

Day Excursion to Milan: Agricola Moderna and "Bosco Verticale":
(all day, including 6 hours of bus travel). Visit to Agricola Moderna, a commercial vertical farm located in Milan's outskirts, and to Bosco Verticale, a complex of two residential greened skyscrapers hosting a vertical forest.

Please note that lunch will not be provided. A lunch break will be scheduled between Agricola Moderna and Bosco Verticale where participants can go to a local restaurant, café or fast-food place and enjoy their lunch in Milan. We will provide a list of suggested places closer to the time of the excursion.

A maximum of 40 participants will be accepted for this excursion.

Place and Time of Departure: Palazzo Re Enzo, Bologna at 07:45 by bus
Place and Time of Return: Palazzo Re Enzo, Bologna at 20:00 by bus

Option 2.

Social and experimental vertical farming in Bologna:

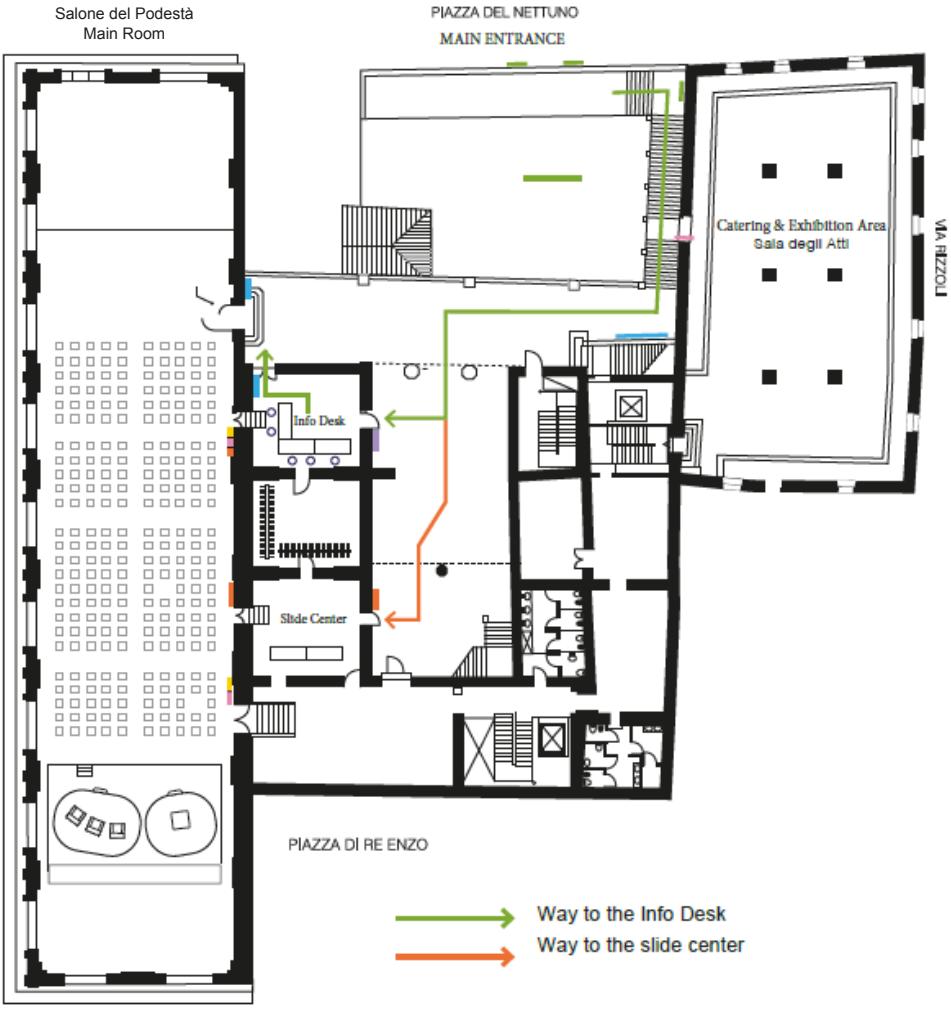
Attendees will have the chance to visit AlmaVFarm, the experimental vertical farm of the University of Bologna, altogether with other experimental facilities (e.g. climate-controlled growth cabinets for LED lighting studies, crop phenotyping tools), and commercial installations including cultivation cabinets for home indoor farming, as well as shipping containers equipped for either mushroom or vegetable plant cultivation at SalusWSpace., a social cohousing space. At the end of the visit, a refreshment is offered.

Place and Time of Departure: Palazzo Re Enzo, Bologna by bus
Place and Time of Return: Palazzo Re Enzo, Bologna by bus

According to registrations, different slots for groups will be organised.
Specific departure time will be communicated at the registration desk during conference.

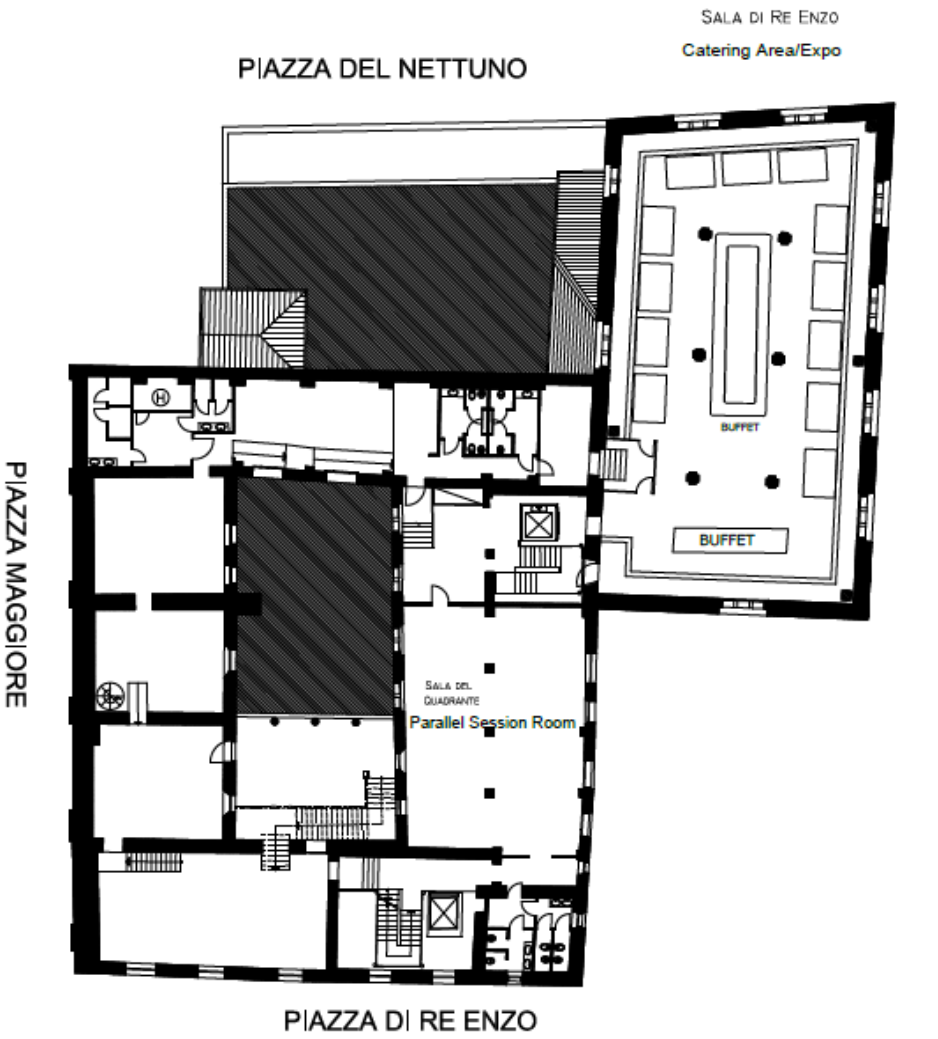
FLOORPLANS

Palazzo Re Enzo - 1st floor plan



FLOORPLANS

Palazzo Re Enzo - 2nd floor plan



VERTIFARM 2024

JANUARY 16TH, 2024

MAIN ROOM

14:30 - 15:00	Welcome Ceremony	F. Orsini; G. Pennisi; D. Ara; R. Lanciotti; I.B. Lee

VISIONS FOR SYSTEM INNOVATION (CHAIR: F. ORSINI)		
15:00 - 15:35	From vertical to space farming (and back)	S. De Pascale; R. Wheeler
15:35 - 16:10	Opening new ways for resource efficient vertical farming	G. Pennisi
16:10 - 16:45	The role of crop modelling in a vertical farming environment	E. Heuvelink

16:45 - 17:15	Coffee break	

NEW CROPS (CHAIR: A. MAGGIO)		
17:15 - 17:25	Breeding crops for vertical farming	A. Maggio
17:25 - 17:45	Faster than fast: accelerating flowering to the speed breeding of lettuce with Far- Red radiation	Y. Ji
17:45 - 18:05	A genetic approach to vertical farming: LED-omics	A. Tsaballa
18:05 - 18:25	The role of red and white light in optimizing growth and accumulation of plant specialized metabolites across light intensities in medical cannabis (*Cannabis sativa L.*)	M. Holweg
18:25 - 18:40	Fast talks (S. David, D. Celentano, V. Jadhav)	
18:40 - 19:00	Biodiversity in vertical farms: to be or not to be	G. Samoulienė

19:00 - 21:30	Welcome cocktail	

VERTIFARM 2024

JANUARY 17TH, 2024

MAIN ROOM

VISIONS FOR SYSTEM INNOVATION (CHAIR: S. DE PASCALE)		
09:00 09:35	Plant factory innovations for sustainable well-being societies	E. Hayashi

LIGHT (CHAIR: T. OUZOUNIS)		
09:35 09:45	New challenges for sustainable lighting	T. Ouzounis
09:45 10:20	Optimizing lighting management in vertical farms	L.F.M. Marcelis
10:20 10:40	Tailored light application for increased produce value in vertical farming	L. Cammarisano
10:40 11:00	Improving lighting conditions for enhanced kale baby leaf production	I. Zauli

11:00 - 11:30	Coffee break

LIGHT (CHAIR: G. PENNISI)		
11:30 11:50	Optimized Far-Red Radiation management for improved yield and resource use efficiency in lettuce (*Lactuca sativa L.*) grown in a vertical farm	L. Carotti
11:50 12:10	LED light manipulation: use of pulsed light recipes in plant growth to reduce electricity consumption	J.E. Olvera González
12:10 12:30	Reducing the energy footprint and enhancing the flexibility of indoor growing systems while maintaining a high growth rate: Examination of disruptive cultivation protocols	D. Avgoustaki
12:30 12:50	Light quality and intensity modulation on yield and quality on leafy vegetables grown in vertical farms	A Ferrante
12:50 13:10	Plant responses to UV-A1 radiation are species and background irradiance dependent	T. Li
13:10 13:30	Fast talks (E. Appolloni, S. Chen, C. Dresch, M. Puccinelli)	

13:30 - 14:45	Lunch

VERTIFARM 2024

JANUARY 17TH, 2024

BUSINESS SESSION (CHAIR: M. J. BUSTAMANTE)		
14:45 - 14:55	Pushing through the trough of disillusionment – collaborating for better indoor farming	M.J. Bustamante
14:55 - 15:05	Modula Farm: vertical farming solution for the cultivation of strawberries	M. Giuliani Modula srl
15:05 - 15:15	Creating a link between the HVAC knowledge and the Vertical Farms needs	D. Gennaro HiDew
15:15 - 15:25	Vertical Farming requires efficient fertilizers' solution	F. Correddu Haifa group specialties
15:25 - 16:15	Panel discussion	M.J. Bustamante
16:15 - 16:45	Coffee break	

PARALLEL SESSIONS

MAIN ROOM

LIGHT (CHAIR: D. AVGOUSTAKI, Y. JI)

16:45 18:35	Fast talks (A. Christiaens, Q. Min, G. Stringari, A. Mäkinen, M.D.C. Martínez Ballesta, M.D. van der Lee, G.K. Ntinas, I. Chatzigeorgiou, N. Akter, A. Morelli, J. Van Brenk, L. Balázs, G. Evangelista, S. Mir, B.B. Ghaley, O.D. Palmitessa, A. Ali, E. Vincenzi, E. Van de Velde, D. Nunez Ocana)

SENSORS (CHAIR: J. E. OLVERA GONZÁLEZ)

18:35 19:00	Fast talks (J. Hua, L. Miserocchi, B. Laekeman)

SALA QUADRANTE

WORKSHOP

16:45 17:45	Medicinal cannabis in controlled environment agriculture (M. Holweg, B. Bugbee)

SUSTAINABILITY (CHAIR: J. MONZINI)

17:55 19:00	Fast talks (A. Koukounaras, S. Amadori, E. Henriksson, M. Ravani, R. Junge, A. Richards, J. Mac-Ginty, L. Mazzaferro, Z. Schmautz, E. Henriksson)

20:00 - 24:00	Social dinner

VERTIFARM 2024

JANUARY 18TH, 2024

MAIN ROOM

CLIMATE CONTROL (CHAIR: E. HAYASHI)		
09:15 - 09:50	Resource use efficient environment control in vertical farms	M. Kacira
09:50 - 10:25	Future-oriented approach of aerodynamics and energy engineering for environmental control of protected cultivation	I.B. Lee

ISHS BUSINESS MEETING (CHAIR: L.F.M. MARCELIS)		
10:25 - 11:15	Activities of the Working Group "Vertical Farming", Definition of the Venue for the "4 th International Workshop on Vertical Farming"	L.F.M. Marcelis I.B. Lee

11:15 - 11:45	Coffee break

PARALLEL SESSIONS

MAIN ROOM		SALA QUADRANTE	
CROP MANAGEMENT (CHAIR: E. HEUVELINK)		WORKSHOP: SOCIETAL CHALLENGES	
11:45 12:25	Fast talks (M. Karpe, L. Purmale, R. Soranz Ferrarezi, A. Macovei, C. Nicoletto, E. Itri, C. Carpineti, C. Amitrano)	11:45 12:15	Setting the scene for policy innovation (M. D'Ostuni, T. Blom)
SENSORS (CHAIR: B. BUGBEE)		12:15 12:35	Resource-saving agricultural production: vertical crop cultivation using nutrients from wastewater treatment plants (A. K. Steines)
12:25 12:45	Fast talks (F. Thoma, G.C. Modarelli, A. Antona, L. Vanacore)		
METABOLITES (CHAIR: I. RIGHINI)		12:35 13:30	Fast talks (A. Tsaballa, M. Leimkühler, A. D'Aprile, J. Muñoz-Liesa, A. Drottberger, V. Arcas Pilz, C. Iodice, P. Tonini, F. Monticone, S. Mengoli)
12:45 13:30	Fast talks (M.D.C. Martínez Ballesta, S.L. Novoa, P.P. Gallego, D. Arena, Y. Liu, P. Gowda, D. Arena, C.M. Profico)		

13:30 - 14:30	Lunch

VERTIFARM 2024

JANUARY 18TH, 2024

RESOURCE USE EFFICIENCY (CHAIR: M. KACIRA)		
14:30 - 15:05	Principles of nutrient and water management for indoor agriculture	B. Bugbee
15:05 - 15:25	Optimization of nutrient supply in leafy vegetables grown in vertical farming using the Decision Support System NUTRISENSE	D. Savvas
15:25 - 16:00	Vertical farming sustainability: what, why, and how	M. Martin
16:00 - 16:20	Food crops: resources to meet human dietary needs	I. Righini

16:20 - 18:30
CLOSING CEREMONY, AWARDS AND FAREWELL COCKTAIL

The activities leading to this publication have received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No. 862663 and from the Italian Ministry of Education and Research (MUR), within the call for Research Projects of National Interest (PRIN), within the project "VFARM - Sustainable Vertical Farming" (Project code: 2020ELWM82, CUP: J33C20002350001). The publication reflects the authors' views. The Research Executive Agency (REA) and the Italian Ministry of Education and Research (MUR) are not liable for any use that may be made of the information contained therein.

VERTIFARM 2024

JANUARY 19TH, 2024

TECHNICAL VISITS

BOLOGNA - 3.5 hours

Department of Agricultural and Food Sciences

SalusWSpace

MILAN - 8 am/8 pm

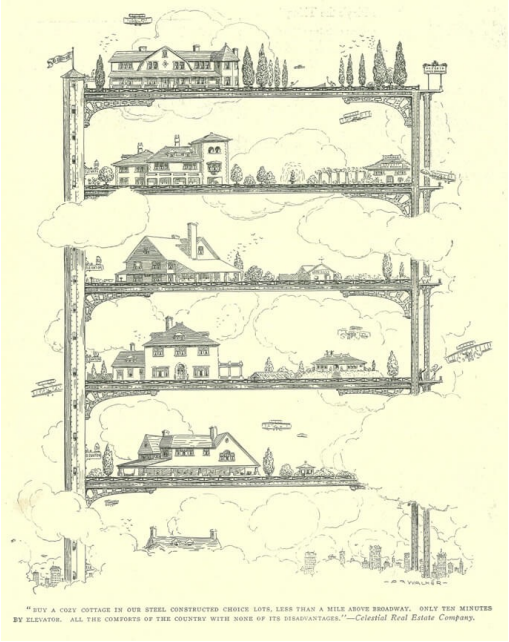
Agricola Moderna

Bosco verticale

Stepstones on vertical farm evolution: part I

1909

115 years ago. Life Magazine featured an illustration by cartoonist A.B. Walker, where farmhouse were placed on multiple layer of a steel structure, connected through elevators.



January 16th

SESSION: VISIONS FOR SYSTEM INNOVATION

CHAIR: F. ORSINI

STEFANIA DE PASCALE

From vertical to space farming (and back)

Space farming has been debated since the early 20th century. Central to the concept is the use of higher plants and light to regenerate air and water, to produce food and to partially recycle organic waste. Ground-based experiments on crops for Space are typically carried out in environmentally controlled growth chambers with artificial light, using closed loop hydroponics. The Biomass Production Chamber (BPC), located at NASA's Kennedy Space Center, has been used to conduct tests on different crops from 1988-1998. In the BPC, plants were grown hydroponically on shelves stacked vertically inside an atmospherically closed 20 m^2 chamber. This was probably one of the first demonstrators of vertical farming. Following these studies, novel technologies and findings have been developed including the first use of light emitting diodes for growing crops. Since then, research on agricultural systems for Space has contributed to, and benefited from research on controlled environment terrestrial agriculture and it is expected to continue in the future.

Keywords: vertical farming, agricultural system for space, LEDs

Stefania De Pascale is full Professor of Horticulture and Floriculture at the University of Naples Federico II. She teaches in courses on Crop-physiology, Greenhouse horticulture and Landscaping and supervises BSc, MSc and PhD students. Since she joined the Department of Agricultural Sciences in 1993, Stefania has performed numerous research both in field and in greenhouse to determine the effects of environmental and cultural factors on plant growth and product quality on a wide range of vegetable and ornamental crops. Recent research activities include the setup of a Bioregenerative Life Support System based on the use of plants for food production, air regeneration and water purification and the effects of "Space environment" (i.e. microgravity and ionizing radiation) on plants. She is the responsible of the Laboratory of Crop Research for Space including the PaCMAN Plant Characterization Unit conceived as a crop research facility within the MELiSSA program, a joint long-term effort, led by the European Space Agency (ESA), focused on the development of a regenerative life-support system in the sight of future long-term manned missions to Moon and Mars.

GIUSEPPINA PENNISI

Opening new ways for resource efficient vertical farming

Vertical farms are claimed to be resources' efficient growing systems thanks to the capability to use the vertical dimension for plants' cultivation, to recover water drained by the substrate and transpired by plants, and to reuse nutrients in closed loop cycles. In the absence of solar light and in an airtight environment, such as the one characterizing a vertical farm, lighting devices and climate control units become fundamental for running the system. Both need electricity, making intensive energy use the most significant drawback of the technology. The aim of this presentation is to critically analyze the sustainability claims of vertical farming, figure out a comparison with other high-tech growing solutions, and highlight strategies that may be adopted to transform this "niche growing solution" into a key component of our future food systems.

Keywords: resource use efficiency, indoor agriculture, artificial light, climate control, water management

Giuseppina Pennisi is a assistant professor (RTDA) at the Department of Agricultural and Food Sciences of the University of Bologna. She obtained her PhD in December 2019 at the University of Turin, in cotutelle with the Universidad Politecnica de Cartagena (in Spain), with a thesis entitled LED lighting for the indoor cultivation of leafy vegetables and herbs. Dr. Pennisi is a council member of the National PhD school on Artificial Intelligence. Her research sectors are: urban agriculture, soilless cultivation, vertical farming, artificial lighting. She coordinates the research unit of UNIBO in the Erasmus project LOFT and contributes to the activities of European projects: "FoodE - Food systems for European cities", the national PRIN project VFarm (Sustainable Vertical Farming), and Erasmus+ project BESTMicrogardens. She was also involved in additional projects as "BUGI - Western Balkans urban agriculture Initiatives", "GardensToGrow", "Innofarming", "Urban Green Train".

EP HEUVELINK

The role of crop modelling in a vertical farming environment

Models are powerful tools to test hypotheses, to synthesize knowledge, to describe and understand complex systems and to compare different scenarios. Process-based models have long been used for predicting yield and understanding the environmental regulation of plant physiological processes and their consequences for crop growth and development. Combining these models with data-driven modelling (machine learning) improves prediction accuracy. Functional-structural plant models explore and integrate relationships between a plant's structure and processes that underlie its growth and development. Several examples for controlled environment agriculture will be presented and the relevance of crop models for vertical farming is discussed.

Keywords: data-driven modelling, plant models, Controlled Environment Agriculture (CEA), crop growth

Ep Heuvelink has over 35 years of experience in scientific research and education in Controlled Environment Agriculture (CEA; greenhouses and vertical farms). He is associate professor in the Horticulture and Product Physiology group of Wageningen University & Research. His expertise is greenhouse crop physiology and crop simulation. He supervised over 130 MSc thesis students and is co-promotor of 25 PhD students. Ep is frequently invited as a keynote speaker at international scientific symposia and teaches advanced intensive courses on greenhouse production and vertical farming, crop physiology and crop modelling all over the world. He is a teacher in the Wageningen Summerschool on Greenhouse Horticulture and (co-) authored 124 papers in refereed scientific journals, over 200 papers in professional journals and 5 books.

January 16th
SESSION: NEW CROPS

CHAIR: A. MAGGIO

ALBINO MAGGIO

Breeding crops for vertical farming

Breeding programs for improving important agricultural traits have been essentially targeted to field crops to reduce yield loss caused by several unavoidable environmental constraints. In contrast, plant cultivation in controlled environments consents to better control those constraints that may affect growth and final yield and to adapt environmental variables to specific cultural needs. Therefore, target traits in breeding programs for indoor crops may conceivably be different from a field ideotype. These may include the efficiency of root-to-shoot ratios in soilless systems, plant response and adaptation to quality and light intensities, accelerating flowering for speed breeding and exploiting biodiversity to identify functional traits for indoor cultivation. These and more specific traits should be addressed to achieve synergies and benefits from combining advanced breeding and controlled environment techniques.

Keywords: breeding programs, Controlled Environment Agriculture (CEA), indoor crops, target traits

Professor of Agronomy and Crop Science at the University of Naples Federico II – Italy. expert on crop responses to environmental stresses with a focus on salinity, water shortage and resource use efficiency in agricultural systems. Contributed over 100 publications in refereed journals and books in the field of functional biology of crop stress adaptation and recently worked on forward look analyses of food systems.

YONGRAN JI

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

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. Modern lettuce varieties have been selected against flowering. Prior to flowering, bolting occurs which is characterized 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 cultivars 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 lettuce (*L. sativa*) cultivars of multi-leaf(cv "ML108") and Batavia (cv "BAT101") type 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 to speed up lettuce breeding with vertical farming.

Keywords: bolting, Far Red, flowering time, lettuce (*Lactuca sativa*), speed breeding, vertical farming

Yongran Ji is a postdoctoral researcher at the Horticulture and Product Physiology group of Wageningen University. He specialises in studying plant responses to different light spectra, particularly far-red. His research not only focuses on understanding the physiological and molecular mechanisms behind these responses, but also their applications in yield improvement, quality enhancement, and speed-breeding of horticultural crops in controlled environment agriculture.

APHRODITE TSABALLA

Introducing LED-omics

Protected cultivation of leafy vegetables inside controlled-environment farming systems poses significant challenges to resource-use efficiency and sustainability. With the horticultural LED lighting systems gaining popularity it is vitally important to understand how different LED lights influence rocket's (*Diplotaxis tenuifolia*) molecular mechanisms that regulate growth and quality traits, physiological and biochemical characteristics. Following a novel comprehensive approach, we employed next-generation RNA-seq technology to deeply explore gene expression changes at the transcriptional level. Through the detailed analysis of transcriptomic data, we examined the differentially expressed gene pathways that govern photosynthesis and phenylpropanoid biosynthesis. The elucidation of the role of genes that participate in the manifestation and control of important plant characteristics under different LED light regimes, paves the way for breeding for higher yield, quality and adaptation of crops grown under these new sustainable indoor cultivation systems.

Keywords: LEDs, next-generation RNA- seq, quality, indoor cultivation

Dr Aphrodite Tsaballa is an associate researcher at the Institute of Plant Breeding and Genetic Resources (IPBGR) of the Hellenic Agricultural Organization (ELGO-Dimitra), in Thessaloniki, Greece. Her research area is plant breeding and genomics. She is currently the national principal investigator of the PRIMA funded project "SAFE" jointly run by the Genomics Lab and Sustainable Agricultural Structures & Renewable Energy Resources Lab (IPBGR). Dr Tsaballa is an agronomist and holds a master's and doctoral degree in plant breeding and genetics from the School of Agriculture, Aristotle University of Thessaloniki. She has been awarded a Marie Sklodowska-Curie Individual Fellowship from the European Commission to carry on research on miRNA turnover at the University of East Anglia, in Norwich, UK. She has co-authored 22 publications, 9 of which as first author (h-index 17), while she has participated as a speaker in numerous conferences. She is engaged in various science communication activities as well as in mentoring programs.

MEXX HOLWEG

The role of red and white light in optimizing growth and accumulation of plant specialized metabolites across light intensities in medical cannabis (*Cannabis sativa* L.)

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} 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.

Keywords: light spectra, light intensity, medical cannabis, specialized metabolites, indoor farming

Mexx Holweg, a PhD researcher at the Horticulture & Product Physiology group of Wageningen University & Research, investigates how the light environment influences

the growth, development, and medicinal compound accumulation in medicinal cannabis. Central to his research is the impact of light intensity and spectrum. Through detailed analyses of plant morphology and photosynthesis, his work seeks to clarify treatment effects and plant adaptability. His research endeavours to expand scientific understanding while also contributing to the standardization of cultivation methods, furthering the integration of medical cannabis into modern pharmaceutical practices.

GIEDRĖ SAMUOLIENĖ

Biodiversity in vertical varms: to be or not to be?

Agriculture currently faces multiple challenges: it must increase production rates to meet the demand of a growing population, adhere to overall development in the many agriculture-dependent countries, adopt more efficient and sustainable production methods, and reciprocate to climate change issues. In line with population increases, the long-term decreasing stock of agricultural land per capita is an emerging global problem. Controlled environment agriculture (CEA) (vertical farming, plant factory, high technology level greenhouses) is assigned a significant, purposeful role in amplifying the resource use efficiency in agriculture. One of the biggest advantages of vertical farming – is the consistent quality of raw material – recovery of detailed quality indices between growth runs during round-year plant production. The global food system depends on a limited number of plant species. Plants with unsatisfactory nutritional value are overproduced, whereas the wide variety of nutrient-rich plant species used in earlier times remains neglected. The introduction of diverse, underutilized green vegetable species of different origins for cultivation in CEA systems promotes its competitiveness and economic efficiency both regionally and globally. However, a lack of crop competitiveness may be an important factor for underutilization. Thus, aspects associated with geographical, social and economic reasons must be highlighted. Health benefits, and human well-being are no less important as well. The feature of added nutritional value can help in fighting hidden hunger. Thus, nutritionally sensitive precise agriculture traits and proposed miscellaneous, rich in different phytochemicals and minerals green vegetable species, would promote the value of vegetable foods. Moreover, by tailoring the controllable cultivation environment parameters, it is possible to attain relevant production quality of plant produce, such as altered contents of target metabolites, serving as nutraceuticals, pharmaceuticals, etc. This is achieved by creating plant-specific optimized cultivation parameter combinations. Concluding, the introduction, maintenance, management, and promotion of underutilized plant species present

several challenges from different scientific fields.

Keywords: Controlled environment agriculture (CEA), crop biodiversity, metabolites, plant-specific optimized cultivation

Giedrė Samuolienė, defended her bachelor's degree in biology (2001), master's degree in chemical analysis and control (2003) and PhD in agronomy (2008) in Vytautas Magnus University (Lithuania). She is the Head and Chief Researcher of the Laboratory of Plant Physiology; Science Coordinator, Institute of Horticulture, Lithuanian Research Centre for Agriculture and Forestry; docent at Vytautas Magnus University, Agriculture Academy; and Member of Lithuanian Academy of Science. Her main research fields are horticulture, plant (photo)physiology, stress physiology, plant productivity, metabolism. She has published 63 publications in CA WoS data base journals with impact factor, in total – more than 100, with a h27. She has National Science Award (2014, with co-authors), Silver medal of Vytautas Magnus University (2015), Scholarship of the Lithuanian Academy of Sciences (2012-2013).

January 16th
Fast Talks - NEW CROPS

CHAIR: A. MAGGIO

Cultivating success: improving growth of strawberry plants in vertical farms

STEPHAN DAVID, Gabriela Ficova, Leo Marcelis, Julian C. Verdonk

Horticulture and Product Physiology, Plant Science Group, Wageningen University and Research, Wageningen, the Netherlands

The last decade has seen remarkable developments in the field of vertical farming (VF). Besides leafy greens, species such as strawberry, which have a more complex cultivation cycle, are being considered for VF cultivation. Many cultivars are commercially available, but until now these have been bred specifically for field or greenhouse cultivation. VFs offer an unmatched potential for manipulation of the cultivation environment. This has created a need for new strawberry cultivars that are specifically adapted to VF cultivation in order to maximize the yield-to-cost ratio. Strawberry cultivars are divided based on flowering behavior into seasonal flowering (SF) and everbearing (EB) types, which are short day and day neutral plants respectively. Besides flowering behavior, these types exhibit differences in vegetative growth and development and runnering behavior. The differences are not well characterized, and the underlying genetic factor (known as the PFRU locus) is not known, although some candidate genes have been proposed. In the current study, two SF and two EB cultivars were grown in a vertical farm under short (10 and 12 hours) and long (14 and 16 hours) photoperiods for ten weeks. Vegetative growth and flowering behavior were analyzed. The EB types flowered in all photoperiods. In the SF types flower initiation (but no emergence) took place only in short photoperiods. Although leaf area and petiole length decreased under short photoperiods in all cultivars, this effect was less pronounced in the EB types. Leaf samples were taken throughout the experiment to analyze the transcriptome. RT-qPCR will be used to compare the expression of genes involved in flowering, vegetative growth and dormancy regulation. Additionally, RNAseq analysis will be used to elucidate which genes, involved in plant development, are differentially expressed between SF and EB types. In the first phase of this research, we found clear differences in vegetative growth and flower development between SF and EB strawberry plants. EB types will flower under any photoperiod. In this sense they are less complex than SF types, which require exposure to short photoperiods followed by chilling to break winter dormancy. However, SF types offer the possibility to dynamically switch between generative (short photoperiods) and vegetative growth (long photoperiods). The results of this research are expected to increase our understanding of the genetic regulation of traits that differentiate SF and EB types. This information may be of use in breeding programs.

Keywords: vertical farming, strawberry, seasonal flowering (SF), everbearing (EB)

Exploring the potentiality of vertical farming: pilot plant of saffron (*Crocus sativus* L.)

DAVIDE CELENTANO, Viktor Kulcsár, Miroslav Hronček

Veles Farming, Železničná, 900 41 Rovinka, Slovakia,

Saffron (*Crocus sativus*) holds a distinctive position in the spices market due to its unique flavour, colour, and medicinal properties. While renowned for its culinary applications, saffron's compounds extend beyond the kitchen. For example, it finds utility in pharmaceuticals where its antidepressant, antiinflammatory, and bio-enhancer properties are extensively employed; and in cosmetics as a skincare ally, with its antioxidants combating ageing, elevating radiance, and fostering a healthy complexion. The EU saffron market faces challenges due to the strong presence of counterfeit products and inconsistent quality. In recent years, the European market has encountered significant issues in offering high-quality saffron. Political instability among major worldwide producers and continuously changing, unfavourable outdoor environmental conditions have resulted in substantial losses in saffron production, both in terms of quality and quantity. Traditionally cultivated in open fields, at Veles Farming, we are exploring the potential of indoor saffron cultivation. The objective is to enhance the quality and consistency of saffron production, reduce human labour requirements, and efficiently regulate critical growth stages through precision environmental control. In our new pilot plant, we investigate the adaptation of saffron cultivation to vertical farming systems. Vertical farming for saffron offers advantages such as space efficiency, the ability to implement automation in the production process and precise environmental conditions for each growth phase. By harnessing advanced technologies, we aim to create an environment that mimics optimal conditions for all the life cycle stages, including dormancy, flowering, and propagation. Moreover, the system allows us to manipulate factors such as temperature, humidity, CO_2, light intensity, and photoperiod to simulate the distinct phases of the saffron life cycle and adapt the cultivation to the market's needs. The optimization of these conditions aims to induce dormancy effectively, trigger flowering at the desired time, and facilitate efficient propagation. Obtained preliminary results are promising for indoor saffron cultivation, with shown potential in producing saffron of superior quality, with the possibility to focus on colour, flavour, and bioactive compound content. Additionally, our findings suggest that the manipulation of environmental conditions can effectively synchronize the saffron life cycle, leading to improved yields and a more predictable harvest schedule.

Keywords: indoor farms, Plant Factories with Artificial Lighting (PFALs), LED lights, phenology

Unveiling the productivity potential of vertical farming through diverse crop cultivation: an empirical analysis

VIVEK JADHAV, Alessandro Pistillo, Laura Carotti, Alberto Tassinari, Giuseppina Pennisi, Silvio Salvi, Giorgio Gianquinto, Francesco Orsini

Alma Mater Studiorum – University of Bologna, DISTAL – Department of Agricultural and Food Sciences, Viale Giuseppe Fanin 44, 40127, Bologna, Italy.

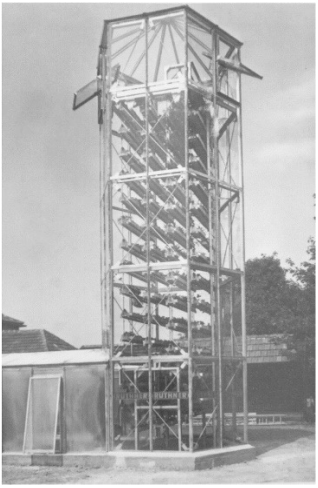
Vertical farms, compared to other crop production systems, are particularly efficient in terms of land use, thus representing a strategy for increasing food security within densely populated urban areas. Main challenges of the sector include both the optimization of energy use efficiency altogether and the need for crop diversification. While it is commonly agreed that the technology needs to move beyond growing leafy greens and herbs, its potential application for the production of more nutritional fruit crops or even stable crops such as grains is being debated, specifically in consideration of their yield potential and resource use efficiency. This research, performed within AlmaVFarm, the experimental vertical farm of the University of Bologna, aims to investigate the yield performance and the resource use efficiency of five different crops. The species used for the experiment were two staple crops (namely rice, *Oryza sativa* and dwarf maize, *Zea mays*), a fruit crop (dwarf tomato, *Solanum lycopersicum*), an herb (sweet basil, *Ocimum basilicum*), and a leafy green, used as control (lettuce, *Lactuca sativa* var. Canasta). All crops were sown in polyethylene trays containing 70% peat and 30% vermiculite placed in a closed-loop ebb-and-flow system. While sweet basil and lettuce remained in the same trays for the entire growth cycle, seedlings of tomato, rice, and maize were transplanted at 19, 15, and 15 days after sowing, respectively, and placed back into the ebb and flow system. All crops were grown under consistent environmental conditions (24/21°C temperature, 65/75% humidity, day/night, 850 ppm CO_2) with LED lighting providing 16-hour photoperiod, and 200 μmol m^{-2} s^{-1} PPFD of a red and blue spectrum with RB ratio of 3. For each crop, morphological destructive measurements have been performed together with physiological measurements (photosynthetic activity, leaf gas exchanges, chlorophyll a fluorescence, and chlorophyll content). Moreover, during the entire growth cycle (with different lengths, depending on the crops) energy consumption associated with LED lamps and water consumption was monitored. The presentation will elaborate on how vertical farming can be applied effectively to various crops, offering insights into resource optimization, energy efficiency, and crop diversity enhancement within this farming system.

Keywords: vertical farming, energy use efficiency, land use efficiency, crop diversity, crop physiology

Stepstones on vertical farm evolution: part II

1964

60 years ago, a prototype vertical farm (in the form of a glass tower) was displayed at the Vienna International Horticulture Exhibition.



1988

About 35 years ago, the Biomass Production Chamber was opened at NASA Kennedy Space Center, resembling an operational vertical farm.

January 17th

SESSION: VISIONS FOR SYSTEM INNOVATION

CHAIR: S. DE PASCALE

ERI HAYASHI

Plant factory innovations for sustainable well-being societies

The technological and socio-economic features of plant factories/indoor vertical farms, the economics of energy and other resource use, and real-world examples of commercial plant factory development and innovations will be introduced. Furthermore, some of the forthcoming technologies, including plant phenotyping based on cohort research, and global challenges to the research and development towards sustainable plant factories for better well-being societies will be discussed.

Keywords: vertical farming, commercial plant factory, plant phenotyping, well-being societies

Eri Hayashi serves as vice president of the Japan Plant Factory Association (JPFA), a nonprofit organization devoted to academic and business advancements in plant factory/controlled environment agriculture (CEA). Before joining the JPFA, Eri worked at a private research institute in Tokyo, specializing in technology advancement for global food production. She has been conducting international field research on plant factories/CEA since 2008. She has published multiple research papers and has been a research project manager on artificial intelligence and phenotyping-based next-generation plant factory for environmental control and breeding. She has a keen interest in technological advances, including phenotyping, in plant factories. She received a Ph.D. from the Graduate School of Horticulture, Chiba University.

January 17th
SESSION: LIGHT

CHAIR: T. OUZOUNIS

THEOHARIS OUZOUNIS

Is the future of LED lighting destined to be D.E.A.D. – Dynamic, Efficient, Affordable, and Durable?

In this brief introduction, Theoharis Ouzounis will discuss this intriguing question that raises vital considerations for ongoing research in the field. He will delve into the pivotal facets of plant research conducted under LED lighting and his insights will set the stage for the forthcoming session and also provide an understanding of the essential elements driving the evolution of LED lighting technology.

Keywords: LEDs, lighting technology

Theoharis Ouzounis serves as the Chief Scientific Officer (CSO) at Red Horticulture, an international scale-up company headquartered in France with offices in the Netherlands. The company specializes in industrial photobiology and offers comprehensive dynamic LED lighting solutions. Prior to his role at Red Horticulture, Haris held a number of positions in the field of Controlled Environment Agriculture. He worked as a Research Manager at Aerofarms in Abu Dhabi and previously served as the Research Project Manager at Fluence in EMEA, based in the Netherlands. His academic journey includes a postdoctoral research position at Wageningen University, a PhD from the University of Southern Denmark (in collaboration with Aarhus University and the University of Copenhagen), a MSc from Michigan State University in the USA, and a BSc from Aristotle University in Greece. Haris possesses expertise in spectral and light intensity responses, as well as extensive experience in planning, defining, executing, and delivering projects within the realms of greenhouses, indoor farms, and climate chambers. He excels in establishing strategic partnerships with both commercial and academic entities, fostering collaborative relationships that consistently yield successful and impactful outcomes.

LEO F.M. MARCELIS

Optimizing lighting management in vertical farms

Light has different characteristics such as intensity, daily light integral, photoperiod, spectrum, direction and heat. All these characteristics can have profound effects on plant growth, development and quality. Besides effects on primary metabolism LED light can also trigger the formation of secondary metabolites in the plant resulting in for instance increased antioxidants such as vitamin C or anthocyanins. The lighting determines to a large extent the energy use of a vertical farm. For profitability and sustainability of vertical farms, it is of utmost importance to improve the light use efficiency. In this presentation, the light use efficiency in vertical farms will first be compared with that in greenhouses and open field. Subsequently, some physiological, developmental and morphological responses of crops to light (intensity, spectrum, position, photoperiod) will be discussed and a number of examples of how to use different lighting strategies to control yield and quality of plants produced in vertical farms and to reduce the energy use will be provided.

Keywords: light characteristics, LEDs, vertical farming, plant responses, light use efficiency

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 the post-harvest quality. Marcelis has a vast experience in studying the physiology, growth and product formation of plants and plant organs 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 partitioning among plant organs in response to abiotic constraints are subject of study. He has (co-) authored more than 90 scientific articles with an H-index of 29 (according to Web of Science) and over 250 articles for growers. He is chief editor of the section Crop and Product Physiology of Frontiers in Plant Science.

LAURA CAMMARISANO

Tailored light application for increased produce value in vertical faming

Light is the primary energy source and cue for plants. Plants are able to absorb photons' radiant energy and convert it into chemical energy to build biomass. In addition to biomass, a whole variety of organic compounds is generated, some of which help the plant to cope with surrounding environment and constitute beneficial substances for human health. Farming in vertically-stacked growth layers requires artificial light which, through LEDs, can be administered with precision to accurately shape the farmed plant produce quantity and quality with resulting increased efficiency.

Laura Cammarisano is a scientist postdoc at Leibniz - Institute of Vegetable and Ornamental Crops (IGZ) in Germany. She obtained her PhD in 2020 from Aberystwyth University in Wales with a project aiming at optimising lettuce biomass and quality in vertical production systems by the sole use of light features. Her research focuses on plant responses to light in indoor farming with the goal to monitor and tailor early plant stress and related quality improvements. She collaborates with non-profit association and industries in vertical farming.

ILARIA ZAULI

Improving lighting conditions for enhanced kale baby leaf production

In recent times, an increased request for highly nutritious, minimally processed, or ready-to-eat products, has been observed. In this scenario, baby-leaf vegetables represent an example of a nutritional food commodity, highly suitable for indoor farming production, thanks to their short growth cycle and small size, allowing for multiple harvests and enhanced yield per year. Moreover, leafy greens, especially in their juvenile stage, have been recognized for their high nutraceutical significance, as for the case of Cruciferae, including kale (*Brassica oleracea* L). Considering the novelty provided by the indoor farming sector, assessments of crop performance and feasibility are still limited to few crop species, mainly belonging to few leafy greens species (e.g., lettuce) and herbs (e.g., basil). The present research work aimed at obtaining valuable data on kale baby-leaf cultivation in vertical farming systems, with the application of different artificial lighting regimes. The main effects associated with different light spectra and a combination of photoperiod and intensity on yield and resource use efficiency will be displayed, to provide indications and new insights for more profitable cultivation of kale baby leaf in vertical farms.

Keywords: vertical farming, resource use efficiency, LEDs, ready-to-eat products

Ilaria Zauli is a PhD student at Bologna University. Her research focuses on new species in aeroponic and hydroponic systems for vertical farming, testing different light and growing conditions to improve yield and resources use efficiency. She is involved in the European project H2020 FoodE (Food System in European Cities) and in the national PRIN project VFarm (Sustainable Vertical Farming).

January 17th
SESSION: LIGHT

CHAIR: G. PENNISI

LAURA CAROTTI

Optimized Far-Red Radiation management for improved yield and resource use efficiency in lettuce (*Lactuca sativa* L.) grown in a vertical farm

Monitoring and optimizing indoor growing systems' energy-use efficiency (g fresh weight kWh^{-1}) and light-use efficiency (g dry weight mol^{-1}) is crucial to ensure their economic and environmental sustainability. A valuable strategy to enhance these two variables, and consequently the yield, is the specific management of light properties. The aim of this research is to evaluate the effect of far-red radiation (700-780 nm) on light and energy use efficiency, characterizing the effects on crop morphology and physiology, and ultimately on the quality of lettuce in relation to other light components (e.g., light spectrum, specifically red and blue radiation, photoperiod and light intensity). The research also allows for elaborating dynamic lighting management strategies in response to the different crop phenological stages.

Keywords: LED lighting, light use efficiency, Far-red fraction, daily light integral, growth analysis

Laura Carotti is a PhD student at the University of Bologna, in the Department of Agricultural and Food Sciences. Her research focuses on cultivation techniques to increase resource use efficiency, in both experimental and commercial systems, particularly through light management. She is involved in several projects, such as the European project H2020 FoodE (Food System in European Cities).

JOSÉ ERNESTO OLVERA GONZÁLEZ

LED light manipulation: use of pulsed light recipes in plant growth to reduce electricity consumption

LED-based artificial light is one of the most important variables in intensive plant production systems for human consumption. Pulsed light techniques are manipulations of the emission of LED light through pulses at different speeds (Hertz) and duty cycles. The different light recipes reported in the literature that have a positive effect on the growth and development of crops can be pulsed to reduce energy consumption in vertical farms and plant factories.

Keywords: LEDs, pulsed light, vertical farming, energy consumption

PhD. José Ernesto Olvera González is a professor-researcher and current President of Technological Institute of Pabellón of Arteaga in Aguascalientes, Mexico. He earned a doctorate in engineering sciences at the Autonomous University of Zacatecas and is the founder of the Artificial Lighting Laboratory (LIA), the only laboratory in Mexico 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 20 published international scientific research and technological innovation.

DAFNI AVGOUSTAKI

Optimizing lighting management in vertical farms

Most of the selected cultivated species in vertical farms, specifically leafy vegetables, require multiple hours of photoperiod to reach their full potential in terms of biomass, leaf size, nutritional value, taste, and color. At the same time, the cost of electricity can be very high due to the many hours of operation and the intense light provision which could be an inhibiting factor for the sustainability status of technology and at the same time jeopardize the financial viability of the farm. In this study, we tested the growth of *Valerianella locusta* plants under continuous and interrupted photoperiodic light intervals. The leaf physiological traits of two different photoperiod treatments were assessed and used to estimate the toleration rate of the plants under different lighting schemes. In the first indoor growth chamber, plants were grown under 14 h of continuous light while in the second chamber under a normalized photoperiod of 14 h with intermittent light intervals of 10 minutes of light followed by 50 minutes of dark. The purpose was to examine, assess and design flexible disruptive light exposure to reduce the compact electricity consumption for crops grown in indoor environments with more flexible protocols while maintaining a high growth rate and biomass production of the plants. The presented results of this experiment show a positive correlation of the plants' responses to abiotic stress when exposed to short light periods of disruptive light, without having significant effects on the physiological responses of the crop. Post harvest measurements revealed that plants under intermittent lighting protocols produced almost double fresh and dry biomass compared to plants under continuous photoperiod, while operated under a more flexible lighting schedule that could act as a load shifted energy demand response unit and operated under the most profitable and ecological energy schemes.

Keywords: energy efficiency, photoperiod, vertical farming, electricity consumption indoor farming

Dafni Avgoustaki is a Postdoc researcher at the Agricultural University of Athens. She is an agriculture engineer and holds a PhD in the optimisation of energy efficiency for

artificial light operation from indoor vertical farms from the Department of Business Development and Technology (BTECH) of Aarhus University in Denmark (AU) (year 2021). She specializes in the development, evaluation and application of new and efficient techniques and technologies for the production of agricultural products in controlled growing conditions (vertical crops, greenhouses, hydroponic systems, and artificial lighting systems), rational, efficient and sustainable management of natural resources in agricultural systems. She also works on remote sensing and crop monitoring through reflective measurements as well as practices for improving the energy efficiency, cultivation management and diseases detections of crop via image processing and analysis and precision agriculture. Additionally, she has participated in 5 scientific projects (national and Danish and European) and worked as project coordinator. She has participated in 3 entrepreneurship programs as the co-founder of her start-up (VerdeCube) based in Denmark that produces smart-decision energy management software for artificial lighting in closed vertical farming crops. She has 15 publications in international peer-reviewed journals and 5 publications in international conferences.

ANTONIO FERRANTE

Light quality and intensity modulation on yield and quality on leafy vegetables grown in vertical farms

The yield and quality in vertical farms are related to light quality and quantity. The light quality has a major effect on crop morphology and composition. The loss of specific bands of spectrum in certain crops can modify the normal growth of leaves, this can compromise the visual appearance of the produce. The increase of specific parts of spectrum such as UV-A, UV-B, or blue light can induce the stimulation of secondary metabolism with increase of phenolic compounds, anthocyanins, and carotenoids. Besides the quality, it is important the intensity that directly influences the photosynthesis and biomass accumulation and nutrient assimilation such as nitrogen with effect on the nitrate accumulation. The intensity of the different different blue and red bands has effect on the crop's performance. Specific light intensity modulation within the photoperiod can affect the crop yield and energy use efficiency.

Keywords: light spectrum, light management, secondary metabolism, biomass, energy use efficiency

Antonio Ferrante is full professor of Horticulture and Floriculture at the University of Milan. He studied Agricultural Sciences at the University of Pisa where he graduated with honours in 1992, he was a student and PhD student at the Sant'Anna School of Advanced Studies in Pisa. He started his academic career as a technician at the University of Pisa in 2001 and from 2004 at the University of Milan first as university researcher until 2016 and as associate professor until 2021. He spent several periods abroad at the University of California, Davis, USA (2000). Member of SOI since 2001 of the International Society of Horticultural Science (ISHS) since 2005, and of the Agricultural Society of Lombardy, since 2018. Appointed Academic Correspondent of the Accademia dei Georgofili in Florence since 2017. President of the Italian of Horticultural Society from 2022. He authored more than 200 publications in scientific and technical journals, most of which indexed in Scopus.

TAO LI

Plant responses to UV-A1 radiation are species and background irradiance dependent

A large fraction of solar UV radiation that reaches the Earth's surface is in the UV-A1 waveband (350-400 nm). Despite its prevalence, it is relatively unknown how strongly plant species differ in their response to UV-A1, and how their responses to UV-A1 depend on the intensity of photosynthetically active radiation (PAR). We grew several horticultural (tomato, cucumber, and two lettuce cultivars) and a model species (*Arabidopsis thaliana*) under low (LL; 150 μmol m^{-2} s^{-1}) and high PAR (HL; 550 μmol m^{-2} s^{-1}), each of which was paired with UV-A1 (peaking at 365 nm) at irradiances of 0, 20, and 100 μmol m^{-2} s^{-1}. *Arabidopsis* was the most strongly affected, as under LL, the addition of UV-A1 resulted in early flowering, changes in leaf shape, and strong decreases in shoot dry weight (~40%). UV-A1 exposure induced photoinhibition (low Fv/Fm) only under LL, but not under HL in all species. Under HL, exposure to UV-A1 also induced strong decreases in the concentrations of UV-absorbing compounds and anthocyanins in *Arabidopsis* (Columbia-0) and lettuce cv. 'Klee', but not in other genotypes. Altogether, we found that UV-A1 exerted only mild stress on the morphology of horticultural crops (e.g. petiole angle, leaf shape and curvature), and did not significantly alter biomass or leaf biochemical compound concentrations. In contrast, these traits were strongly affected by UV-A1 in *Arabidopsis*, highlighting the importance of not relying solely on model species when exploring environmental effects on plants.

Keywords: UV radiation, light intensity, *Arabidopsis thaliana,* horticultural crops

Tao Li was awarded a PhD degree in Horticulture and Product Physiology group of Wageningen University in January 2015. Since July 2015 he worked at Institute of Environment and Sustainable Development in Agriculture, Chinese Academy of Agricultural Sciences (CAAS). In January 2022 he was promoted as a professor in subject of Controlled Environmental Agriculture. His research activity is to explore the potential of crop yield and quality improvement by applying LEDs. At present, he is the chief scientist of a National Key Research and Development Program of China, mainly focusing on exploring the potential of using plant factory for speed breeding

of staple crops. To date, he has published more than 50 scientific papers in the international peer reviewed journals, and he often attend international symposiums and give presentations.

January 17th
Fast Talks - LIGHT

CHAIR: G. PENNISI

Use of luminescent plastic films for horticultural and aromatic crops cultivation: possible applications in indoor environments

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Light quality is a fundamental aspect for optimizing the growth, productive capacity and products quality of various horticultural and aromatic species. LED light is the best technological tool on the market for providing plants with specific wavelengths. However, other wavelength selection methods could be applied in horticulture, both in greenhouses and indoor contexts. In particular, luminescent films based on spectral converting molecules can be used to tune the light spectrum improving plant growth. The present study aims to evaluate the effect of two luminescent films (red and orange) in multilayer and monolayer versions for the cultivation of *Lactuca sativa* and *Ocimum basilicum*. The experiment was carried out in an indoor environment, providing LED illumination with white light at an intensity of approximately 150 µmol m^{-2} s^{-1} for 16 h d^{-1}. The indoor environment temperature was around 25°C during the day and 21°C during the night, with an RH of 70-80%. The experiment was divided into two phases. The first phase tested the monolayer orange and red films, compared with an uncolored control film, for both species. The second phase involved a test on multilayer films with the same colors and uncolored control, for both species. The use of luminescent films for the selection of specific light wavelengths could prove to be an interesting method to favor some qualitative and growth characteristics of horticultural and aromatic species. If applied to tune natural sunlight in greenhouse context, such method could reduce the costs of electricity determined by the control of the spectra by LED light.

Keywords: luminescent plastic film, wavelength, LED light, Ocimum basilicum, Lactuca sativa

The effect of red/blue light ratios on fruit set and plant growth of sweet pepper

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Plant growth in vertical farming is based on artificial lighting. Red is often considered as the most efficient color of light for plant growth, but plants do not develop normally when grown solely under monochromatic red light. The addition of blue light can aid normal plant development. Consequently, a mixture of red and blue light became one of the most popular lighting spectra for artificial lighting. Different red: blue ratios of lighting was found to have a great influence on plant morphology and physiology. Fruit set is a crucial plant developmental process, determining yield in many crops. In pepper (*Capsicum annuum* L.) typically about two-thirds of all flowers abort, even in protected cultivation. However, the influence of light spectrum on fruit set has hardly been investigated. In the current study, we aim to investigate how different red: blue ratios in a red-blue light spectrum influence fruit set of sweet pepper. A climate chamber experiment was conducted, where young sweet pepper plants were grown under a red: blue ratio of 0.1, 1, 3, 10 with a total photosynthetic photon flux density of 200 µmol m^{-2} s^{-1}. Since most flower and fruit abortion appeared in the second week after anthesis, we collected flower samples when they were at anthesis and on day 7 after anthesis for hormonal profiling and carbohydrate analyses.
Sweet pepper plants grown under the lowest red: blue ratio showed the lowest number of fruits (around 3 fruits per plant), while the other three treatments showed similar fruit numbers (6-7 fruits per plant), where each plant was allowed to retain 12 flowers on 4 main stems. This finding correlated with a lower starch content in the flowers both at anthesis and on day 7 after anthesis under a red: blue ratio of 0.1. These flowers also had a lower auxin (IAA) concentration, a higher salicylic acid (SA) and a higher cytokinins (CKs) concentration on day 7 after anthesis. At lower red: blue ratio, plants showed a reduced plant dry mass aboveground, which correlated to a lower leaf area. However, the number of leaves, specific leaf area and plant height were hardly affected. The lowest red: blue ratio of light caused a low fruit set in sweet pepper probably by altering the carbohydrate accumulation and hormonal status of flowers.

Keywords: Capsicum, light quality, carbohydrates, phytohormones, fruit set

Matching the photoperiod with the circadian rhythm of lettuces is necessary to save energy efficiently in indoor farming

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Energy consumption of indoor farming facilities is highly dependent on lighting periods. Moreover, the cost of indoor productions can be efficiently reduced by modifying the photoperiod, because lighting can be provided when electricity prices are at their lowest. However, photoperiod affects the physiology of plants through their circadian rhythm, an endogenous 24 hours-based rhythm that regulates metabolisms, and therefore growth and light use efficiency. Thus, it is necessary to better characterize the link between the circadian rhythm and energy savings of indoor productions. In this work, we studied two lighting management that reduced the energy consumption of lettuces production by disrupting their circadian rhythm. The control was cultivated under a standard photoperiod of 16/8 (16h of light and 8h of darkness). The first modality, '12.5%', saved 12.5% of light-related energy by reducing the lighting period by 6 hours every 3 days. The second modality, '25%', saved 25% of light-related energy by reducing the lighting period by 12 hours every 3 days. Lettuces were cultivated in GiGrow® cultivation system for 30 days and photosynthetic activity, yields and light use efficiency were determined. At harvest, the fresh weight of lettuces under the '12.5%' modality was similar to the control but dry weight and light use efficiency were significantly lower. For lettuces under the '25%' modality, fresh weight, dry weight and light use efficiency at harvest were significantly lower than the control. Dry weight of '12.5%' and '25%' modalities were approximately 30% and 55% lower than the control respectively. These data were consistent with the study of the photosynthesis, as the photosynthetic activity was altered the day following the reduced lighting period. We can conclude that the circadian rhythm limits energy savings by decreasing the light use efficiency of plants. Thus, matching the photoperiod with the circadian rhythm is necessary to efficiently reduce the energy use in indoor farming.

Keywords: energy saving, indoor farming, circadian rhythm, photoperiod, lettuce

Effect of continuous lighting on growth and quality of basil plants grown indoor

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In indoor cultivation with strict climate control and artificial lighting, such as greenhouses and vertical farms, crop yield is closely correlated with the daily light integral (DLI), which is the total amount of light intercepted by plants in 24 h and depends on both light intensity and photoperiod. In vertical farms, crop plants are typically illuminated for 14-18 hours at photosynthetic photon flux density (PPFD) of 150-250 μmol m^{-2} s^{-1}. Continuous lighting (CL), which maximizes the illumination period while minimizing the light intensity and the peak demand of electricity at the same DLI, is a method to reduce the investment cost for the lighting system (less fixtures are necessary) and the operational costs for air conditioning. However, CL have both negative and positive effects on crop performance, depending on plant species. Sweet basil (*Ocimum basilicum* L.) is an important aromatic herb grown and consumed all over the world thanks to its organoleptic, nutritional and nutraceutical properties. The short cycle, the rapid growth, the easy cultivation, and the ability to adapt to different growing conditions and cultivation systems make basil one of the most used crops in vertical farms. This study intended to investigate the effect of CL on how sweet basil grew in a growth chamber under red, blue, and green LED lights (R:B:G=3:1:1). Basil plants were grown hydroponically for 15 days with the same DLI (12.8 mol m^{-2} d^{-1}; the optimal DLI for basil) with a 16-h photoperiod and a PPFD of 220 μmol m^{-2} s^{-1} or under CL with a PPFD of 148 μmol m^{-2} s^{-1}. Crop yield, leaf dry matter content, and total dry matter accumulation were not significantly affected by the light regime. Compared with the 16-h photoperiod, CL increased the leaf antioxidant capacity, as measured by FRAP (+45%) or DPPH assay (+56%), and concentration of total carotenoids (+10%), flavonoids (+36%), and phenols (+44%). Continuous light also reduced leaf area index (-15%) and the plant concentration of several mineral nutrients (for instance, Mg, Ca, K, Mn and Zn in leaf tissues).

Keywords: photoperiod, LED lights, *Ocimum basilicum*, hydroponics

January 17th
SESSION: BUSINESS SESSION

CHAIR: M.J. BUSTAMANTE

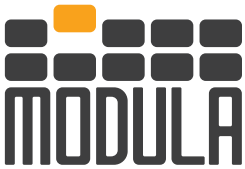
MARIA J. BUSTAMANTE

Pushing through the trough of disillusionment – collaborating for better indoor farming

After a difficult period including company closures, layoffs and reduced valuations, indoor farming is in a moment of path correction as questions about viability and technological limitations arise. During this roundtable, we will bring together perspectives from practice and research to discuss the opportunities and challenges for collaborating around building and running efficient, sustainable and profitable indoor farms in order to weather the trough of disillusionment. The roundtable will include representatives from value chain actors in areas such as plant nutrition, climate control and system design and manufacturing, among others. The discussion will focus on key topics and debates such as – what types of current industrial solution adaptations are working versus what are the needs for tailor-made solutions for indoor agriculture? As the indoor farming industry matures, what should farms look to do themselves and where should they collaborate? How can sustainability across the value chain be improved?

Keywords: vertical farming, industrial innovation, sustainability, viabilty

Maria J. Bustamante is a postdoctoral researcher at KTH Royal Institute of Technology in Sweden where her research focuses on high-tech vertical farming. Her research project seeks to understand the sustainability and viability of modular vertical farming systems by studying the new service and data-driven business models these systems represent for both retailers and vertical farming companies. The overall goal is to build a greater understanding of the potential impact and changes needed within organizations and the broader value chain to achieve both organizational and societal goals related to sustainability. Maria holds a Ph.D. in Business Administration from the Stockholm School of Economics.



M. GIULIANI

D. GENNARO

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January 17th
Fast Talks - LIGHT

CHAIR: D. AVGOUSTAKI, Y. LI

Ornamental young plant production using a dynamic light strategy in a vertical farm

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High quality rooted cuttings are essential for optimal growth and production of ornamental plants. Producing these high-quality young plants requires a high level of specialization and highly controlled climatic conditions. Young plants are also characterized by a relatively short production phase, a high number of plantlets per production area and small dimensions, which makes them highly suitable for multilayer production. Furthermore, using spectral light quality to influence adventitious rooting and compactness might lead to a faster and more uniform quality of young plants. Since far-red light stimulates adventitious rooting, but also enhances elongation growth, a spectrum with continuous far-red light might improve rooting quality but impair plant quality as compactness is an essential quality trait. To both stimulate rooting and maintain compactness, a dynamic light strategy was tested during the production of young plants of Nemesia, Petunia, Verbena and Lobularia. Adventitious rooting took place under sole LED lighting, using blue (B), red (R) and far-red (FR) LEDs (Philips Green Power LED research modules) with a 12 h photoperiod for 2 weeks. Three fixed light spectra with the following photon flux densities (subscript in $\mu mol\ m^{-2}\ s^{-1}$): B16 R44, B16 R44 FR16, B16 R44 FR50 and 2 dynamic light spectra: B16 R44 FR50/0 and B22 R33 FR50/0 in which FR was switched off after 1 week, were tested. Adding far-red light to the light spectrum increased rooting for all bedding plants. This positive effect was present in the fixed light spectra as well as in the dynamic light spectra. Plant height increased with an increasing amount of far-red light in the fixed light spectra, while the dynamic light spectra could control the elongation of the cuttings. The supplemental blue light in B22 R33 FR50/0 resulted in equally compact cuttings compared to B16 R44. While cuttings rooted under B16 R44 FR50/0 were slightly longer depending on the genotype but still significantly shorter than under the fixed spectrum with an equal amount of far-red light (B16 R44 FR50). The results show the potential of using a dynamic light spectrum during the production of ornamental young plants in a vertical farm.

Keywords: bedding plants, adventitious rooting, light quality

Enhancing fruit quality in tomato cultivation: the interaction of electrical conductivity and light intensity

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Increasing electrical conductivity (EC) in nutrient solutions is a common practice to enhance fruit quality, especially sweetness, in tomato cultivation. However, high EC levels often reduce yield and may lead to fruit disorders like blossom-end rot. Increasing light intensity promotes photosynthesis and the biosynthesis of phytochemicals, such as carbohydrates and vitamin C, which not only contribute to higher yield but also improve flavor and nutritional quality. Simultaneously increasing both the EC level and light intensity presents an opportunity to produce high quality tomatoes without compromising yield. We investigated the interaction effects of different EC levels and light intensities on dwarf tomato yield, nutritional value, flavor, and shelf life. Dwarf tomato varieties (cv. Cherry Red and cv. Cherry Orange) were subjected to varying EC levels (2, 4, 6, and 8 dS m^{-1}) and light intensities (150, 215, 280, and 345 µmol m^{-2} s^{-1}, supplemental light) at 25 days after sowing, and mature fruits were harvested after 9 weeks of treatment. The interaction effect of EC level and light intensity significantly influenced fruit fresh weight, fruit flavor, Brix level, shelf life, and vitamin C content. Increased light intensity compensated for the negative effects of high EC on fruit fresh weight, as the fruit fresh weight under EC6 with 345 µmol m^{-2} s^{-1} was similar to that under EC2 with 215 µmol m^{-2} s^{-1} in both cultivars. Fruit flavor and Brix level were improved with increasing EC levels, and these effects were magnified by high light intensity. Fruit shelf life was prolonged by approximately 4 days under EC6 and EC8 with the highest light intensity. Fruit vitamin C content increased with higher light intensity, with the highest values observed under EC2 and EC8. Furthermore, fruit carbohydrate content significantly increased with improved EC levels in both cultivars, while the interaction effect of high light intensity further enhanced the carbohydrate level found only in the red cultivar. These results offer valuable insights for optimizing cultivation practices in vertical farms and greenhouses to produce tasty, nutritious, and long-lasting fruits without compromising yield.

Keywords: light intensity, electrical conductivity, yield, nutritional quality, flavor

Measuring indoor emissions in vertical farm under different LED lighting

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To enhance qualitative and quantitative crop features, researchers are exploring the integration of LED technology in Vertical Farms (VFs). However, the indoor environment poses challenges due to the accumulation of Biogenic Volatile Organic Compounds (BVOCs) released by plants, which can impact the overall quality of these setups. The impact of two distinct red (R) and blue (B) light ratios, denoted as RB1 and RB3, on BVOC emissions from basil plant cultivated in the experimental vertical farm of the University of Bologna (AlmaVFarm) was assessed. The levels of compliance with the Lower Concentrations of Interest (LCIs) outlined in the European Regulation were considered. We collected emission data at different stages of the crop cycle under static conditions, monitoring various physiological and environmental parameters. In the aromatic blend representative Mono-, Sesqui- and Oxygenated Mono- Terpenes, Phenylpropanoid compounds, and Lipoxygenase derivatives (LOXs) were determined. While we observed differences in BVOC profiles and quantities between the light treatments and the stages, statistical analysis did not yield significant evidence implicating light as a major factor. Interestingly, RB1 marginally stimulated BVOC emissions in young plants, whereas RB3 primarily induced emissions in the mature stage. Moreover, multiple correlations between certain emitted volatiles and monitored variables were encountered, which were linked to a defined wavelength. Overall, most of the BVOC emissions remained below corresponding LCIs, except for occasional bursts of LOX volatiles exceeding these levels, indicating that basil cultivation in indoor VFs is generally safe in terms of detected emissions. Nevertheless, findings suggested that further investigation will be necessary to clear up the intricate relationships between emissions and the involved variables.

Keywords: basil, BVOCs, artificial light, aeroponics, integrated agriculture

Dynamic control of LED-light intensity in vertical farming: growth, metabolic compounds, and electricity savings in lettuce (*Lactuca sativa* L.) cultivation

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In highly advanced indoor vertical farming (VF) systems, where artificial lighting consumes 70–80% of electricity costs, modern control and automation systems present attractive opportunities for manipulating the light environment and designing lighting regimes. These systems enable growers to plan their lighting regimes in ways that simultaneously facilitate sufficient crop growth and economical electricity consumption through appropriately timed adjustments to light intensity. Photobiological responses to changing light intensity conditions have mostly been studied in Arabidopsis thaliana, but less so in agricultural crops. In the present study, we tested three dynamically changing lighting regimes where periods of high light intensity were scheduled to occur either at the beginning, midpoint, or end of the photoperiod. The daily light integral (DLI) between the regimes was kept constant. Growth and metabolite responses of lettuce (*Lactuca sativa* L. cv. 'Katusa') as well as production cost-efficiency were studied. The results indicated that moderate light intensity fluctuations may be incorporated into lighting regimes without major disruptions to growth in lettuce cultivation. Primary metabolite compounds such as starch and sucrose accumulated during high light intensity periods as expected. In terms of secondary metabolites, mostly flavonol derivatives accumulated towards the end of photoperiods regardless of changes in light intensity, implying that flavonol biosynthesis could be controlled by the circadian clock. The results suggested that in a scenario where electricity consumption is charged by the hour according to the daily/seasonal electricity market price fluctuations, up to 20–30% reductions in electricity costs (total electricity consumption remaining the same) could be achieved with dynamically adjusting lighting regimes.

Keywords: vertical farming, LED-technology, electricity consumption, photobiology, daily light integral

Supplemental Red light to cope with salt stress in pepper (*Capsicum annuum* L.) plants

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The use of complementary light spectra is a potential new approach to studying the increase in plant resilience under stress conditions. In this work, the effect of R LED on the plant response to salinity was studied. For that, pepper plants were treated with 50 mM NaCl, during 2 weeks, with and without previous R LED pulse (GH CSSRM5.24 OSLON ® Square model). Thus, the studied treatments were CON, R LED NaCl and LED+NaCl. Plant growth, antioxidant capacity of the plants, stomata opening, gas exchanges parameters and the expression of different intrinsic membrane proteins, aquaporin (AQPs) isoforms involved in water and CO_2 transport, were determined. LED+NaCl treated plants showed higher shoot biomass, stomata conductance, transpiration and photosynthesis rate with regard NaCl treated plants, alleviating toxicity symptoms of salt stress. This increase in biomass and photosynthesis can be related to enhanced stomata opening and the higher expression of PIP1;2 isoforms in LED+NaCl treated plants with regard NaCl treated plants, since this isoform is involved in water and CO_2 transport. In roots, PIP2;7 expression was lower in LED+NaCl treated plants compared to NaCl plants, according to the PIP down-regulation that might limit water loss and create a hydraulic signal that may induce stomatal regulation. Total flavonoids and phenolic compounds involved in plant protection against salt stress as well as antioxidant ABTS capacity were higher in LED+NaCl treated plants regarding NaCl plants. Therefore, R LED may alleviate salinity damage in pepper plants through an improved water and CO_2 uptake and antioxidant capacity.

Keywords: antioxidants, aquaporins; *Capsicum annuum*; LED-lighting; photosynthesis

Effect of two weeks of continuous light treatment on dwarf tomato at different developmental stages

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The application of continuous light (CL) to grow plants in a controlled environment agriculture setting can potentially save energy by shortening the growth cycle and reducing the need for climate control; with CL the same DLI can be reached with lower light intensity while less heat is produced by the light fixtures. In some crops, CL can increase growth and yield. However, in tomato CL can cause injuries (continuous light injuries [CLI]), which often include epinasty, chlorosis, necrosis and senescence. To quantify these injuries, an experiment was conducted on dwarf tomato plants. Plants of different ages (4-12 weeks) were treated with either CL (154 μmol m^{-2} s^{-1}) or control (230 μmol m^{-2} s^{-1}, 16 h photoperiod) for a 2-week period; plants under CL and control received the same daily light sum. The temperature was kept constant in all treatments. Regular measurements included gas exchange, chlorophyll fluorescence, and leaf epinasty. After two weeks of treatment, total fresh and dry weights, stem diameter and stem length were recorded. Our results indicate that at all plant ages, there was an overall trend for higher fresh and dry weight, thicker stems and higher fruit weight under CL compared to control. The largest effect was observed when the treatment was applied on 6-8 weeks old plants. There was no treatment effect on Fv/Fm, suggesting that CL did not result in sustained photoinhibition. Photosynthetic light use efficiency (net photosynthesis rate divided by incident light intensity) was slightly higher under CL. Overall, we conclude that short-term (i.e., two weeks) application of CL did not result in any observable damage, may increase light and electricity use efficiency in controlled environment agriculture.

Keywords: continuous light, dwarf tomato, gas exchange, light use efficiency

Resource use efficiency of *Diplotaxis tenuifolia* vertical cultivation, as affected by different Red:Blue ratio provided by LED lighting

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The effect of different light spectra on *Diplotaxis tenuifolia* quantitative and qualitative characteristics was examined in this study, considering Resource Use Efficiency (RUE) per each different spectrum. The experiment took place in a controlled conditions growth room equipped with climate control system, applying three different photon flux ratios of Red (651nm) and Blue (451nm) (Red:Blue=0.3/1.0/4.0) having White light as control. All resources used (water, energy, fertilizers) were recorded throughout the cultivation period. Plants were grown from seed and upon first true leaf formation they were placed in culture tanks, filled with 24 L of a standard Hoagland nutrient solution 100% strength, while photoperiod was set at 14/10 h (day/night). The above treatments were evaluated based on yield, RUE, product Carbon Footprint, as well as qualitative characteristics (total phenolic content, antioxidant activity, nitrate content), and leaf photosynthetic parameters (transpiration rate, stomatal conductance, photosynthetic rate). Regarding the results, yield was slightly lower in all R:B treatments compared to White. Energy and Water Use Efficiency, being proportional to yield, follows the same approach, with White being the most efficient one. However, no statistically significant differences were found either regarding yield or RUE. Concerning total phenolic content and antioxidant activity, all R:B treatments were significantly higher in concentration than White, having no statistically significant differences in between, though as far as nitrate content, White treatment noted significantly higher concentration than the R:B treatments. Regarding photosynthetic parameters no statistically significant differences were found between the tested treatments. In summary, R:B treatments have no important differences between them in yield, quality, and RUE, while they uptake White regarding quality characteristics.

Keywords: energy use efficiency, water use efficiency, light use efficiency, land use efficiency, product carbon footprint

Growth and resource use efficiency of *Primula veris* L. vertical cultivation, under different light spectra in a controlled growth room

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In this study, it was evaluated whether *Primula veris* L. (cowslip) plants could efficiently develop as a crop under controlled conditions in a vertical arrangement, while testing their quantitative and qualitative characteristics under different light spectra. The experiment was conducted in an insulated growth room with controlled conditions, so that minimum interaction with the environment was achieved. The growth room was equipped with devices appropriate to assess the sustainability of the structure and energy use efficiency, such as climate data recording system, as well as an energy meter. Three different photon flux ratios of Red (651nm) and Blue (451nm) were applied (Red:Blue=0.3/1.0/4.0) having White light as control, and the photoperiod was set at 14/10 h (day/night). Young plantlets were transplanted into pots and irrigated twice a week, both with plain water and a half strength Hoagland nutrient solution. The above treatments were evaluated primarily based on total fresh weight (root system and aerial parts), growth rate, resources use efficiency and product Carbon Footprint. The concentration of qualitative characteristics, and leaf photosynthetic parameters were also assessed per treatment. According to the results, R:B=4.0 treatment significantly promoted the growth rate of leaf size characteristics, compared to all the examined LED light ratios. Total fresh weight, determined at the end of flowering stage, showed no statistically significant differences between the three R:B ratios, while only R:B=1.0 noted significantly higher yield than the White one. In contrast, White, despite the lowest total yield, resulted in the highest EUE, due to the LEDs' lowest energy consumption. Comparing the major secondary metabolites of cowslip, it was proven that their concentration was affected both by light quality, as well as the plant's growth stage. Phenolic glycoside primeverin's concentration for example, was proven to reduce by more than half from vegetative to flowering stage, having the highest concentration under R:B=4 lighting and being significantly higher than White treatment in both stages. In conclusion, cowslip is a plant highly profitable due to its medicinal use, that can be grown indoors under artificial lighting of different R:B photon flux ratios, depending on our respective needs.

Keywords: artificial lighting, vertical farming, controlled conditions, data recording device, sustainability

Enhancing nutritional quality and biomass production of cilantro plants (*Coriandrum sativum* L.) by regulating light spectra in an aeroponic setup

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The increase in global population is accompanied by a substantial rise in food demand. The production of plants under controlled environmental conditions, such as a greenhouse or vertical farm, could satisfy these demands because these systems can produce a considerable amount of high-quality fresh produce year-round. In a controlled environment, light is one of the most important environmental factors. Light intensity, photoperiod, and spectrum are three essential characteristics of light. The light spectrum includes visible light (wavelengths 380-700nm) and far-red light (FR, 700-800nm) plays a crucial role in plant growth and development. Although the impact of light spectrum on growth and yield has been extensively studied, the influence of light spectrum combination on growth, yield, and especially quality has not been highly explored. Therefore, the objective of this study is to investigate the impact of optimum light spectrum combination on the growth, yield, and quality of Cilantro plants. The experimental investigation will be conducted at a vertical farm under the Biological and Agricultural Engineering department at UC Davis, USA. The study will encompass Cilantro (*Coriandrum sativum* Cv. Santo) plants and will involve three different light spectrum combinations i.e., R: B=4:1, R:B: FR:4:0.5:0.5 and R:B: FR=3:1:1 with 200 μmol m^{-2} s^{-1} light intensity. Parameters related to growth and yield will be meticulously recorded. Quality parameters, including shelf life test, ascorbic acid, total phenolic content, antioxidant assay, mineral content, and chlorophyll content will be analyzed using High-Performance Liquid Chromatography (HPLC) and spectrophotometer. We expect that the R:B: FR=3:1:1 treatment combination will be the optimum combination for growth, yield, and quality of vegetables. The findings of this proposed study will provide valuable insights into the manipulation of light in controlled environments, offering significant benefits to the horticultural sector as well as meeting food demand by improving both the yield and quality of crops.

Keywords: aeroponic system, cilantro crops, light spectrum, quality, yield

The use of bumblebees as potential pollinating agents in vertical farming: drawbacks, feasibility and defining protocols for prospective research

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Food security across the globe is drastically threatened by pervasive phenomena such as climate change, scarcity of agricultural resources and human population growth. Vertical farming (VF) is an innovative plant production system that can potentially counteract these issues by improving food production without further aggravating land use. However, among other concerns, VF development is constrained by high labour costs. This study explored the feasibility of insect pollination in VF to potentially decrease labour costs and produce high-quality products. Buff-tailed bumblebees, *Bombus terrestris* (Hymenoptera: Apidae), were assessed as pollinating agents by introducing them to a climate room with artificial lighting, simulating a VF system. Ornamental cyclamen (*Cyclamen persicum* v14) plants were placed under different light treatments: red and blue wavelengths (RB) in a ratio of 3, RB in a ratio of 3 with an addition of green, full white and, lastly, dark condition. Through cultivation of cyclamens under different spectra, bumblebee behaviour and response to this indoor environment were evaluated to determine whether they can survive and maintain pollination activity. This preliminary trial was used to develop protocols for future experiments on this subject. The current findings suggest that bumblebees could be a helpful resource in VF but, to eventually be introduced within an active VF, the protocols need much refinement. Integrating UV into the light treatments could be a solution to stimulate flower visitations. Given the paucity of research related to this topic, the limitations, practical considerations and suggestions on how to optimise the methods and experimental design for prospective research are also discussed.

Keywords: vertical farming, bumblebees, pollination, artificial light, food production

Keep it colourful: maintaining lettuce metabolic profiles with dynamic blue light irradiance

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Vertical farming allows for reproducible, customizable, and year-round crop cultivation; however, as lighting is a considerable expense, efficient light usage is paramount. In commercial use, a combination of monochromatic red and blue LEDs is often used, with red LEDs having higher efficacy than blue LEDs. Although plants have evolved under fluctuating light conditions, they are often grown in vertical farms under constant light conditions, resulting in more drastic responses. For example, plants exclusively exposed to red light often display a "red light syndrome", with negative repercussions on morphology and photosynthesis; consequently, blue light is added to growth recipes with high red fractions. High fractions of blue light severely stunt plant growth, but high blue also increases concentrations of several nutritional phytochemicals. It is evident that a balance must be struck between improving light efficiency, crop yield, and nutritional content – a solution addressable by dynamic light treatments, harnessing plants' evolutionary ability to adapt to dynamically changing environments. The aim of this experiment was to determine how dynamic light spectra treatments impact photosynthetic responses and metabolic compounds produced by lettuce. To determine treatment effects on different cultivars, both a red and a green lettuce cultivar were grown to harvest at a baby leaf stage in a controlled-environment setup. Lettuce was grown under different Red:Blue spectra applied during select parts of the photoperiod; treatments were categorized as "whole day", "morning", and "evening", referring to the length and timing of exposure to one of five different Red:Blue ratios. The cultivar responses were markedly different: red lettuce sharply decreased in photosynthetic capacity during high blue irradiance, whereas green lettuce did not have as drastic a reduction, if at all. Unsurprisingly, the metabolic profiles of both red and green lettuce showed increasing nutritional metabolic content with increased blue light. Interestingly though, "whole day" high blue exposure resulted in similar nutritional metabolite concentrations as the truncated exposure of "morning" and "evening" treatments. This suggests that durations of high blue exposure can be significantly shortened to produce the same metabolic contents, maintaining high nutritional quality while saving electricity by reducing the use of energy-intensive wavelengths.

Keywords:
controlled environment agriculture, light quality, physiology, photosynthetic capacity, metabolic compounds

Measuring individual plant growth traits reveals the effect of nonuniform light intensity distribution on the crop yield in vertical farms

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One of the main challenges of vertical farming is to optimize lighting conditions for the plants, as energy cost limits the economics of plant factories with artificial lighting. LED luminaires are near the plant canopy; therefore, plants are exposed to different lighting conditions depending on their horizontal position. Spatial variation of photon irradiance drives differences in individual plant growth, but other noise factors in commercial production often hide the effect of nonuniform illuminance. We present the results of pea (*Pisum sativum* L.) microgreens growth experiments aimed at quantifying the effect of photon irradiance variations on crop yield in a vertical farm. Pea seeds were soaked in distilled water for 12 hours and germinated at 20 °C in a propagator. Seedlings with radicle lengths of ~6 cm and shoot lengths of ~3 cm were selected for the growth test and placed on cultivation trays with 7x12 holes arranged in a square grid having 4 cm spacing in each direction. Growth experiments in the trays were carried out simultaneously in the same nutrient solution at a constant temperature of 20 °C and a photoperiod of 16 hours. By adjusting the power of LED luminaires, two different light treatments characterized with approximately the same average PPFD (249 and 230 μmol m^{-2} s^{-1}) but different overall uniformity (U_o=0.94, 0.42) were set in adjacent positions of the vertical farm. The experiment used luminaires comprising 450 nm (21%), 660 nm (54%), and 730 nm (17%) narrow-band LEDs and one type of phosphor-converted white LED (8%). Plants were cut 12 days after the start of light treatment and measured for shoot height and fresh mass. We found no significant difference between the crop yield on trays having the same average PPFD but different uniformity. However, individual shoot height and fresh weight measurements showed statistically significant differences between the different photon irradiance distributions. Correlation analysis revealed that 31% of the fresh mass variation was explained by local PPFD differences, the rest was attributed to differences in seeds and noise in the germination process. In our study, we also discuss the implications of our findings for the design and optimization of vertical farms.

Keywords: vertical farm, LED, PPFD distribution, *Pisum sativum*

Comparative analysis of internal radiation effects on tomato yield in a rooftop greenhouse: a case study in Barcelona

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Solar radiation is a key characteristic of tomato growth in greenhouses and is largely affected by the transmissivity of the covering material. This study analyses how the transmissivity of polycarbonate changes during time in a rooftop greenhouse in Barcelona and how this can affect the yield of tomato crops grown in an integrated hydroponic system. The research focuses on three tomato cultivation cycles (cv. "Arawak") set in the Spring-Summer months of 2020, 2022 and 2023. During April 2023, part of the polycarbonate sheets covering the greenhouse was replaced to increase the rate of transmissivity. In the study, values of external and internal radiation (MJ m^{-2}) and yield (kg $plant^{-1}$) over the three campaigns were assessed. Comparing the external radiation across the years, the lowest values were reached in 2022 (2768 MJ m^{-2}), followed by 2023 (3094 MJ m^{-2}) and 2020 (3380 MJ m^{-2}). Regarding internal radiation, in 2022 a significant reduction (952 MJ m^{-2}) was perceived compared to 2020 (1389 MJ m^{-2}), with a light transmissivity of 34.3% and 41.1%, respectively. Potentially due to the replacement of polycarbonate sheets, in 2023, the internal radiation reached 1437 MJ m^{-2}, which increased the transmissivity up to 46.4%. The yield followed a consistent trend corresponding to the changes in transmissivity and internal radiation, with values of 4.8 kg per plant in 2020, declining to 3.5 kg per plant in 2022, and notably rising up to 6.7 kg per plant in 2023. While fertilization, temperature, and other factors play essential roles in plant growth, internal radiation emerges as the primary driver impacting harvest outcomes. These findings shed light on the potential advantages of periodic maintenance and the replacement of greenhouse covering materials to enhance internal radiation and ultimately boost crop yields.

Keywords: rooftop greenhouse, radiation, transmissivity, tomato, hydroponics

Variability of biomass yields and chlorophyll content in 14 microgreen species under two light intensities

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Microgreens are known for their vibrant colors, intense flavors and rich nutrient profile and used in culinary applications as food garnishes, salad ingredients, or as flavor to various dishes. The objective was to determine the microgreen biomass yields and chlorophyll content of 14 microgreen species grown under two different light intensities viz. 209.5 and 40 µmol m^{-2} s^{-1}. The experiment was conducted in a walk-in growth chamber located at the University of Copenhagen, Denmark. Inside the growth chamber, we assembled a grow-rack system, which consisted of six-layer growing system, supplied by a commercial microgreen producer, INSTAGREEN from Spain. The trial was carried out in the uppermost two grow racks with the top grow rack using OSRAM Phytofy (OSRAM LED) and the second grow rack was fitted with four 1 meter long 24-volt LED (INSTAGREEN LED) lights. The OSRAM and INSTAGREEN LED light intensity was 209.5 and 40 µmol m^{-2} s^{-1} respectively and photoperiod was 16 hours of light. Under OSRAM LED, highest fresh biomass was recorded in sunflower and radish whereas the lowest biomass accumulation was recorded in nasturtium. Among the 5 brassica species, radish accumulated the highest biomass significantly higher than kohlrabi, whereas the lowest biomass was recorded in kale. Hence, the differences in biomass yields were present between the species from the same family and between the species demonstrating the differential responses of the microgreens to same quantity and spectrum mix of light. Under INSTAGREEN LED, sunflower and radish accumulated the highest biomass whereas amaranth accumulated the lowest biomass. In brassica species, radish accumulated the highest biomass whereas kale accumulated the lowest biomass. Under OSRAM LED, chlorophyl content (SPAD) was highest in sunflower, significantly higher than radish. Among the brassica species, radish recorded the highest SPAD whereas cress recorded the lowest SPAD. Under INSTAGREEN LED, sunflower recorded the highest SPAD and the lowest SPAD was recorded in amaranth. Overall, the data suggests that different plant species exhibit varying levels of SPAD and fresh biomass yields, highlighting the diversity in their growth. Under both OSRAM and INSTAGREEN LED, sunflower produced the highest biomass and recorded the highest SPAD, indicating that the high chlorophyll content was decisive factor in enhanced photosynthesis leading to production of highest biomass yield in sunflower.

Keywords: microgreens, LED, crop yield, legumes, Brassica

Effects of light spectrum mix and intensity on secondary metabolite accumulation in 14 microgreen species under controlled environment conditions

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Microgreens are known for their vibrant colors, intense flavors and rich nutrient profile and used in culinary applications as food garnishes, salad ingredients, or as flavor to various dishes. The objective of the study was to determine the total anthocyanin, flavonoid and phenolics content of of 14 microgreen species grown under two different light intensities viz. 209.5 and 40 µmol m^{-2} s^{-1}. The experiment was conducted in a walk-in growth chamber located at the University of Copenhagen, Denmark. Inside the growth chamber, we assembled an off-the-self grow-rack system, which consisted of six-layer growing system, supplied by a commercial microgreen producer, INSTAGREEN from Spain. The trial was carried out in the uppermost two grow racks with the top grow rack using OSRAM Phytofy (OSRAM LED) and the second grow rack was fitted with four 1 meter long 24-volt LED (INSTAGREEN LED) lights. The OSRAM and INSTAGREEN LED light intensity was 209.5 and 40 µmol m^{-2} sec^{-1} respectively and photoperiod was 16 hours of light. With OSRAM LED, among the 14 microgreen species, phenolics content was the highest in nasturtium and amaranth. Among the Leguminosae species, mungbean measured the highest phenolics content and significantly higher compared to lentil and pea. Flavonoid content was highest in nasturtium whereas total anthocyanin content was highest in radish followed by kale. With INSTAGREEN LED, comparing the 14 species, phenolics content was highest in radish, nasturtium, cress and kohlrabi. Among the Leguminosae species, lentil contained the higher phenolics compared to peas and mungbean but was not significantly different among species. Among the Brassica species, radish, cress and kohlrabi had significantly higher phenolics content compared to broccoli. Flavonoid content was significantly higher in radish, nasturtium, cress and kohlrabi compared to other tested species whereas total anthocyanin was the highest in radish and significantly higher than other species tested. The differences in content of phenolics, flavonoid and total anthocyanin in the 14 microgreen species indicated that the different microgreens respond differently to a particular light intensity and spectrum mix. With OSRAM LED, nasturtium content of phenolics and flavonoids were highest and whereas with INSTAGREEN LED, radish content of phenolics, flavonoids and total anthocyanin was highest demonstrating that species and light selection need to be specific in order to enhance the profile of particular phytochemicals.

Keywords: microgreens, LED, secondary metabolite, flavonoids, phenolics

Red, blue and red plus blue supplementary light differently influenced the growth of microgreens, microleaf and baby leaf of two Brassica local varieties

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With the development of vertical farming, it is necessary to identify new production techniques that allow for the utilization of limited available space and efficiently utilize agronomic inputs, including artificial radiation. Leafy vegetables are the most cultivated crops in vertical farming systems thanks to their fast growth cycle and limited canopy expansion. For these reasons, microgreens, microleaf and baby leaf are suitable productions for vertical farmings system and, based on the literature, the botanical family of Brassicaceae lends itself well to these productions. During the experimental activity carried out in the greenhouse, two local varieties of Brassicaceae - "cima di rapa" (*Brassica rapa* L. subsp *sylvestris* L. Janch. var. esculenta Hort) and "cavolo riccio" (*Brassica oleracea* L. var. acephala) - were grown for the production of microgreens, microleaf, and baby leaf using linear LED modules with red (R), blue (B), and red + blue (R+B) spectrum as supplementary radiation source. "Cima di rapa" grew faster than "cavolo riccio" and the harvests of microgreens, microleaf, and baby leaf of the first genotype was made at 15, 32 and 37 days after sowing (DAS), respectively, while for the second genotype it was made 17, 33 and 40 DAS. Regardless of the light treatment, "cima di rapa" showed higher yields than "cavolo riccio": 15% for microgreens, 45% for microleaf, and more than 80% for baby leaf. In general, the application of supplementary lighting increased the productive performance, with more pronounced effects in baby leaf rather than microgreens. Furthermore, the effect of spectra on yield and seedling morphology was genotype-specific. Finally, considering the yield per unit of surface area, it emerged that for "cavolo riccio" the yield of microgreens resulted approximately 15% higher compared to baby leaf of the same species, while for "cima di rapa" the yield of baby leaf led to a biomass production increase of about 40% compared to microgreens. These results demonstrate how genotype selection and knowledge of appropriate cultivation techniques can determine more or less satisfactory outcomes in vertical farming. The experimental test conducted is part of a research project aimed at identifying production techniques and/or new types of products that enhance the efficiency of agronomic input utilization in soilless cultivation and vertical farming.

Keywords: vertical farming, light emitting diodes, light use efficiency, soilless, leafy vegetables

Evaluating spearmint's (*Mentha spicata)* morpho-physiological responses towards different artificial lighting systems

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Indoor agriculture is becoming more applicable as a result of artificial lighting, which makes it possible to increase productivity, improve quality and cultivate, where natural light is insufficient. The present study was conducted by growing spearmint inside a glasshouse under light emitting diode (LED), high pressure sodium (HPS), and light emitting diode assisted infrared (LED+IR) light treatments, while the control was managed outside the glasshouse under natural sunlight. Greenhouse growth conditions included a mean temperature of 24.3 ± 0.03 °C, mean relative humidity 62.7 ± 0.12 %, and daily mean light intensity as 43.7 ± 0.45 W m^{-2}. The growth condition for the control were mean temperature 25.5 ± 0.13 °C, mean relative humidity 48.6 ± 0.35 %, and daily mean light intensity as 269.94 ± 6.77 W m^{-2}. In each condition, supplementary light intensity at plant level was 55 µmol m^{-2} s^{-1} for both LED and HPS, and the photoperiod was 16 h. Morphological analyses revealed that LED supplemental light performed better in terms of plant height, number of stems per plant and fresh weight of the produce compared to all other tested light treatments whereas HPS favored an increased internode spacing. The analytical determinations revealed the outperformance of LED considering the total carotenoids, anthocyanins as well as total sugar accumulation. The plants grown under both LED and LED+IR accumulated less nitrates which was otherwise under HPS. HPS treated spearmint also showed a reduction in total carotenoids as well as total sugars accumulation. Moreover, non-significant changes were observed for lipid peroxidation, expressed as TBARS, among all the treatments. On the other hand, control plants observed the highest phenolic index relative to the other light treatments which overall provided us an overview of the effects of light spectrum of artificial lighting such as LED, HPS, LED+IR and natural sunlight on spearmint's growth, lipid peroxidation and secondary metabolites production. Taken together, these preliminary results suggest a possible application of IR integration to LED in indoor cultivation systems.

Keywords: indoor, HPS, infrared, LED, spearmint

Enhancing tomato fruit yield through Far-Red light in controlled environment agriculture

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Incorporating far-red light into lighting recipes holds great potential for enhancing tomato fruit yield in controlled environments where LED lighting constitutes the primary light source. However, this improvement comes with the drawback of increased electricity consumption. While previous studies have focused on the application of far-red light throughout the entire photoperiod, the role of the timing of far-red light application on the growth and development of plants remains largely unexplored. Our research aims to investigate whether applying far-red light for a limited period during the photoperiod can enhance fruit yield while reducing energy consumption compared to continuous far-red lighting. To achieve this, we assessed the impact of different timings and lengths of far-red light application on fruit yield and quality in a high-wire tomato crop. The experiment involved the cultivation of two commercial tomato hybrids for 20 weeks in a greenhouse under supplementary lighting provided by red and white overhead LED modules. Additionally, far-red light was introduced during either the first or the second half of the photoperiod, and those plants were compared to plants grown under whole-photoperiod far-red or no far-red. The addition of far-red light enhanced plant dry weight and dry matter partitioning to the fruits and resulted in a higher cumulative fruit yield. Cumulative fruit fresh and dry weight showed a positive linear increase with the length of far-red light application, while no significant difference was found between the timings of far-red application during the photoperiod. Despite the increase in tomato yield, the fruit quality was not lowered, as supported by measurements of fruit dry matter content, total soluble sugars, and pH. We conclude that the duration of far-red application during the photoperiod is more important than the timing. This finding offers valuable insights for growers, as it provides them with the flexibility to optimize the use of far-red light based on external factors like electricity prices. Our research contributes to the optimization of supplementary lighting practices in controlled environment agriculture.

Keywords: far-red, tomato, timing, yield, quality

Towards a dynamic light spectrum for butterhead lettuce: effects of different light qualities on plant performance

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In indoor farming, artificial lighting is essential to drive plant growth and development. LED lighting allows the application of specific wavelengths that influence different photoreceptors, such as cryptochromes and phytochromes. In addition, the efficacy of photons for photosynthesis also depends on their wavelength. LEDs allow to apply light recipes more dynamically throughout the cultivation process to obtain a high-quality product. In this work, we characterized the effects of well-chosen wavelength combinations on the growth and development of butterhead lettuce (*Lactuca sativa* L. var. capitata). 3-week old plants were transplanted to a deep-flow hydroponic system in a growth chamber and subjected to different blue/red, blue/green or red/far-red ratios, while PAR was kept constant at 200 µmol m^{-2} s^{-1}. Plants were harvested every 3 to 4 days for a total cultivation period of 3 weeks. Photosynthesis, chlorophyll fluorescence, and stomatal conductance were measured just before harvest. The observations at harvest included fresh and dry biomass, leaf area, head area, and leaf optical properties. To study internal quality, chemical analyses of plant pigments, stress metabolites, and soluble carbohydrates were performed. In addition, the occurrence of physiological disorders such as tipburn and glassiness was monitored. The results of these experiments will contribute to a more dynamic management of light spectra in indoor farms, with light recipes that are optimized for specific plant stages during cultivation.

Keywords: butterhead lettuce, LEDs, light spectrum, internal quality

Diel length and photoperiod control effect on growth, morphology and LUE in lettuce

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A 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 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 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. At the moment, data are being analysed and final results will be presented during the workshop.

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

January 17th
Fast Talks - SENSORS

CHAIR: J. E. OLVERA GONZÁLEZ

Digital twin of the controlled environment agricultural system – application in enclosed ecological system and vertical farm

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Precise control and efficient management are essential in controlled environment agricultural systems, where energy use efficiency is a critical concern. It is especially meaningful for closed ecological life support system (CELSS), designed to ensure a stable supply of food, water and oxygen, and vertical farms (VF), which are highly sensitive to energy consumption, particularly in terms of their lighting sources. Digital twin is a virtual system that reflects the corresponding physical object based on sensed data and generates valuable insights to improve the processes of the original object. In this work, we simulate dynamic mass flows (C, O, H) within closed or semi-closed systems with plant growth. We use the GreenLab model, partially coupled with the TomSim model, to model and visualize the role of plants within the whole system. Our analyses include the calculation of plant contributions to CO_2 and O_2 exchange, edible products, internal biomass allocation, and external 3D structures. For CELSS, we also simulate the activities of humans and microbes. We further conduct simulations and visualizations of mass flows, yields and energy usage in both CELSS and VF. These results provide the basis for energy-saving environmental control and crop planning management, aiming to ensure a stable supply. When coupled with online monitoring and learning, the digital twin can provide decision support according to the current situation.

Keywords: digital twin, parallel control, greenLab, IoT, mass flow, visualization

Strategies for improving energy use efficiency in vertical farming

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Vertical farming represents a revolutionary approach to agricultural practices by utilizing vertical space to maximize crop yields. It involves cultivating plants in stacked layers or vertical surfaces within controlled environments. This innovative technique offers numerous advantages, such as efficient land utilization, reduced water and fertilizer consumption, and enhanced crop productivity. However, one aspect that deserves considerable attention is the energy requirements and implications of vertical farming. Vertical farming poses intriguing questions regarding energy aspects as it has the potential to bring about a paradigm shift in agriculture with potential energy savings compared to traditional greenhouse cultivation. By conducting an analysis of the industry and various contexts where vertical farming is practiced, this study aims to draw attention to the energy aspects and critically evaluate the significance of the data dispersion observed in the literature, which highlights the insufficient attention given to this element thus far. By evaluating and synthesizing the available information, the aim of the paper is to identify gaps in knowledge and directions for further research and development in this area. The control of the physical environment emerges as the main responsible for the increases in energy intensity and for changes in the energy demand. If in greenhouses it led to the use of fossil fuels for heating in winter and electricity for cooling in summer, in vertical farms it will lead to a large switch from fossil fuels to electricity for lighting and cooling throughout the year due to the replacement of sunlight with artificial lighting. The findings will contribute to a better understanding of the energy implications associated with vertical farming and emphasize the importance of considering energy efficiency as a fundamental component for the future upscaling of this agricultural practice.

Keywords: energy use efficiency, vertical farming, lighting, climate control

Real-time computer vision-based cultivation control system for ornamental vertical farming

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With a total export value of over 700 M euros in 2021, the Belgian ornamental greenhouse sector is a blooming but resource-demanding business. To align with the EU Green Deal and EU Blue Deal ambitions, future-proof innovations requiring less (fossil) energy, water and other resources will therefore be needed. Vertical farming (VF) offers a great potential due to its highly controlled environment and circular use of resources. Moreover, the precise adjustment of the indoor climate to the individual plant needs, allows for accurate production planning and year-round quality assurance. Hence this project aims to develop a real-time computer vision (CV) based cultivation control system for ornamental vertical farming. As use case, the forcing phase of pot azaleas (*Rhododendron simsii*) was chosen because of its high economic value and large energy/water demand. In total 3 batches of pot azaleas ('Sachsenstern') were forced until flowering at different temperatures (18-21-23°C) in the VF system of PCS. All cultivation tables (2 tables/rack - 4 racks in total) obtained the same photoperiod (PP: 16h/day) and light spectrum (UV: 0.1%, B: 14.3%, G: 11.0%, R: 73.4%, FR: 1.2%) using LED lamps (LED Lighting Bar - Urban Crop Solutions, Waregem, Belgium) while the light intensity was adjusted per rack (photosynthetic photon flux density (PPFD): 60-90-120-150 µmol m^{-2} s^{-1}). Plants of an entire cultivation table (235cm x 165cm) were phenotyped every 1-2 days in a dedicated phenotyping chamber using a DSLR camera (Canon EOS 90D, EF-S 18-55mm). After image correction (Darktable), the colour stain (CS = areaflowers/areatotal plant [%]) of each individual plant was extracted for each timepoint using a dedicated image processing script (Python - PlantCV & OpenCV). Subsequently, a forcing model was built based on the driver's thermal time (growing degree days (GDD, °C.day)) and daily light integral (DLI, mol m^{-2} day^{-1}) to predict the phenological stage (CS) of the azalea plants. The combination of the visual colour stain assessment and forcing model will finally lead to a real-time CV based cultivation control system which can suggest changes in environmental conditions (temperature, PPFD and PP) based on the real-time flowering stage of the azalea plants in order to meet production quality/delivery dates.

Keywords: vertical farming (VF), Controlled Environment Agriculture (CEA), cultivation control, computer vision (CV), ornamental plant phenotyping

January 17th

PARALLEL SESSION

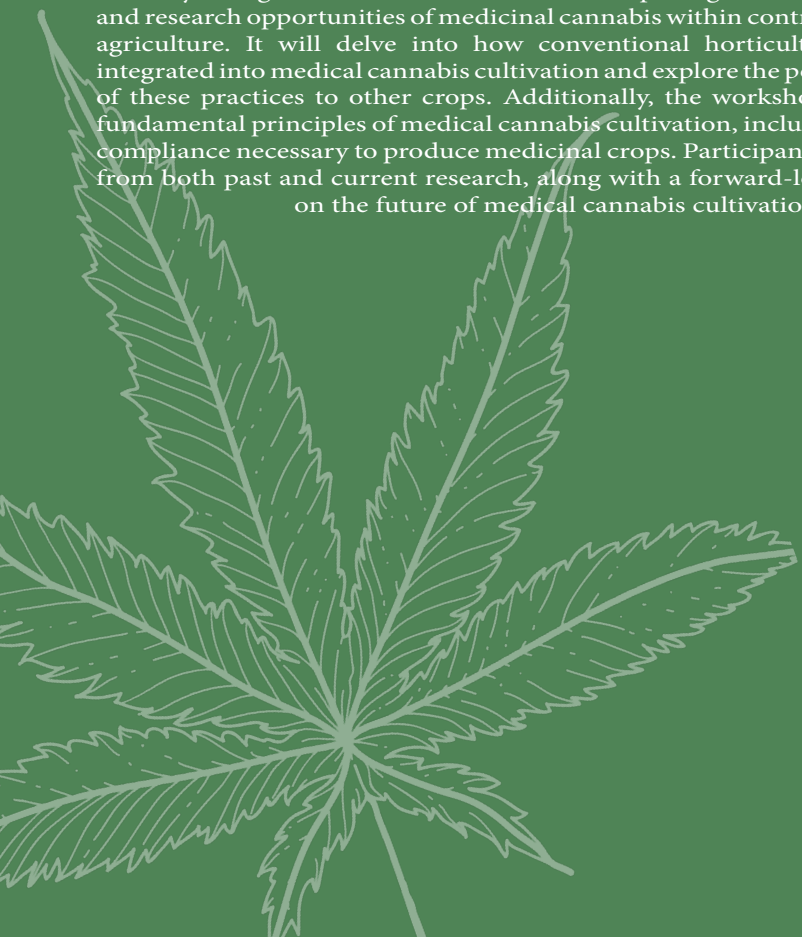
in SALA QUADRANTE

WORKSHOP: MEDICINAL CANNABIS IN CONTROLLED ENVIRONMENT AGRICULTURE

CHAIR:
M. HOLWEG, B. BUGBEE

Medicinal Cannabis in Controlled Environment Agriculture

This workshop is designed to inform and discuss with people from academia, industry, and governmental institutions about plant growth, yield, and business and research opportunities of medicinal cannabis within controlled environment agriculture. It will delve into how conventional horticultural practices are integrated into medical cannabis cultivation and explore the potential application of these practices to other crops. Additionally, the workshop will discuss the fundamental principles of medical cannabis cultivation, including the regulatory compliance necessary to produce medicinal crops. Participants will gain insights from both past and current research, along with a forward-looking perspective on the future of medical cannabis cultivation.



January 17th
Fast Talks- SUSTAINABILITY

CHAIR: J. MONZINI

Vertical farming in urban agriculture: production of kale baby leaves in a restaurant

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Vertical farming in controlled conditions including plant factories with artificial lighting (PFALs) offers all the advantages of hydroponic crop production, while they can also be established in urban areas. For example, such production systems can be established in restaurants and hotels to meet their needs for fresh vegetables and also minimize the distance from farm to fork. One such case was studied in a restaurant in the centre of Thessaloniki, Greece, a city with a population of about 1 million people. Kale (*Brassica oleracea* var. sabellica) was cultivated in a vertical system built in the premises of the restaurant. Light was provided by light-emitting diodes (LEDs). Specifically, two spectra, a red + blue (RB) and a white (W) were used to test their effect on the kale baby leaves' yield, quality and physiology. The yield had no significant difference between the two treatments. However, quality was enhanced under the effect of W as reflected by the measurements of total soluble solids, chlorophylls and carotenoids. Phenolics and total antioxidants were similar in both treatments. On the other hand, nitrate content, a negative compound related to the safety of vegetables, was increased under the W light. In conclusion, vertical farming is a fine option for the production of kale baby leaves in restaurants and other indoor spaces, especially with the use of a white LED lighting. In addition, white light is desirable as it facilitates plant monitoring and operations within the cooking and dining areas.

Keywords: *Brassica oleracea*, plant factory with artificial lighting, PFAL, controlled-environment agriculture, light quality, LED

How to promote sustainable vertical farming? Towards a common science-based definitional framework

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The transition toward sustainable urban food systems requires the adoption of technical, organizational, and social innovations. Indoor Vertical Farming (IVF) represents an emerging practice to respond to some of these challenges by reducing environmental burdens (i.e. improving water and land use efficiency), rationalizing logistics, and providing social benefits. However, it entails highly energy-intensive systems and requires significant investments. A better understanding of IVF sustainability trade-offs is key to fostering the development and implementation of such systems. The current storytelling of IVF products proposed by commercial vertical farms is scattered and lacks consistent scoping. This hampers the establishment of a systematic set of features allowing consumers to recognize and choose sustainable IVF products. To fill this gap, the current study aims to develop a definitional framework for sustainable IVF. This framework has the potential to support the exploration of hotspots and trade-offs to inform a common understanding of the sustainability of indoor vertical farms, contributing to advancing both consumer awareness and market positioning. To this scope, a systematic review of the state of the art is performed to explore current perspectives on IVF sustainability and build a coherent understanding through a definitional framework. Then, the framework is tested on some selected European commercial vertical farms' storytelling to understand the focal points of their marketing strategies. The study details a set of sustainability features, analyses their occurrence and framing in the literature, and investigates if those features are absent, partially touched upon, or at the core of the storytelling of European commercial vertical farms. This work posits that a definitional framework would support the industry in developing a consistent understanding of sustainable IVF products and in delivering on its sustainability claims.

Keywords: vertical farming (VF), sustainability framing, definitional framework, commercial vertical farm, marketing strategy

Environmental life cycle assessment of a pilot aquaponic system

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This study uses an attributional Life Cycle Assessment to investigate the environmental impact of a small commercial aquaponic system located in central Sweden where leafy greens and rainbow trout are produced. The study highlights the main hotspots of the system impacts and investigates four scenarios for impact reduction of the investigated facility. These scenarios target these main hotspots or examine the effects of planned changes to the system, including packaging, bioreactor treatment of fish sludge, reduction of photoperiod and use of insect-based feed. This study thus contributes knowledge to the research field while also supporting the development of reducing environmental impacts in aquaponics. Life cycle assessment was employed to analyse the environmental impacts of the baseline system, and the included scenarios. Modelling was performed according to the Environmental Footprint v 3.0 Life cycle impact assessment (LCIA) method. The functional unit is 1 kg of produce, allocated on energy or economical basis. This is a cradle-to-grave analysis, with the system boundary including the fish hatchery, the material and energy inputs, the infrastructure of the system, transport from farm to client (primarily restaurants, direct delivery) and waste at client. The results highlighted that energy expenditure in the form of electricity was a major contributor to climate change, at >50% of total GHG impact. Energy also strongly influenced water use, as the Swedish energy mix largely consists of hydropower. Infrastructure was influential in several categories, including acidification, resource use and fresh water ecotoxicity. Supplemental fertilisers contributed a significant portion of freshwater ecotoxicity. Results for scenarios and comparison with other studies are not yet available at the time of writing. Energy is the major contributor to the GWP impact of the aquaponic system which is mostly used for lighting. The per kg impact was found comparable to other Swedish state-of-the-art systems. As the company is planning scale-ups to large-scale, automated facilities with additional circular flows, future research to follow development is highly interesting.

Keywords: aquaponics, LCA, insects, trout

Life Cycle Assessment of multilayer greenhouse production with smart control systems

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Simultaneous production of vegetables and energy, or animals, such as fish in aquaponic cultivation, Combined Heat and Power (CHP) in greenhouse and vertical farming, provide economic benefits to the producers. According to Farm2Fork strategy, it is important to examine the overall environmental impact of the systems, by Life Cycle Assessment (LCA) method. In this study, the findings of a pilot greenhouse application in a vertical arrangement are presented, with the aim of baby leaves and rainbow trout combined production, by utilizing smart automation systems and IOT technologies. Two baby leaf vegetables, lettuce and spinach were grown hydroponically, at the top floor of the greenhouse, using three different nitrate-synthesis tanks; a) synthetic fertilizers only (Hoagland), b) processed water from trout farming (Fish) at the bottom floor of the greenhouse and c) processed water from trout farming, mixed with synthetic fertilizers (Mix), resulting in six production scenarios. The yield of produced vegetables and fish, as well as all the inputs used in each scenario constitute the primary data for conducting a full LCA, using SimaPro software 9.2.0.1 and ReCiPe 2016 Midpoint (H) method. The analysis highlighted the effects of the system in 16 environmental indicators. Indicatively, Global Warming Potential (GWP) was found to be higher in spinach Fish scenario (Fish: 77.2, Mix: 76.8 and Hoagland: 21 kg CO_2-eq respectively). The hotspot with the greatest impact on the GWP, was electricity (98.47%). In addition, the use of trout feed had significant effects on the Land Use (LU) indicator (> 95%). Although the absolute values of the carbon footprint (GWP) were increased in the scenarios where water from trout farming was used, it is important to consider the possibility of dual production and its application in the context of circular economy, by utilizing the waste of a system as raw material for another production system.

Keywords: Life Cycle Assessment, Carbon Footprint, greenhouse production, greenhouse, hydroponics

A new(ish) kid on the block: Bioponics

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Soilless horticulture currently accounts for approximately 80% of the global indoor farming market share and is continuously expanding. Clearly, resource-efficient horticulture using soilless cultivation methods will play an increasingly important role in providing food for the growing urban population. Bioponics refers to the use of organic nutrient sources within hydroponic cultivation. Conversely, conventional hydroponics mostly relies on non-renewable mineral fertilizers for nutrient supply. Moreover, some hydroponic farms use open systems where the culture solution is discharged after a single use and cause eutrophication since many countries still lack legislation requiring recycling of the effluents. Moreover, organic substrates and fertilizers recovered from waste(water) can support a diverse community of microorganisms that mediate essential functions, including disease suppression and phytostimulation. In this way, they contribute to improved productivity and yield quality more than soil-based or mineral-fertilizer based systems. Bioponics relies on two systems (waste treatment and food production) and thus connects organic waste streams with microbial transformation and soilless food production that considers food safety aspects. It is a versatile and adaptable concept that can be tailored to consider the material and energy sources available in the urban and peri-urban environment. While there is a large backyard community implementing a wide array of recovered fertilizers there is a noticeable reluctance among commercial hydroponic farmers to adapt their well-established cultivation practices. To convince these practitioners, bioponics must be developed to achieve reliability, predictability, efficiency, safety, and security comparable to conventional hydroponics. We need a roadmap towards the transformation of the commercial hydroponic industry by facilitating the abandonment of mineral fertilizers and tap water as inputs and encouraging the use of recovered fertilizers and reclaimed water instead. This transformation is becoming increasingly relevant considering the current energy crisis, increasing fertilizer prices, and increasing water scarcity due to climate change.

Keywords: aquaponics, hydroponics, fish, vegetables

Evaluation of a modular aeroponic system as a strategy to improve productivity, water footprint and food security in small farmers of chile

★ ALAN RICHARDS[1], Jorge Mac-Ginty[2], José I. Covarrubias[1], Ian Homer[2], Carlos Meza, Javier Navarrete, Ricardo Pertuzé[1]

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Aeroponics has been developed as a root study tool in 1920's, and since its origins has become a water use optimizer, becoming a real contender when in 1990's The National Aeronautics and Space Administration (NASA) began to experiment with this systems as an option to ensure food produce in soilless environments such as the space. It is considered as a part of the hydroponics production systems, where the recirculating film nutrient solution were replaced by a fog nutrient solution in the root zone as we did on this study. In Chile, crops and vegetables are traditionally cultivated in soil-based systems, so aeroponic systems are still novel. Vegetable production in Chile is grown by small farmers (with no more than 4 greenhouses of 210 m^2 of surface), so the objective of this study is to demonstrate that a modular aeroponic tower production system can be an alternative for small farmers especially those located in extreme areas with water restriction and needs for controlled and automated production. Several trials were conducted to determine the correct tower diameter maximizing yield and quality in lettuces and other leafy vegetables. Furthermore, the water footprint and efficiency as compared to NFT hydroponics systems, and a drip irrigation system, were addressed. The proposed modular aeroponic system uses 12 productive towers, with a 200 L pond and a modified Hoagland nutrient solution, with an irrigation frequency of 30 min on and 120 min of latency within the day (16 h), and 8 h of latency at night. The system allows to cultivate 124 plants/m^2. During the harvest, growth and development variables such as the number of leaves, the number of living plants, the width and length of the leaves, the concentration of internal chlorophyll and fresh weight of the plants were evaluated. During the experiment, significant differences were observed in lettuces size. Finally, this study concludes that aeroponic tower production systems can consolidate as a very efficient and useful method for small farmers and urban farming due to its capacity to produce more than 100 plant $m^{-2,}$ and also a practice to face the food insecurity, and the ongoing drought, making the production more efficient (in terms of supplies and resources) and also easier.

Keywords: aeroponics, water efficiency, hydroponics, hydric footprint, lettuce

Use of digestate, blood meal and other industry residues as an organic nutritive solution for a vegetable aeroponic production

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Lettuce is the third most important vegetable in Chile, and one of the most important leafy vegetable crops worldwide. Accordingly, it is one of the top commercially attractive vegetables, also because its components like vitamin C, polyphenols and folic acid, its gastronomic attraction in salads. Aeroponics and hydroponics productions use a recirculating solution were nutrients are dissolved. A trial was carried out between May and June 2023, using lettuce (*Lactuca sativa* var. "Neil", winter variety). The trial was performed in 3 aeroponic production systems composed by 12 recirculating towers each, each with a separate 200-liter tank of capacity, where 3 treatments were carried out (T1: Digestate 1 + blood meal; T2: Digestate 2 + blood meal; T3: Modified Hoagland control solution). The three production systems involve irrigation pulses of 30 minutes on, versus 120 minutes of standby, along with 8 hours of overnight standby. The crop cycle was 71 days from transplant to harvest. At harvest time, nutritional concentration in leaves, chlorophyll concentration, plant weight, plant diameter and leaf length were evaluated in 36 plants of each module, totalling 108 plants. T2 and T3 did not have significant differences in weight, plant diameter and leaf length, while they differ from T1 in terms of nutritional content. In turn, the plants of T1 and T2 denoted a higher foliar content of microelements. Finally, this study proves that the use of organic fertilizers is an alternative for aeroponics to be a more sustainable production system, increasing water and energy efficiency, and also as a replacement of inorganic fertilizers with organic origin nutrition, allowing the possibility to make aeroponic crops to be certified as organic.

Keywords: aeroponics, nutrition, hydroponics, organic growing system, lettuce

Exploring the urban symbiosis potential of vertical farms: the case of the Stockholm region

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The human population is expected to reach 9 billion individuals by the year 2050, mainly in urban areas, with consequences such as an increase in resource consumption, greenhouse gas (GHG) emissions, and waste treatment costs. Additionally, the consequent increase in food demand will exacerbate the already over-exploited resources like water, fertilizer, and arable land. To address these challenges, Vertical Farms (VFs) have been proposed as a promising way to tackle the abovementioned issues. However, VFs are characterized by intensive energy usage and high GHG emissions. Therefore, to improve resource use efficiency and environmental performance, it is crucial to implement circular economy strategies, like urban symbiosis, where different companies exchange their by-products to use as raw materials. The present work is a literature review that aims to investigate the potential use of urban residual streams in VFs to achieve resource circularity. The study combines data obtained through on-site visits, semi-structured interviews, and findings from the existing literature to identify potential synergies to implement. The research reveals the presence of optimal synergies that can be implemented in VFs, allowing a circular utilization of resources. Subsequent studies will involve conducting environmental assessments of the potential synergies to further implement in real-case scenarios to gather empirical data and refine optimal resource use efficiency strategies in VFs.

Keywords: vertical farming, resource efficiency, industrial symbiosis, urban symbiosis, circular economy

Eight living labs in African countries featuring soil independent food production: Concept and Implementation.

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The EU funded Project "INtegrated and Circular Technologies for Sustainable city region FOOD systems in Africa (INCiTiS-FOOD)" aims to enhance food and nutrition security (FNS) in African city regions, reduce environmental impacts, and promote circularity in food systems. It also empowers communities by creating opportunities in agri-food supply chains and promoting environmental justice through transformative food policies. INCiTiS-FOOD adopts an interdisciplinary approach, integrating technologies, engaging stakeholders, building capacity, and fostering Europe-Africa partnerships for collaborative engagement. At the core of the project are eight living labs located in six African countries (Kenya, Nigeria, Sierra Leone, Cameroon, Gabon, Ghana). These living labs, led by African partner organizations operate in a real-life context with a user-centric approach and foster socio-technological innovation through participatory research and development as well as capacity development of local end-users through training. Initially, the circular agri-food technologies of the living labs focused on hydroponics, recirculating aquaculture systems (RAS), aquaponics, and insect farming because these technologies do not require substantial land area and capital, which is ideal for urban African context. This expertise development is also the ideal basis for testing the suitability of bioponic: a cultivation method that uses fertilizers, recovered from waste streams, such as insect frass, biogas effluent, and greywater. As the living labs started their operation, the concepts needed to be adapted to the local realities, including limited availability of some materials and/or parts. A Prototype Aquaponic system was constructed in all living labs and put into operation. Three Training of Trainers were completed by the end of 2023 in Ghana, Kenya and Gabon. The curriculum focused on practical work, as the participants obtained basic theoretical knowledge in the online course Aquaponics prior to the on-site training.
We report on the insights gained so far.

Keywords: aquaponics, hydroponics, aquaculture, fish, vegetables

Understanding the potential for peat replacement in vertical farming: A Swedish perspective

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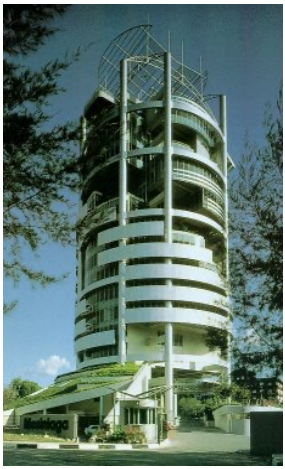
Swedish year-round farming of leafy greens in controlled environments is a rapidly growing sector. Conventionally used soilless growing media is, however, increasingly put under scrutiny for its environmental impact and linear production chains. The aim of this study was to investigate the needs of companies operating in the vertical farming and hydroponics sector in Sweden, to examine potential alternative materials for growing media production and relate these to the currently active EU legislation and EU Ecolabel. Alternative growing media tested in research was investigated through a literature search with search terms such as "soilless substrate", "hydroponic substrate", "growing media" etc. Volumes of materials were assessed using data from public databases and grey literature. Regulatory documents on EU and Swedish levels were reviewed. Company needs and experiences were assessed qualitatively by semi-structured interviews, with an interview guide of themes and specific questions focusing on areas such as operative and functional needs, desires for future growing media development, and need for adaptation to automated systems. Materials found in literature included broad categories such as wood by-products, compost, biochar made from different feedstock, spent mushroom substrate, organic waste, and novel materials such as hydrogels and biopolymer-based foams. The EU Fertilising Products Regulation is the main regulatory document that impacts the production, trade, use and waste management of growing media. EU Ecolabel and KRAV ecolabel have additional demands. The company interviews revealed production methods and operative needs. The volumes of growing media needed are, on an international scale, relatively small. Companies are generally interested in the development of more sustainable growing media. Processing techniques and logistics of growing media in Sweden need to be developed to ensure a functioning value chain with reliable products. Further research and growing experiments are needed to verify the commercial quality of these alternative substrates. As pointed out in a 2016 review, new growing media must live up to the production standards of traditional growing media to succeed.

Keywords: growing media, vertical farming, substrate, peat alternative, interviews

1989

Architect and ecologist Kenneth Yeang created the concept of "vegetated architecture", mixed-use buildings integrated with green spaces.



2009

15 years ago, the scientific American opened an edition on "A plan for a sustainable future", hosting a visionary paper by Dikson Despommier entitled "Growing skyscrapers: the rise of Vertical Farms".

Stepstones on vertical farm evolution: part III

January 18th

SESSION: CLIMATE CONTROL

CHAIR: E. HAYASHI

MURAT KACIRA

Resource use efficient environmental control in vertical farms

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The operational costs and resource-use efficiency of multi-tier-based plant factory systems can be improved by appropriate production-system design modifications for key technologies and control strategies while considering the crop-specific minimum environmental requirements. Lack of detailed engineering analysis in the system design can lead to inefficient use of resources (i.e. energy, CO_2, water), non-uniform environment, higher system costs, and limit production quality, yield, and profitability. For indoor farming, the outdoor climates, characteristics of building envelope, and HVAC systems have a significant effect on the heating and cooling thermal loads of an indoor plant factory and therefore influence energy consumption. The typical way of controlling plant growth in a vertical farm (VF) is to keep environmental conditions as constant as possible. However, it is desirable to use dynamic controls and co-optimization of environmental variables that can lead to cost savings with improved resource use efficiency.

Keywords: vertical farming, resource-use efficiency, environmental conditions, system design

Murat Kacira is director of the Controlled Environment Agriculture Center and he is a professor in the Biosystems Engineering Department at the University of Arizona. His research involves environmental control, automation, alternative energy, and resource use optimization in controlled environment agriculture systems including greenhouses and vertical farms. He is a member of American Society of Agricultural and Biological Engineers (ASABE), American Society of Horticultural Sciences (ASHS), and International Society for Horticultural Science (ISHS). He served a Chair of Division Precision Horticulture and Engineering and Executive Board of ISHS for eight years.

IN-BOK LEE

Future-oriented approach of aerodynamics and energy engineering for environmental control of protected cultivation

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The Korean Agriculture is continuously facing several challenges such as the integration of global economy, a dramatic decrease in population in some places leading to a decrease in a number of dedicated farmers, aging society, climate change and an increasing gap between rural and urban areas. Such conditions are also affected by very small territory of the country where more than 70% of the area is mountain area and by the 4 distinguished seasons. Though maintaining a certain level of food and grain self-sufficiency is not easy because of those reasons, protected cultivation can guarantee a stable high annual income, maintain rural society, and revitalize the rural economy as well as keep food self-sufficiency at a safe level. Moreover, recently, interest in and research on urban agriculture has been actively conducted in consideration of climate change, carbon neutrality, and a win-win strategy for consumers and producers. In recent years, various ICT technologies have been actively developed and then applied to the field focusing in the fields of sensing, monitoring, crop-environment modelling, control, mechanization, automation, education, etc. In this presentation, the application of ICT technologies related to aerodynamic and energy engineering studies are introduced for smart-farm and urban agriculture.

Keywords: urban agriculture, ICT technologies, aerodynamic, energy engineering smartfarming

In-Bok Lee is Professor at Seoul National University, College of Agricultural and Life Sciences, Republic of Korea. He received a PhD degree in 1998 in aerodynamics and energy in agriculture at the 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, urban agriculture, information and communication technology and smart farm greenhouses, Virtual Reality (VR) and Digital Twins (DT) of greenhouse, 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, etc 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.

January 18th
Fast Talks - CROP MANAGEMENT

CHAIR: E. HEUVELINK

Move it to improve it – Increasing plant spacing during cultivation in dwarf tomato production

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Profitability in vertical farming (VF) requires efficient resource use, e.g., of growing space and of electricity for artificial lighting. High constant planting densities show trade-offs between yield and fruit quality due to plant-plant competition. Dynamic spacing is a possible strategy to use light and growing space more efficiently in VF systems, where plants are grown in substrate blocks or in pots. In this study, planting density is dynamically managed during cultivation to maintain a high ground cover percentage resulting in high light interception of canopy incident light. Here, light use efficiency (LUE) is defined as the harvested fresh weight of dwarf tomato fruits per applied photosynthetic photon flux density (mol PPFD) of photosynthetically active radiation (PAR; 400-700 nm) on one meter of growing space. The aim of the study was to investigate how different planting densities affect fruit yield, LUE, and fruit quality. Dwarf tomato (*Solanum lycopersicum* var. "Plum Tomato Red", Vreugdenhil, Netherlands) was grown in a climate-controlled room at 22/19°C (16h photoperiod), a relative humidity of 70%, and 800 ppm CO_2. An incident light intensity of 213 µmol m^{-2} s^{-1} was provided by red (89%) and blue (11%) LEDs. Two constant (high and low) and two dynamic (90% and 75% ground coverage) density treatments resulted in 100, 54.4, 41.1, and 18.5 plants per m^2 on average during 100 days from transplant to destructive harvest. To adequately present yield that was produced per dynamic spacing treatment, we introduce the unit square meter days (m^2 d) which is growing space area (m^2) integrated over time (d). A constant high planting density resulted in the highest LUE and yield per m^2 d, but lowest fruit size, °Brix, acidity content, and firmness. A constant low density resulted in the lowest LUE and yield, yet fruit size and quality parameters were significantly higher than at high density. The spacing treatments resulted in the same quality as constant low density but a higher yield and LUE. We conclude that increasing spacing during cultivation produces the same fruit quality as constant low density but with a much higher yield per unit ground area.

Keywords: planting density, dwarf tomato, light use efficiency

Evaluation of In vitro and hydroponic techniques for strawberry plantlet production

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Strawberry is a widely grown plant species for it's aromatic, bright red berries. Unfortunately, farmers around the world face a loss of yield due to frosts, drought, and plant pathogen invasions. Latvia farmers, in Kurzeme region, have reported 100% loss of yield in season 2023 due to late frost. Also, previous losses due to low quality planting material have been reported. To address these issues (e.g., low plantlet quality, inappropriate climate conditions), it was decided to initiate in vitro culture for strawberries, micro propagate them and test hydroponic techniques to produce stolons for having healthy daughter plantlets. Strawberry shoot culture was initiated from the first nod of the stolon using Murashige and Skoog (MS) basal salt mineral medium supplemented with 0.5 mg L^{-1} kinetin and 0.1 mg L^{-1} indole-3-acetic acid, sucrose 30 g L^{-1}, 6 g L^{-1} agar, pH adjusted to 5.8 before autoclaving. Every four weeks plant material was transferred to fresh ½ MS medium supplemented with 0.5 mg L^{-1} 6-benzyl amino purine, sucrose 30 g L^{-1}, 6 g L^{-1} agar. For rooting ½ MS medium supplemented with 0.75 mg L^{-1} Indole-3-butyric acid was used. During acclimatization stage, several approaches were tested. Plantlets were grown in perlite, vermiculite and peat substrates. Plantlets from perlite substrates after acclimatization were transferred to hydroponic and aeroponic systems, and plantlets from peat substrate were transplanted in bigger pots to initiate stolon formation. From 5 strawberry sorts tested four of them formed stolons in conditions 16h day/ 8 h night. Each plantlet formed on average 2 stolons with 2-3 plantlets on each stolon that were successfully rooted in raised humidity conditions. The approach seems promising for healthy plantlet production.

Keywords: aeroponics, cuttings, micropropagation, stolon, rooting
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Airflow, fertilizer solution recipes, and calcium concentrations influence lettuce and spinach growth in an indoor vertical farm

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Indoor vertical farming is a potential solution to address the high food production demands generated by the increased global population and urbanization. However, the maximum potential of indoor farms can only be achieved when optimal cropping systems are used. Currently, there is a lack of information concerning vertical farms in the Southeast U.S. since this technology is new and in constant development. The objective of our study is to evaluate the effect of airflow rates and nutrient concentrations for lettuce 'Rex' (*Lactuca sativa*) and spinach 'Lizard' (*Spinacia oleracea*) production in a deep water culture system inside an indoor vertical farm. We tested four airflow rates (0.4, 0.7, 1.0, and 1.3 m s^{-1}), two fertilizer solution recipes with different nutrient concentrations (Mattson and Resh), and three levels of calcium concentration (regular with 90 and 200 mg·L^{-1} Ca for Mattson and Resh, low with 40-50 mg L^{-1} Ca lower than regular, and high with 40-50 mg L^{-1} Ca higher than regular). Results showed that a high airflow rate (1.3 m s^{-1}) significantly increased plant water use and solution electrical conductivity ($P < 0.01$), negatively affected lettuce P, K, and Mg concentrations ($P < 0.05$) while having no significant effects on spinach growth performance and mineral concentrations. Lettuce and spinach plants grown using the Resh recipe had higher leaf area, yield, shoot and root biomass than the Mattson recipe. High Ca concentrations in the solution further accelerated these improvements, with additional benefits on increasing tissue Ca concentrations ($P < 0.01$). No nutrient deficiencies were found, indicating no Ca deficiency induced by low Ca availability, and reduced plant transpiration was presented using these airflow rates and solution Ca concentrations. Overall, slow airflow rates (0.4-0.7 m s^{-1}) and a Resh recipe with high Ca concentration can be used for lettuce and spinach production in vertical farms to increase yield.

Keywords: leafy greens, biomass, leaf quality, mineral composition, water use

Seed priming as a mean to improve seed germination in vertical farming

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With the growing interest in healthy eating and lifestyles, there is a high demand for the promotion of novel, fresh, and ready-to-eat foods, products often found in vertical farming setups. This is also highly applicable in the context of sustainable, Km0 food production and circular economy, where any waste products can be repurposed. Herein, sprouted seeds and microgreens are becoming increasingly popular foods, having an important potential to diversify and enhance the human diet. Among the different aspects that affect microgreen production, aside from selecting appropriate species, growing systems, and substrates, considerable attention has to be given to the evaluation of seed quality, germination performance, and seeding growth.

Fast and uniform seed germination and successful seedling establishment should represent high priorities, especially for vertical farming systems. Technologies designed to improve germination performance, generally known as seed priming, can contribute to building up a sustainable system for the cultivation of sprouts, microgreens, and baby leaf products.

Seed priming is the process of regulating seed germination by managing a series of parameters during the initial stages of germination. During priming, seeds are advanced to a homogeneous stage of the germination process to enable fast and uniform radicle emergence. This can be applied in a multitude of approaches including physical (radiations, microwaves, sonication), chemical (osmopriming, hormopriming, nutripriming), biological (biopriming with plant growth-promoting bacteria and fungi), or hydration (hydropriming, soaking) techniques. Priming treatments applied to enhance germination trigger the 'pre-germinative metabolism', a process that takes place during early seed imbibition and includes the activation of DNA repair pathways and antioxidant mechanisms, essential to preserve genome integrity and proper seedling development. However, the techniques are still based on empirical trial-error protocols that require constant optimization.

Our group has long-standing expertise in optimizing seed priming protocols and identifying hallmarks to be used as indicators to determine seed quality and priming efficiency. These can be applied to a multitude of plant species, including those dedicated to microgreens and sprouts production. In this work, data regarding hydropriming and/or nutripriming will be presented for alfalfa, soybean, and lettuce.

Keywords: seed germination, hydropriming, nutripriming, microgreens, sustainability

Cultivation of *Pleurotus ostreatus* and *Pleurotus cornucopiae* in vertical farming system

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Vertical cultivation systems, mainly used for vegetable species, can increase the productivity and reduce soil consumption. About cultivated mushrooms, this technology is mainly applied for *Agaricus bisporus*, but not for the cultivation of *Pleurotus* spp. In this study (funded by PRIN 2020ELWM82 V-FARM), the cultivation of *P. ostreatus* (3253 – Sylvan) and *P. cornucopiae* (3040 – Sylvan) in a vertical farming system using single shelves (SS) and twin shelves (TS) rows layout was considered (December 2022 - March 2023). Shelves were placed in a mushroom cultivation facility and each shelf had 4 cultivation racks: G (ground), 1R (first rack), 2R (second rack) and 3R (third rack). This system quadrupled the typical cultivation density using 12 bags/m^2. For both *Pleurotus* species 25 kg bags were used and filled with a straw-based commercial substrate. Overall, the experiment considered 108 bags for each species. The pinhead formation was monitored and during harvest time mushrooms were collected measuring the yield per bag and the number of families. Three families per bags were used to evaluate number, diameter, width and colorimetric parameters of fruiting bodies. Pinhead's appearance in the first flush showed a faster growth in 3R for both the species and for *P. ostreatus* the SS disposition showed a highest number of pinheads. In the second flush of P. ostreatus G and 1R showed the highest production of pinheads (78% and 70%). The yield of the first flush for *P. ostreatus* was higher in G (0.19 kg/kg substrate) and decreased in higher racks (0.15 kg/kg substrate). For *P. cornucopiae*, the yield was higher in 3R (0.04 kg/kg substrate) and lower in G (0.01 kg/kg substrate). During the first flush P. cornucopiae had a bigger diameter in G, whereas *P. ostreatus* showed the highest one in 3R. *P. cornucopiae* and *P. ostreatus* can be cultivated in a vertical farming but cultivation height can affect yields and other productive traits. The shelf arrangement (SS or TS) did not influence the production; however, the economic and labour cost consequences need to be evaluated. The thermal gradient detected within the mushroom cultivation facility between G and 3R (±1.5 °C), if not mitigated through air mixing, could be exploited for cultivating both *Pleurotus* species within the same environment, providing a potential combined production and optimizing energy consumption. Moreover, arranging differently the bags of the two species on the same shelf could be useful to optimize their yield.

Keywords: edible mushrooms, quality, yield, space use efficiency, temperature

Potential and limitation of Alginate hydrogels application as cultivation medium in vertical farming

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Alginate hydrogels as a biodegradable material represent a green technology for new alternative substrates for a sustainable agricultural industry compared to peat or rockwool usage. Vertical farming systems guarantee the production of food in a climate-resilient manner, with the possibility of potentially applying zero pesticides and fertilizers, and with lower land and water use than conventional agriculture. Adopting natural hydrogels as cultivation mediums in vertical farming would contribute to increase the provision of high-quality products from sustainable soilless cultivation systems. In this regard, three alginic acid concentrations (2, 2.5 and 3 w/v%) used for Ca-alginate hydrogel (Alg) creation are currently tested in order to understand their potential and limits for plant cultivation. In addition, the same concentrations are experimented adding 1 w/v% of active biochar (ab) to the alginate solutions (Alg + ab) to test possible differences in the hydrogels and plant nutrients uptakes meanwhile providing a dark substrate for root development. Two model plants for vertical farming have been selected: *Rhodiola rosea*, perennial plant that accumulates salidroside and rosavin in its roots and rhizome and *Lactuca sativa* as a fast-growing plant. The cultivation is taking place under controlled environmental conditions using artificial light sources and a deep-water irrigation system. The experimental set up hosts a plant density of 100 plants per m^2 and a light intensity of 300 µmol m^{-2} s^{-1} with the addition of 2,2 % UV-B light for a photoperiod of 16 hours per day. The results will focus on the differences in the hydrogels (Alg and Alg+ab) initial rheological properties (texture analysis), nutrients absorption (macro and micronutrients analysis) and by providing a visualization of its natural degradation. In addition, critical aspects on the plants growth will be presented, in particular yield and secondary metabolites accumulation examined by HPLC analysis. The findings can provide a basis for further analyses specifically focusing on plant ingredients accumulation. One further approach would be the usage of plant growth promoting bacteria encapsulated in alginate hydrogels.

Keywords: alginate, vertical farming, *Rhodiola rosea*, *Lactuca sativa*, horticulture

Impact of vertical farming systems on lettuce yield and quality: a comparison study

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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. Because of this, standardization and reproducibility of the characteristics of the final product are expected no matter which farm is used and where farms are geographically placed. However, experience from industry shows that this has not yet been reached due to, among others, different system and control designs. To investigate the effect of cells technical designs and realized growth conditions, a comparison study was run simultaneously at Delphy, Logiqs, Signify, Vertify, WUR indoor research facilities. Propagated Batavia lettuce Caipira was grown with the same cultivation recipe and irrigation strategy for 3 weeks: 24/20°C d/n temperature; 70/80% d/n relative humidity; 1000ppm CO_2; under LED lamps (90% Red – 10% Blue and +5% Far Red) with a DLI of 12.5 mol m^{-2} d^{-1}. Each cell was equipped with extra T-RH sensors below (laying on the raft) and on top of the plants to study the realized climate around the crop and link it, on one side, to cell climate and, on the other side, to final yield. After 21 days of cultivation under same setpoints, a significant difference in lettuce production and quality was found. The average weight was 233 g/head pulled for Delphy, Signify and Vertify compared to 174 g/head at WUR and 68 g/head at Logiqs. Analysis of the supplied and extracted air composition (temperature and relative humidity) and realized climate around the crop showed that, starting from same setpoints, different climate system controls realized different conditions. When different cells have the same climate control system, similar average yield was achieved pointing towards the conclusion that the way the climate is steered is more critical than the sizing of the cell.

Keywords: vertical farming, climate control, lettuce, standardization, yield

Anatomical traits modulate the morpho-physiological response of cultivated plants to VPD and light intensity.

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Phenotypic plasticity is defined as the capacity of a plant to generate rapid changes in response to any variation in the environmental condition and it is a fundamental characteristic to enable sessile plants to adapt to any sudden changes in their surroundings. Both leaf anatomical and physiological traits exhibit plasticity in response to variations in light intensity and Vapor Pressure Deficit (VPD). However, it is not clear yet how the combination of these environmental factors changes leaf anatomy, thus influencing the capacity of plants to acclimate. We conducted an investigation measuring morpho-anatomical and physiological traits in green and red lettuces (*Lactuca sativa* L. var. capitata 'Salanova') grown in a vertical farm under optimal/low VPD (0.78 kPa, LV) or sub-optimal/high VPD (1.4 kPa, HV) in combination with three light intensity levels: i) 200, ii) 300, iii) 360 µmol m^{-2} s^{-1}. Almost all the measured traits were significantly influenced by the interaction between VPD and light, particularly the highest light intensity level in combination with sub-optimal/high VPD created a very dry micro-environment surrounding the leaves, which consequently affected the proper development of leaves' mesophyll. Our results imply that genotypes presenting higher photosynthetic rates at low light intensity and VPD levels do not necessarily maintain the same coordination of morpho-physiological traits under higher light intensity and VPD conditions. This study also highlights the fundamental role of leaf anatomy plasticity in the exploitation of crop acclimation potential to a changing environment and may have practical implications for cultivar selection/plant breeding for vertical farming.

Keywords: anatomical traits, plant biology, phenotyping, *Lactuca sativa* L., vapor pressure deficit

January 18th
Fast Talks - SENSORS

CHAIR: B. BUGBEE

Non-destructive measurement of secondary metabolites in plants

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Vertical farming and indoor farming have gained significant attention due to their potential to revolutionize agricultural practices. The controlled environment in these systems allows precise control over plant cultivation, thereby influencing plant quality, including the content of secondary metabolites which, however, can vary enormously. As knowledge of such parameters is crucial for food, medicinal, and brewing cultivars, currently, destructive, expensive, and time-consuming measurement and analytical methods are employed. Here, we propose a non-destructive measurement approach based on chlorophyll fluorescence, which allows for the estimation of secondary metabolite content through epidermal absorption measurements. Since secondary metabolites are primarily located in the epidermis, the measurement of epidermal absorption can provide insights into secondary metabolites and their content. We developed a routine involving serial excitation of plant samples at varying wavelengths, measuring the response signal. To validate the effectiveness of this method, we conducted initial experiments in-vitro and investigated the transferability of the findings to in-vivo samples. The in-vitro experiments provided encouraging results, and the transferability of the method to in-vivo samples showed promising outcomes, suggesting its potential application in real-world scenarios. Non-destructive measurement methods are essential for assessing plant quality parameters not only in controlled environment agriculture. Our study presents a novel approach based on chlorophyll fluorescence and epidermal absorption measurements to estimate secondary metabolite content. The preliminary results demonstrate the potential of this method, offering a non-invasive, cost-effective, and time-efficient solution compared to traditional destructive measurement techniques. Further research is required to optimize the method and validate its effectiveness across a wide range of crops. Implementing non-destructive measurement approaches in precision farming can significantly benefit both consumers and industries seeking accurate information on plant quality and secondary metabolite content.

Keywords: non-destructive, plant-quality, secondary

A low-cost computer vision system to optimise Cannabis light cuttings production

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The "Cannabis light" sector accounts in Italy for a market of € 150 million and is continuously growing. Cannabis is a multi-use crop: inflorescences are used in the therapeutic sector, seeds for the extraction of essential oils or to produce biodiesel and stem fibres are valuable for the textile and building sectors. In Italy cannabis has been historically grown in open fields. However, its cultivation in Controlled Environment Agricultural (CEA) systems, such as greenhouses and vertical farms, achieves higher yield by scheduling and standardising the crop growth cycle through fine-tuning of environmental conditions (light, temperature, CO_2 concentration) and mineral nutrition. The quality of the propagation material is of great importance to obtain high-quality inflorescences. Technological advancement in the areas of Internet of Things (IoT), Machine Learning (ML) and Computer Vision (CV) has allowed us to develop systems for monitoring plant growth and their nutritional status to have a complete control of the growth process. However, the cost of such systems is elevated. Low-cost micro-computers, such as the Raspberry Pi, may also be used to implement ML and CV models and reduce the investment costs. Therefore, the aim of this work was to analyse the growth and variations in the Normalized Difference Vegetation Index (NDVI) during the Cannabis light cuttings production cycle, in four varieties (Fibror 79, Earlina 8FC, Tiborszallasi and USO 31) with a low-cost phenotyping system created with Raspberry Pi Zero W, and visible (400-700nm, VIS) and visible + infrared (400-800nm, VIS+IR). Cannabis light cuttings were grown for 20 days in a growth chamber under LED light (Meg-Sciences, Milan, Italy) with a light spectrum composed of 40%Red, 40%Blue, 10% Green+ 10% Far Red. Light intensity was set to 150 μmol m^{-2} s^{-1} for 18 hours of photoperiod. Temperature and Relative Humidity were set at 23°C and 60%, respectively. Results showed that applying CV models with Raspberry Pi, in both operative ranges (VIS and VIS+IR) allowed us to correctly analyse and monitor plant growth and nutritional status and differentiate the four varieties' growth rate. Compared to the VIS camera, using VIS+IR camera is preferable since it provides a more reliable monitoring of plants growth, and it correctly calculates the NDVI index. Integrating the Light Detection and Ranging (LiDAR) sensors into the system could improve crop growth monitoring for a longer cultural cycle.

Keywords: artificial intelligence, phenotyping, micro-computers, vegetation indexes, python language

Energetic optimisation of a vertical farm design using an integrated discrete-event simulation method

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High structural investment and running costs, particularly energy, are currently among the major challenges for operating Plant Factories. This is especially true when considering the recent fluctuations in gas and electricity price, which raise concerns about the return of such investments. In this context, Vertical Farming companies are forced towards the adoption of highly efficient cultivation techniques that aim at maximising the productivity per square meter per year, while at the same time minimising the amount of agronomical and energetic inputs. As a consequence, a crucial aspect in the design phase of a new Plant Factory is the ability to forecast and optimise its energy efficiency performance and resilience with respect to several realistic energic scenarios. We present the case study of a future 1.1 ha, highly-automated vertical farm in Northern Italy, and an integrated methodology to simulate its yearly agronomical, logistic and energetic output at a fine granularity of 1 s. A production planning algorithm was made to process an input market demand and, based on a set of enabled crops and growth configurations, determine the schedule of daily agronomical operations as well as the time allocation of resources for each individual growing cycle. Agronomical parameters such as evapotranspiration rate and yield for each crop and growth configuration were determined through experiments in a 1:24 scale prototype growing cell having the same modular layout of the designed farm. Subsequently, a discrete-event simulation was built upon the farm layout and mechanical logics, using the nominal characteristics of the selected machinery including CCHP trigeneration, HVAC, LED lighting, warehouse logistics and packaging. Results of the simulations indicate that for high-throughput lettuce varieties (> 105 kg/m^2/year) the design considered in this study will achieve a state-of-the-art energy efficiency of less than 10 kWh/kg edible product. Moreover, to optimise electricity cost, several provisioning scenarios were run to evaluate several size configurations for the trigeneration unit and an auxiliary photovoltaic plant, taking into account the energy demand distribution at an hourly resolution as well as uncertainty of gas/electricity price.

Keywords: Plant Factory design, energy efficiency, discrete-event simulation, operational research

Artificial neural networks to optimize light and mineral nutrition for leafy vegetables in aquaponics

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Developing sustainable food production systems able to use resources in a smart and efficient way is essential. Aquaponics is an integrated production technique in which fish feeding is the only nutrient input required to produce both fishes and plants. However, during the winter, due to the reduced solar radiation and temperature, the photosynthetic activity decreases in line with the plant's capacity to absorb water and nutrients. Nitrate and ammonium at high concentrations in the nutrient solution can be toxic to fish, forcing to frequent discharge of waste nutrient solution and resulting in high economic and environmental costs. Predictive models of plant development and eco-physiological performance can be used to estimate real-time plant requirements and to optimize resources utilization. The most common models are based on simple linear regressions for estimating a single variable or multiple linear regressions (MLR) for complex physiological processes. Artificial Neural Networks (ANNs) are mathematical models composed of artificial neurons inspired by biological neural networks, used to solve Artificial Intelligence problems in various technological fields. However, no studies seem to be performed in aquaponics. This study aims to compare the performance of an MLR model with that of an ANN model created from environmental, physiological and nutrients solution concentration data recorded during two cultivation cycles. Specifically, the models were used to predict leaf net photosynthetic rate (A), stomatal conductance (gs), transpiration (E), intrinsic Water Use Efficiency (WUEi), in endive and lettuce plants grown under natural light or natural light integrated with supplementary LED lighting (LI, average PPFD: 173 µmol m^{-2} s^{-1}, average Daily Light Integral (DLI): 10 mol m^{-2} d^{-1}) in combination with fish in a recirculating aquaponic system. The results show that the model accurately predicts all variables. However, the performance of both models decreases when considering less variables due to dataset reduction. Nevertheless, the ANN model exhibited lower errors and a higher accuracy than the MLR model, that strongly correlate with total biomass data obtained at the end of the crop cycles. In conclusion, using ANN to predict leaf gas exchange can improve energy and nutrients use efficiency while reducing water consumption and environmental impact in aquaponics. Further studies should focus on the integration of plant´s growth features and vegetation indexes to increase the accuracy of the model.

Keywords: artificial intelligence, Light-Emitting Diode (LED), aquaponics 4.0, Controlled environment agriculture (CEA), smart farming, model

January 18th
Fast Talks - METABOLITES

CHAIR: I. RIGHINI

Red LED light improves pepper (*Capsicum annuum* L.) seed germination through the modulation of aquaporins, hormone homeostasis and metabolites remobilization

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Red LED light (R LED) is an efficient tool to improve seed germination and plant growth under controlled environments since it is most readily absorbed by photoreceptors phytochromes with regards to other wavelengths of the spectrum. In this work, the effect of R LED (GH CSSRM5.24 OSLON ® Square model) on the radicle emergence and growth (Phase III of germination) of pepper seeds was evaluated. Thus, the impact of R LED on water transport through different intrinsic membrane proteins, aquaporin (AQPs) isoforms was determined. Also, the remobilization of distinct metabolites such as amino acids, sugars, organic acids and hormones was analyzed. R LED induced a higher germination speed index regulated by an increased water uptake. PIP2;3 and PIP2;5 aquaporins isoforms were the highly expressed and could contribute to a faster and more effective hydration of embryo tissues leading to a reduction of the germination time. By contrast, TIP1;7, TIP1;8, TIP3;1 and TIP3;2 gene expressions were reduced in R LED treated seeds pointing out a lower need of protein remobilization. NIP4;5 and XIP1;1 are also involved in radicle growth but their role needs to be elucidated. Also, R LED induced changes in amino acids and organic acids as well as sugars. Therefore, an advanced metabolome oriented to higher energetic metabolism was observed, conditioning better seed germination performance together with a rapid water flux.

Keywords: aquaporins; *Capsicum annuum*; LED-lighting; radicle emergence; seed germination

Biostimulant assessment on the culture of basil in a hydroponic system

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Hydroponics is a soilless cultivation technique, where mineral nutrients are dissolved in the circulating solutions. These are necessary for the development and growth of plants on inert supports, allowing their roots to absorb the nutrients. Basil is a plant whose aromatic leaves are used as a condiment, ornamentally, for cosmetics and also traditionally as a medicinal plant in countries around the world. The objective of this study was to test the efficacy of 4 different biostimulants marketed for soil culture in a hydroponic basil crop. Two of them stimulate the growth of the aerial part of the plant (increased biomass) and the other two of the roots (improved nutrient uptake). The experiment was conducted in two batches, in the first batch three treatments were tested: the control in which only the nutrient solution was used, the nutrient solution with the biostimulant SalicylPuro, and the third in which the nutrient solution was supplemented with the biostimulant SilicaPower. In the second batch, three other treatments were used, once again the control, another one supplemented with a specific biostimulant for aromatic plants (TricoStimulant®) and the third one an organic biostimulant, Verme Ditoso®. For hydroponic cultivation, 3 Sananbio® vegetative growth modules were used in each batch. The plants were maintained under a photoperiod of 16 h light and 8 h dark, with a thermoperiod of 24 ± 0.4 ºC during the day and 21± 04 ºC in the dark period. The relative humidity in the chamber was maintained at 70 ± 3 %. Growth parameters were determined to evaluate the effect of biostimulants on a total of 566 basil plants. Also, radical scavenging activity against 2,2-diphenylpicrylhydrazyl (DPPH) was determined and expressed as inhibitory concentration 50 (IC50).The results reflect that the commercial biostimulants did not cause an improvement in growth with respect to the controls. Nevertheless, the radical scavenging activity varies in relation to the biostimulant. Verme Ditoso is the treatment that causes the greatest stimulation of the metabolic pathways related to radical scavenging activity. The only treatments with lower activity than the control were Silica Power and SalicylPuro. However, it would be advisable to conduct further studies to evaluate whether they improve other properties, such as post-harvest preservation, or increase the nutraceutical properties of the plant, before completely discarding their use in hydroponic basil cultivation.

Keywords: soilless culture, *Ocimum basilicum*, phytostimulants, growth parameters, IC50

Effect of biostimulants on secondary metabolism of hydroponic basil culture

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Despite the potential benefits of biostimulants, their use in hydroponics is still in its early stages. Further research is needed to determine the most effective types and concentrations of biostimulants for different hydroponic crops and systems. Additionally, the regulatory framework for biostimulants is still evolving, and growers need to be aware of the potential risks and limitations of these products. Overall, the use of biostimulants in hydroponics shows great promise for improving crop quality and sustainability. The objective of this work was to evaluate the efficacy of four different biostimulants marketed for soil culture, in a basil crop in hydroponics, in relation to its secondary metabolism. The experiment included a total of 560 basil plants grown in three Sananbio® hydroponic modules. The experiment was conducted in two batches, in the first batch three treatments were tested: the control in which only the nutrient solution was used, the nutrient solution with the biostimulant SalicylPuro, and the third in which the nutrient solution was supplemented with the biostimulant SilicaPower. In the second batch, three other treatments were used, again the control, another supplemented with a specific biostimulant for aromatic plants (TricoStimulant®) and the third an organic biostimulant, Verme Ditoso®. The plants were maintained under a photoperiod of 16 h light: 8 h dark, with a thermoperiod of 24 ± 0.4 ºC during the day and 21± 0.4 ºC during the dark period. Relative humidity in the chamber was maintained at 70 ± 3 %. After collection, the aerial part of each plant was freeze-dried and weighed. The plant was extracted in methanol and total phenols, flavonoids and antioxidant capacity were determined. The biostimulants had different effects on basil metabolism. Tricostimulant and Verme Ditoso increased the concentration of total phenols more than the control group, while flavonoids were highest in the control group. Verme Ditoso and TricoStimulant significantly improved the scavenging capacity, indicating better plant health compared to the control group. Although they did not directly improve biomass growth, these biostimulants enhanced the overall quality of the plants. Further research is needed to determine the optimal dosages of these biostimulants for hydroponic cultivation.

Keywords: total phenol content, *Ocimum basilicum*, soilless culture, antioxidant, flavonoid

The Impact of light on morphometric characteristics and biochemical profiles of Brassica crops

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Novel foods, including sprouts, microgreens, and baby leaves, have gained popularity in the market due to their high nutritional value, as they represent a rich source of antioxidant compounds known for their potential in preventing chronic-degenerative human diseases. The purpose of this study was to investigate the effects of light conditions on the morphometric and biochemical profiles of two commercial varieties of rocket (*Eruca sativa* Mill. var. darkita and *Eruca sativa* Mill. var. lobata) and one Sicilian landrace of sprouting broccoli (*Brassica oleracea* L. var. italica Plenck, Broccolo nero). The plants were placed under two different types of shade nets to evaluate the plant growth and the response to different light conditions. These nets included a green shade net (with a shading percentage of 30%, 30% SP) and a black polyethylene net (providing a 50% shade, 50% SP), in comparison with a control set of the plants grown without any shade net (0% SP). The experimental trial was conducted in a cold greenhouse in Catania, following standard organic agriculture techniques. The plantlets were collected at different growth stages and characterized for their main morphometric traits. For sprouts, these traits included the weight of 10 individuals, hypocotyl length, cotyledon length and width. Additionally, for microgreens, the number, length, and width of the true leaves were determined, and, the stem length for baby leaves. Total phenolic content (TPC), total flavonoids compounds (TFC), and antioxidant capacity (DPPH, ORAC, and FRAP assays) were performed. The results revealed several differences among the considered experimental factors. A significant interaction was observed among the morphometric traits, genotype, and light conditions. The antioxidant capacity was significantly affected by both genotype and plant growth stage, showing an increase from the sprout growth stage to the microgreens and baby leaves. Broccolo nero, notably, exhibited the highest antioxidant capacity. These findings underscore the valuable contribution of Sicilian landraces, providing interesting insights of novel foods, by supporting the biodiversity in organic agriculture.

Keywords: Brassicaceae, landraces, novel foods, antioxidants compounds, shadow

Blue light increases anthocyanin content in purple pepper fruit

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Basil (*Ocimum basilicum* L.) is a popular culinary herb known for its unique aromatic quality. Its fast growth cycle, high harvest index, high profitability, and good adaptability to hydroponic systems make the herb one of the most suitable model crops for the Controlled Environment Agriculture (CEA) systems. Vertical farming is an advanced CEA system in which plants grow in a closed environment that is independent of solar light and outdoor conditions, allowing for complete control of all environmental parameters. The main light spectrum in vertical farming system is the photosynthetically active radiation (PAR, 400-700 nm), supplied by light-emitting diodes (LEDs). Generally, UV light is not implemented in crop production due to its potential to damage plant cells and cause stress, but the absence of UV light may reduce the synthesis of metabolites, negatively affecting product quality. Therefore, providing short-term exposure to UV light could be a solution to the problem. Although UV radiation does not contribute to photosynthesis, it can induce, to some degree stress responses that trigger a series of physiological and biochemical changes that improve crop quality. We investigated the effects of UV radiation on basil quality, particularly on their metabolic level. In this study, 30-day-old green basil plants (cv. Dolly) that were cultivated with 200 μmol m^{-2} s^{-1} red-white LEDs from germination were exposed to supplemental UV-B (0.6 W m^{-2}, 30 min day^{-1}) or UV-C (0.6 W m^{-2}, 15 min day^{-1}) lamps at the end of production for four days. The metabolic profile of basil leaves at harvest was determined using the metabolomics technique 1H NMR. Both UV-B and UV-C exposed leaves showed the high level of phenolic compounds compared to the leaves without supplemental UV. After harvest, basil leaves were stored at 4°C for 12 days, and their overall visual quality and shelf life were not affected by the supplemental UV treatments. These results provide valuable insights into the effects of UV radiation on the metabolic profile of basil plants.

Keywords: basil quality, UV LED, metabolomics, phenolic compounds

UV radiation as an elicitor to increase the secondary metabolites content in *Rhodiola rosea*, cultivated in an indoor vertical farm

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By 2028, the European medicinal plant market is forecasted to grow at a CAGR (Compound Annual Growth Rate) of 6.02 %. Only 10 % of these medicinal herbs are cultivated while 90% of the raw material for the pharmaceutical industry is harvested from wild flora. Accordingly, many medicinal plants have become endangered due to excessive harvest. Additionally, climate change has a great influence on both wild and cultivated medicinal plants. Indoor vertical farming gives us an advantage in optimizing the climatic conditions according to crop requirements hence helping us to preserve and cultivate these species. Furthermore, it enables the cultivation of medicinal plants using elicitors to increase the secondary metabolite content. UV radiation is among the effective elicitors affecting phytochemical production like phenolic compounds. The cultivation of endangered species like *Rhodiola rosea* in indoor vertical farms increases the supply of raw materials for pharmaceutical industries all year round. Cinnamyl alcohol glycosides like rosin, rosavin, and rosarin are a group of important secondary metabolites present in *Rhodiola rosea*. The project "VerticalRegioPharm", aims to analyse the potential of *Rhodiola rosea* cultivated in indoor vertical farms with additional UV radiation as an elicitor to increase secondary metabolites compared to field production. The study shows the conceptual structure of the research project, especially the main experimental setup. In indoor vertical farming, plants will be subjected to three different treatments including, UV-A, UV-B, and a combination of UV-A and UV-B with an ebb&flow system. Every six months, the shoot and root yield (g/m^2), height (cm), and secondary metabolite will be measured. Based on the results, further research will be conducted on the concentration of UV radiation.

Keywords: indoor vertical farming, *Rhodiola rosea*, UV light, medicinal plant, secondary metabolites

The effect of melatonin on morphometric traits and antioxidants profile of sprouts, microgreens, and baby-leaves of *Brassica oleracea* L.

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Melatonin has gained prominence in recent years due to its potential to enhance several agronomic characteristics of the plants, such as the plant growth, seed germination, and flowering, while also promoting the antioxidant capacity of bioactive compounds known for their potential effects against chronic-degenerative human diseases. This trial aims to assess the effects of melatonin as biostimulant on morphometric traits and antioxidant profiles of two *Brassica oleracea* L. cultivars, considering three different growth stages: sprouts, microgreens, and baby-leaves. Specifically, we analysed a Sicilian landrace of sprouting broccoli, Broccolo nero, grown on the slopes of Mount Etna, and a commercial broccoli cultivar Cavolo broccolo ramoso calabrese. The experimental design adopted was a spilt plot randomized with three experimental factors: the first factor was the melatonin treatment (MT), the second the genotype (GE), and the third the plant growth stage (GS). The sowing was carried out in a cold greenhouse located in Catania, following organic cultivation practices. The plantlets were treated by foliar spray at the three different growth stages considering three doses of melatonin (0, 50, and 100 μM). All fresh biomass samples were collected and characterized for the main morphometric descriptors, including the weight of ten individuals, hypocotyl length, and cotyledon dimensions for sprouts. Moreover, for microgreens, the number and dimensions of true leaves were additionally recorded, while in addition for baby-leaves, the stem length was determined. The antioxidant analyses were carried out (TPC, ABTS, and FRAP assays). The results acquired showed that exogenous melatonin application significantly affected the morphometric traits. The foliar application of 100 μM of melatonin increased the antioxidant capacity. Both genotypes were influenced by the MT. Further molecular research will be conducted to validate these findings and pinpoint genetic markers associated with the antioxidant pathway.

Keywords: broccoli, biostimulant, food chain, novel foods, landrace

Eustress and biofortification: effects of *Anethum graveolens* L. in a Micro - Indoor Farm

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Selenium is an essential micronutrient for humans. Plants are primary sources of selenium for humans and mammals. The availability of Se in the soil can vary greatly depending on geographical region and agricultural practices, resulting in different amounts of Se present in plants. Increasing Se concentration in plants tissue is possible through various techniques, such as agronomic biofortification and salt eustress technique. In this study, dill (*Anethum graveolens* L.) plants were used to increase Se content using sodium chloride in the nutrient solution (salt eustress) and sodium selenate sprayed on plants (agronomic biofortification). Sodium selenate (1 µM) and/or sodium chloride (10 mM) were added to some of the plants, while the control plants were grown in the nutrient solution alone. The plants were grown in a micro-indoor farm using two soilless cultivation systems: Floating Growing System and Nutrient Film Technique. Biometric data, yield, macro- and microelement content, total phenol and chlorophyll content, and activities of catalase (EC 1.11.1.6), ascorbate peroxidase (EC 1.11.1.11) and guaiacol peroxidase (EC 1.11.1.7) were evaluated. The results showed a higher concentration of Se in the plants grown with Se (ca. 30 mg kg^{-1} DW). Furthermore, plants grown with both sodium chloride and Se absorbed 25% more Se than plants with only Se. Increasing selenium in plants in the presence of sodium chloride could be an opportunity to use water rich in soluble salts in soilless cultivation systems. Growing selenium biofortified crops through the exploitation of the indoor farming can be a suitable alternative to traditional growing systems for reducing selenium deficiency in human beings and mammals.

Key words: soilless cultivation, selenium, dill, sodium chloride, sodium selenate

January 18th

PARALLEL SESSION

in SALA QUADRANTE

WORKSHOP: SOCIETAL CHALLENGES

CHAIR: M. D'OSTUNI, T. BLOM

Setting the scene for policy innovation

In the book Vertical Farming, D. Despommier starts to envision a new possible way to produce food which is now detached from the soil, alienated from the rural fringes of our world, and it is located right in our highly-dense, compact cities. The premises for this book are quite disarming, since the high soil pollution, the intensive use of herbicides and pesticides, and the monocultural approaches of industrialized agriculture have limited our capacity to produce enough food in a sustainable manner in the foreseeable future. Nonetheless, if vertical farming can be one viable solution, it is not the only answer. Living in a world where all the (or most) of our food is produced indoors in giant plant factories looks much more like a dystopian scenario rather than a utopian one. In this sense, to be effective, vertical farming should be intended as a complementary production to rural agriculture, taking off the pressure of agricultural soils and fostering sustainable mitigation practices: for instance, it can favor re-wilding processes in marginalized or unused agricultural lands. On the other hand, vertical farming practices should also be complementary to urban and architectural development, being a key asset to recycle resources from buildings activities into production practices. All in all, vertical farming is facing the really not easy challenge to be the linchpin between the rural productive world, and the highly dense urban habitat of our metropolis and megalopolis. To make sense of it, it is important to frame a set of interdisciplinary policies where the topics of agricultural food production, urban food production, urban planning, and climate change mitigation strategies should converge into one holistic set of legislations and regulations. Furthermore, to be even more effective in this sense, vertical farming initiatives should overtake the present decoupling between the real urban food demand and what is actually being produced indoors (often identified as high-priced produce) which is still quite limited. On this trail, the objective of the presented workshop is to envision future scenarios for vertical farming, and how it can be connected both to the rural environment and to present and future cityscapes.

Keywords: rewilding, community engagement, food demand, policy innovation

ANN-KRISTIN STEINES

Resource-saving agricultural production: vertical crop cultivation using nutrients from wastewater treatment plants

In times of increasing urbanization, growing sustainability awareness and increasing resource scarcity, feeding the expanding global population faces various challenges. Beyond the effects of climate change, the unavailability and limitations of fertilizer inputs are expected to have an impact on current and future agricultural production systems.

The potential of resource recovery from wastewater for agricultural production and for linking wastewater systems to food production has not been sufficiently examined until now. With the development of a local, hydroponic (soilless), vertical food production system that is directly coupled to wastewater technology, nutrients can be obtained from the wastewater of a wastewater treatment plant of the future and used for cycle-based agricultural production. Our objective is to investigate this innovative approach to food production, which can be integrated into urban structures reducing supply distances and enhancing food security in a self-sufficient and sustainable manner. In pursuing this goal, we are investigating how agricultural systems can be designed to be climate-sensitive, resource-efficient, and efficiently integrated into urban spaces. Collaborating with stakeholders from science and practice, a multi-stage scenario study was conducted in 2021 to identify different influencing factors for future pathways of a resource-saving, urban agricultural system. Following this analysis, scenario narratives were formulated based on three selected key factors for different locations in the Ruhr area in Germany. As a result of the interdisciplinary process, five scenarios outline opportunities, necessary actions, as well as potential risks and challenges for integrating urban agriculture with wastewater treatment plants. The scenarios illustrate the dynamics between urban development and the new ways of linking wastewater systems and agricultural systems (so-called NEWtrient® centres) up to the year 2050. Moreover, they outline the involvement of residents in future agricultural production and nutrient recovery. Additionally, the scenarios provide insights into the potential appearance of future wastewater treatment plants as sustainable, resource-efficient agricultural production systems. With an interdisciplinary research approach, it makes an important contribution to the innovative further development of sustainable urban food production as well as

resource-efficient urban water management.

Keywords: urban agriculture, circular economy, wastewater

Ann-Kristin is a researcher at the ILS Research, Affiliated Institute of ILS – Research Institute for Regional and Urban Development gGmbH in Dortmund, Germany. Her research focuses on urban agriculture, in particular the integration of vertical, hydroponic agricultural production on wastewater treatment plants in the sense of a circular economy, as well as in food system transformation and the strengthening of city region food systems. She is involved in several national and international projects, such as the European project H2020 FoodE (Food System in European Cities).

January 18th

PARALLEL SESSION

in SALA QUADRANTE

Fast Talks - SOCIETAL CHALLENGES

CHAIR: M. D'OSTUNI, T. BLOM

An innovative system of water reuse practices for the promotion of sustainability in vegetable production

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Smallholder farmers are globally the main producers of food and provide 60-80% of the food produced in the Mediterranean region. Climate change impacts severely water availability for agriculture with worsening climate conditions set to threaten water supply. Treated wastewater for irrigation can be used to mitigate water scarcity. This, however, poses problems of introducing organic micro-pollutants, high content of nutrients, and salinity from wastewater into the soil. Under these circumstances, Prima 2021-SAFE project major challenge is the development and improvement of tools to: sustainable increase yields through good quality of water for irrigation and improve adaptation of plants to salinity conditions and wastewater use while at the same time expand agricultural practices that could facilitate this adaptation (i.e. irrigation, fertilizer use, grafting). SAFE is a PRIMA2021 - RIA project with 11 partners from 8 Mediterranean countries that will promote the use of reclaimed wastewater for agriculture providing a multi-beneficial approach with a novel, sustainable decentralized wastewater solution. ELGO-Dimitras' role includes the employment of renewable energy sources to mitigate carbon footprint and maximize resource use efficiency of wastewater reuse in greenhouse hydroponics and soil cultivation of vegetables. Results of the use of modern -omics tools such as transcriptomics for the in-depth analysis of the impact of wastewater reuse on plants genes and physiology are also presented. The focus is on the gene networks involved in plant responses to abiotic stresses, mainly salinity. Exploring molecular mechanisms controlling important aspects of plants' response and adaptation to salinity stress leads to the development of molecular markers that can be used further in plant breeding for better adaptation to wastewater reuse. Furthermore, the use of sustainable agriculture practices such as vegetable grafting that helps plants adjust to wastewater reuse is presented.

Keywords: wastewater, renewable energy, -omics, grafting, sustainability

Using the Net-Map tool to analyze stakeholder networks in the city region food systems of seven European cities.

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The current global food system is characterized by anonymity in the value chain, global food trade, loss of knowledge about food sources and a distant producer-consumer relationship. In addition, the negative environmental impacts of the agricultural sector, such as pollution, degradation of soil and water quality, loss of biodiversity and significant greenhouse gas emissions, make this sector a major driver of climate change. In contrast, the city region food system (CRFS) approach captures the complexity of a food system and its actors at the local level. It aims to meet the requirements of sustainable transformation along the food value chain and offers an alternative approach to the challenges of the global food system. To better understand the relevant actors and their dynamics within this framework, our study focused on analyzing CRFSs as networks. We used the Net-Map tool to study seven European cities (Bologna, Naples, Lansingerland, Tenerife, Oslo, Dortmund, and Romainville) with different CRFS networks. The aim was to show how the NetMap tool can effectively support the evaluation of the CRFS by identifying different actor roles, recognizing patterns of relationships, assessing the strengths and weaknesses of the network and suggesting potential solutions for improvement with additional strengths, weaknesses, opportunities and threats (SWOT) analysis. This work highlights the limitations, advantages and practical use of the Net-Map results and discusses potential transferability to other case studies.

Keywords: City Region Food System, Net-Map tool, social network analysis, stakeholder networks

Feasibility of mushrooms cultivation in a shipping container: a case study from Bologna, Italy

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Urban farming is acknowledged as a potential strategy to reduce food insecurity in densely populated regions. In highly populated settings, where green spaces are usually lacking, vertical farming represents a means to enhance urban food production within the limited available land. The technology is commonly promoted as a way to regenerate vacant urban voids, enabling to produce food without further soil and landscape exploitation. Among innovation technologies for urban farming, a possible solution is the refitting of shipping containers into food production units. Such containers are originally designed to be thermally insulated and often feature a climate control unit. Besides, they can be easily placed in empty spaces such as car parks, squares, or abandoned buildings where water and energy connections are available. When redesigned to host urban farms, they usually feature hydroponics and LED fixtures, allowing to produce microgreens and baby leaf vegetables. Indeed, produce diversification has also recently emerged and among new promising products, the cultivation of edible mushrooms has emerged, also thanks to their reduced energy needs. The present research builds on a case study (a shipping container farm located in Salus Space, Bologna), where edible mushrooms are produced inside a social co-housing project, elaborating on both food productivity potential and economic feasibility.

Keywords: urban farming, container farm, edible mushrooms

Improving cities circularity and sustainability thorugh vertical farms: the ECOFARM-CITY project

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There is a growing interest in urban agriculture to produce local food closer to cities. There are many urban agriculture forms resulting from a wider range from reusing and recycling strategies, for instance by taking profit of urban unused spaces or by cultivating in pallet gardens. Vertical indoor gardens are a relatively new form of urban agriculture expanding around the world and especially in Northern Europe to produce crops all-year around. However, little is known about how these vertical farms could be better integrated with the nearby urban flows to reduce the current dependency on external resources to produce food. This would reduce the consumption of primary resources and improve sustainability of cities metabolism. For example, waste heat from buildings can be recirculated to fuel energy needs from vertical farms instead of conveying these waste heat to the environment, which is then not used. To investigate these circular developments, the ECOFARM-CITY project aims to improve the environmental performance of vertical farms and their surrounding urban environments through the development of circular strategies. In order to do so, we will closely collaborate with current vertical farming stakeholders to assess the sustainability of their current operating systems and identify potential circular strategies aiming to diminish resource consumption in vertical farms. Then, we will investigate whether such circular strategies could be upscaled to a broader context according to commonly available waste resources in multiple cities across Europe (Stockholm, Barcelona, Zurich). By doing so, we aim to assess urban food systems in a more holistic view of the inflows and outflows involved and thus, to better integrate food systems in the urban planning. The impact of the ECOFARM-CITY project aligns with many of the sustainable development goals supported by the United Nations; these include innovation on industry, improved sustainability of cities, and promoting responsible consumption and production of goods. The ECOFARM-CITY project will also provide a range of theories that can serve as a conceptual framework to provide guiding principles for future urban agriculture and circular assessments. This will give response to policy makers and stakeholders related to urban farming that are currently developing farms in a number of cities worldwide.

Keywords: industrial ecology, urban agriculture, life cycle assessment

Urban agriculture the case of cultivation systems in supermarkets

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Global food production is facing serious challenges including loss of biodiversity, climate change, and deterioration of natural ecosystems in combination with an increasing population and urbanization. More sustainable food production practices are needed to address these challenges, which calls for research that contributes with knowledge on the governance of innovation to achieve more sustainable food and farming futures. In this work, we focus on the emergence of farming-as-a-service innovations that combines controlled environment agriculture with digital technologies to produce food in cities. These initiatives have the potential to secure local food provision while reducing the environmental impacts in systems. Drawing on case study research on the development and uptake of farming-as-a-service innovations we contribute with knowledge on innovation in food and farming sector. The study focuses on key actors involved in the development and uptake of farming-as-a-service initiatives across Sweden. Qualitative data were collected via interviews and observations at sites where development and uptake proceed such as testbeds and supermarkets. Our study shows that farming-as-a-service innovations involve novel configuration of product- service and system innovations. Since development and uptake of farming-as-a-service is a situated and contingent process, we examine how such food production practices develop in the contexts in which they are deployed. We conclude that, while innovation in food production is needed to address sustainability challenges, reducing innovation to change in technology limits knowledge on governing innovation for sustainability in food and farming sectors. Innovation rather involves novel configuration of product, service, and system. Understanding how such novel configurations develops can open up new ways for governing innovation for more sustainable food production. We identify implications for researchers and policy makers to govern innovation in food and farming sectors that have potential to help society reach sustainability goals.

Keywords: CEA; product-service-system, smart vertical farming, innovation governance

Creating circular buildings with the integration of agriculture and nutrient recovery strategies from yellow wastewater: The BINAFET project

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Is estimated that 21-37% of all greenhouse gas (GHG) emissions are currently attributed to agriculture and the entire food system, and these emissions are projected to rise by 30% by the year 2050 as a result of population increase, dietary changes, rising incomes, and concomitant land-use changes. At the same time, cities consume 80% of the World's energy, produce more than 70% of the total waste, and emit more than 60% of the planet's greenhouse gas emissions. Population growth will also have an impact on urban areas, resulting in their development and excessive densification. Making urban areas more resilient and self-sufficient would be a solution to reduce these heavy stresses while also feeding cities. This approach would foster an environment for food production within the city through the lens of circularity. Through the BINAFET project the combination of urban resources and crop production are tested on a building scale with the direct recovery of human yellow water and its application as nitrogen fertilizer in the rooftop garden. The ICTA-UAB building serves as a case study for the BINAFET project with two integrated rooftop greenhouses, serving as urban agriculture laboratories and the potential of the building sewage system for the collection of source-separated urine through dry urinals. The nitrogen content in urine is mostly in the form of ammonia, which can be detrimental for crop growth and therefore has to overcome a nitrification process to obtain nitrogen in the form of nitrate. This will be achieved with the use of a moving bed biofilm reactor (MBBR) installed in the ICTA-UAB building basement where the source-separated urine is collected. Several parameters will be analyzed along the process to ensure the quality of the nitrogen source, testing the yellow water before and after the nitrification process on nitrogen content and the presence of pharmaceutical component traces, as well as the plant health and quality through metal and elemental analysis of plant biomass and substrate. Preliminary results of the BINAFET project are the determination of nitrogen production capacity, the quality of the alternative fertilizer and crops and the resulting production with an experimental lettuce trial, compared to synthetic fertilizer.

Keywords: urban agriculture, circularity, urine, nitrogen recovery, integrated rooftop greenhouse

Transformation of food systems in European cities: factors for the replication of successful projects

CHIARA-CHARLOTTE IODICE

ILS Research, Spatial planning & urban development

To counteract the negative impacts of conventional agriculture in Europe, which is intensified by conventional agriculture, the urban food systems, the so-called City Region Food Systems (CRFS), are increasingly becoming the focus of politics and of society. Based on the European guiding principles and concepts, it is necessary to make the food systems more sustainable and resilient and CRFS can contribute to achieving such a sustainable change in our cities. To achieve this, it is necessary to promote the replication of CRFS projects by analysing already implemented projects to advance the transformation of the food system in Europe. Of course, the respective CRFS are individual, but they are generally influenced by the same factors, both negatively and positively. These factors and the project orientation play a major role in the replication of these CRFS. Methodologically, qualitative expert interviews were conducted with representatives of existing and former CRFS initiatives (CRFSI) to be able to work out both the success factors and the failure factors. Subsequently, this multitude of factors was validated by the members of the initiatives (with points from 3-1) to generate a reduction of the total of 132 factors identified. Finally, recommendations for future CRFSI were derived. It has emerged that there are many factors that can influence the success of CRFSI. Depending on the business model type (Focusing, Sharing, Deepening/Broadening), these differ in some cases, but all future CRFSI depend on similar factors which are presented in two checklists. If these factors are considered, the failure of initiatives can be reduced and thus the transformation of the food system can be advanced. Therefore, this presentation identifies which factors in the areas of political, financial, technical, social, and other may be relevant for future CRFSI and which recommendations they should consider. The results were produced as part of the FoodE research project.

Keywords: City Region Food Systems, initiatives, transformation, factors, replication

Transforming food systems: the FoodE certification for sustainable initiatives

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During the FoodE project (Horizon 2020), an innovative certification has been devised to catalyze sustainable and local initiatives within the food system. The label emerged from an in-depth analysis of cutting-edge sustainability assessments in the food sector, involving extensive co-creation processes with stakeholders. The FoodE Label incorporates three crucial elements for evaluating initiatives: 1) a comprehensive sustainability framework based on environmental, social, and economic indicators, 2) a geographical scope to define "local," and 3) a holistic perspective encompassing the entire value chain. The sustainability assessment encompasses three key dimensions: environmental impact divided in food production, waste management, and product transportation, the social impact including job creation and community outreach as well as the economic performance. Each dimension holds equal weight in evaluating the overall sustainability of the initiative. This work aims to shed light on the characteristics of current and future vertical farms based on the FoodE certification. Vertical farms have garnered substantial interest from investors and researchers due to their efficient resource utilization. The FoodE label identifies critical resource-saving practices in vertical farms, such as closed-loop systems, natural ventilation, and renewable energy adoption. Additionally, the initiative's focus on marketing products within the local region and active engagement with the community to promote sustainable food and resource utilization are highly encouraged. Lastly, economic sustainability plays a pivotal role, requiring operational costs to be lower or equal to the initiative's income. Employing a multidimensional approach to assess sustainability, the FoodE label outlines the key characteristics of vertical farms capable of fostering a positive impact at the territorial level.

Keywords: sustainability certification, vertical farm, urban agriculture, City Region Food Systems

Identifying food policy coherence in Italian regional policies: the case of Emilia-Romagna

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Achieving a coherent set of food-related policies is a challenge for policymakers worldwide, as food matters are addressed at more than one level of governance and across several policy domains. Policies in different domains can sustain each other by sharing the same objectives and actions or they can hinder each other, resulting in different levels of coherence. Focusing on the case study of the region Emilia-Romagna (Italy), the present research aims to answer the following research questions: to what extent is food mentioned in regional policies? Are the food-related objectives of Emilia-Romagna policies coherent with each other? Mixed methods were used in three subsequent research steps. Step 1 consisted of collating an inventory of regional policies where food is present. In Step 2, identified policies were analysed with quantitative content analysis, to examine their objectives, degree of targeting, which food supply chain step they focus on, and which policy instrument type they plan to use. Step 3 aimed to assess the coherence of the identified food-related policies' objectives among each other through expert interviews, analysed with thematic coding. Overall, regional policies reached a good degree of coherence around the common intention of making Emilia-Romagna thrive economically. However, some level of incoherence is present, as a systematic process that lowers incoherence in policymaking is not in place yet. Therefore, implementing the use of a Policy Coherence Matrix as a standardised practice for policy approval is recommended to coordinate food-related policies.

Keywords: policy coherence, policy analysis, content analysis, regional food system, regional government

Criteria and construction methodologies to increase environmental performance in the implementation of vertical gardens, green roofs and other architectural green solutions

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The research activity is aimed at identifying environmental, ecological landscape parameters in the botanical design of architectural greenery in order to develop a guideline for the design and management of these plants. The study method was organized in phases and is related to the selection of 40 species, including ornamental and wild species in the area, which were intended for the establishment of test areas by cultivation on an experimental vertical garden wall of 5 m^2, on roof garden of 100 m^2 and for the establishment of 16 m^2 on a wall of a public residential building. It was also complemented by test fields for leaf biomass measurement by destructive systems and non-destructive methods based on image analysis (phenomena platform, Scanalyzer 3D System): resistance to water stress and response to root stimulation (waterlogging with organic compounds from earthworm biodigestion, root biostimulation with trichoderma and with protein hydrolysate, rhizospheric microorganism mixture) were tested between theses and control. The purpose of the research was to highlight which species, among ornamentals and land species, have the statistically highest biometric values for evaluating photosynthetic efficiency and O_2 production capacity. At the end of the field tests and from the findings of related research activities aimed at the analysis of performing species and biological forms, the data collected will allow the construction of a guideline for the creation of vertical gardens, green roofs and other architectural green solutions, with recommended criteria and construction methods to increase the environmental performance and botanical-ecological-agronomic benefit of these works that will become complementary to city tree plans in the work of urban cooling and subtraction of air pollutants.

Keywords: green architecture, ecosystem systems, green walls, roof gardens, environmental benefits

January 18th
SESSION: RESOURCE USE EFFICIENCY

CHAIR: M. KACIRA

BRUCE BUGBEE

Principles of nutrient and water management for indoor agriculture

Mass balance principles have not been widely used to optimize plant nutrition for indoor agriculture. These principles underly efficient fertilizer use in recirculating hydroponic and soilless-substrate systems. Water removed by transpiration is replaced with solution that supplies the nutrients taken up with the water. The concentration of nutrients in this solution is determined by multiplying the optimal concentration of each nutrient in plant tissue by the water use efficiency (WUE; ratio of dry mass to water transpired). We have applied these principles across multiple species and environments to optimize nutrition with no discharge or leaching of solution.

Keywords: indoor farming, mass balance principles, water use efficiency, optimized nutrition

Bruce Bugbee is a professor at Utah State University and President of Apogee Instruments. He has collaborated with NASA for over 40 years to design food production systems for people living on Mars. In 2011 he was awarded the Utah Governors Medal for Science and is a Fellow of both the Agronomy and Horticulture Societies. He has recorded multiple videos on plant cultivation in controlled environments; one has over two million views. In 2015 he recorded a TED talk entitled, "Turning Water into Food."

DIMITRIOS SAVVAS

Optimization of nutrient supply in leafy vegetables grown in vertical farming using the Decision Support System NUTRISENSE

The use of suitable decision support systems (DSS) in combination with frequent control of the nutrient concentrations in the root zone can minimize or even eliminate the need to flush out the nutrient solution in vertical farming. In the current study, the Decision Support System (DSS) NUTRISENSE (https://nutrisense.online/) was tested as a tool to optimize nutrient supply in lettuce crops grown hydroponically in vertical systems. NUTRISENSE was used in combination with ion selective electrodes to monitor the composition of the nutrient solution in the root zone of the plants and frequently readjust the supply of nutrients, thus maintaining an optimal nutrient status in the root zone of the plants. Results are presented and discussed.

Keywords: Decision Support System (DSS), nutrient solution, indoor farming, root zone

Dimitrios Savvas was awarded a Diploma in Agriculture from the Agricultural University of Athens (AUA) in 1985 and a Ph.D. degree from the University of Bonn, Germany, in 1992. From October 2015 he has been a full Professor in AUA. Since October 2016 he has been the Director of the Laboratory of Vegetable Production and, since September 2019, he is the Dean of the Faculty of Plant Sciences. He specializes in soilless culture, plant nutrition, water management, and applied stress physiology with emphasis on salinity and greenhouse crops. He has published over 110 papers in refereed international scientific journals (with IF) and many other papers in congress proceedings (Acta Hort.) and as book chapters. According to the bibliographic classification of Baas J, Boyack K, Ioannidis JPA. (2021) Professor Savvas ranks within the top 2% of scientists worldwide in his scientific field. He has been involved in many EU research projects. In the last 5 years, in addition to several national projects, he has been the coordinator of the AUA team in the European projects LEGUME FUTURES (FP7), EUROLEGUME (FP7), TOMRES (HORIZON2020), TRUE (HORIZON2020) and VEGADAPT (PRIMA) and core member of the research team in the H2020 Project RADIANT. Since November 2022 he is coordinating the consortium of the European Innovation Project of HORIZON Europe ECONUTRI.

MICHAEL MARTIN

Vertical farming sustainability: what, why, and how

Vertical farms are often promoted as a sustainable option for food provisioning. However, there are few sustainability assessments available worldwide. Concurrently, the critique of vertical farming systems and their sustainability is mounting. Michael will guide us through common claims made to promote the sustainability of vertical farms in addition to the critique often met. He will then provide guidance on how sustainability assessments can and should be conducted, the state of the art in sustainability assessments, and provide results from sustainability assessments of vertical farms with tips to improve the impacts associated with crops and products from vertical farms.

Keywords: sustainability assessment, indoor farming, Life Cycle Assessment (LCA)

Michael Martin is a Senior Researcher at IVL Swedish Environmental Research Institute and Adjunct Professor of Sustainable Production and Consumption Systems at KTH Royal Institute of Technology in Sweden. He holds a Ph.D. in Environmental Systems Analysis and Environmental Management and has extensive experience from the research field of industrial ecology, including industrial symbiosis, circular production systems, urban agriculture, and sustainability assessments across stakeholder categories to promote sustainable production and consumption. He leads the Sustainable Urban Food Lab group at IVL where his research is focused on assessing and improving the sustainability and resilience of urban and regional food systems in collaboration with many of the urban and vertical farms in Sweden. He has recently contributed to an FAO study on the sustainability of urban and vertical farming systems.

ISABELLA RIGHINI

Food crops: resources to meet human dietary needs

Meeting current and future food needs as efficiently and robustly as possible is a challenge. Cultivation systems ranging from open field to high-tech vertical farms have the potential to produce a wide range of food crops that provide both macronutrients (e.g. protein) and micronutrients (e.g. vitamins) essential for a healthy, balanced diet. But how many resources do we need to produce these crops and thus meet food needs?

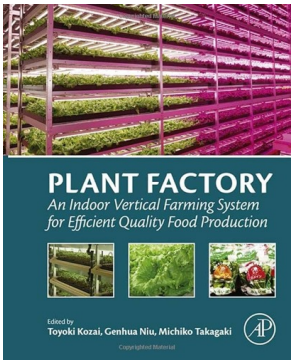
Keywords: macronutrients, micronutrients, food crops, high-tech vertical farms

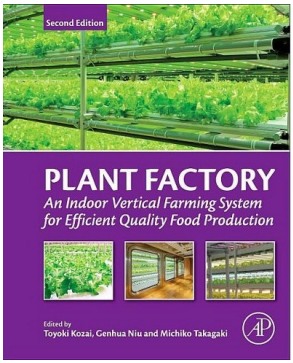
Originally from Italy, Isabella is living and working in the Netherlands since 2018. With a background in Horticultural Science, she is currently working as Researcher at Wageningen Research in the unit of "Greenhouse Horticulture". At the same time, she is doing a PhD within the "Horticulture & Product Physiology" at Wageningen University focusing on production efficiency and resource use in Controlled-Environment Agriculture for urban and peri-urban areas. Her research over the years has included: projects in Vertical Farming and high-tech greenhouse (both academic and B2B) to investigate resource use efficiency and production of different crops (e.g., tomato, cucumber, soybean and, to a lesser extent, strawberry, basil, lettuce); validation of greenhouse-climate models adapted to different climatic regions; use of validated greenhouse-climate models to assess the effect of greenhouse investments (e.g., greenhouse structure, climate equipment) and management (e.g., climate settings) on crop yield, resource and energy use.

Stepstones on vertical farm evolution: part IV

2015

9 years ago. The first edition of the book Plant Factory by Toyoki Kozai, Genhua Niu and Michiko Takagaki was released. A second edition was then published in 2019.





2019

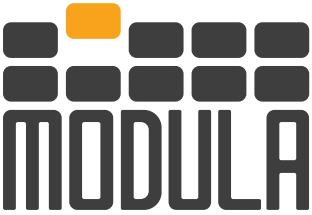
5 years ago. The 1st International Workshop on Vertical Farming was organized in Wageningen, The Netherlands. In 2023, the second edition was organized in Chengdu, China.

PLATINUM SPONSORS

Haifa Group

Haifa Group is a multi-national corporation and a global leading supplier of specialty plant nutrition. The company's decades of operations have made Haifa a world leader, known for delivering innovative solutions in all the areas of its expertise. Haifa Group, founded in 1966, develops, produces and supplies a wide range of specialty fertilizers in more than 100 countries. Haifa group includes 17 subsidiaries worldwide and production facilities in Israel, France and Canada. Haifa's premium products provide optimized plant nutrition and are valued for their high efficiency, crop-suitability, low chloride content, and purity. Haifa's portfolio includes soluble fertilizers for soilless, Nutrigation™ and foliar sprays supplying more than 30% of world greenhouses nutrition. The range is completed by Micronutrients, Biostimulantsand Controlled Release fertilizers for soil application. With innovative plant nutrition schemes and highly efficient application methods, Haifa's solutions provide balanced and precise plant nutrition. This ultimately delivers maximum efficiency, optimal plant development and minimized losses to the environment.

https://www.haifa-group.com/



MODULA

Modula is an Italian company that designs and manufactures automatic vertical and horizontal warehouses, ideal for every sector and industrial environment. The first Modula dates to 1987 and since then the brand has been synonymous with innovation and made in Italy. The product range includes vertical automatic storage solutions, horizontal automatic storage solutions and picking solutions ideal for optimizing order preparation. Vertical warehouses are designed to reduce 90% of occupied floor space, increase productivity, speed up picking operations and improve warehouse efficiency, reducing risks for people and goods. The horizontal carousel, on the other hand, is an automatic warehouse ideal for all intensive picking applications, both in the distribution and production sectors or in environments where it is not possible to exploit the vertical space due to height limits or due to particular geometries. To date, Modula has over 15,000 customers worldwide and a production capacity of 3,500 machines per year built in 4 production centers, in addition to 9 branches in Europe, America, Asia and Africa and a network of over 100 authorized dealers.

https://www.modula.eu/

HiDew

HiDew's story began in 2011 with the aim of improving people's living comfort and agriculture/industry processes' quality by proposing solutions to fix problems caused by excessive humidity and becoming a share-point of experience and solutions for customers. Gradually, new features were implemented in the portfolio, such as ventilation with heat recovery, the temperature control and air cleaning by the non-thermal plasma generators. With more than 200 models, HiDew's complete range of solutions is able to meet any customers' requirements, guaranteeing high quality level coming from 100% in-house design and production.

https://hidew.it/

GOLD SPONSORS

Aquaponic Design

Aquaponic Design Srl was founded in 2021, as an innovative startup and spinoff company of the University of Bologna. Thanks to a multidisciplinary team of designers, agronomists and fish farmers, it focuses on urban agriculture and soilless crops. The company designs, builds, distributes and manages aquaponic and hydroponic systems for private partners, individuals and the public administration. A strong collaboration with the Bologna City Council and the University of Bologna led to the implementation of a number of activities for urban regeneration and agriculture. Aquaponic designs also offers training courses and consultancies on commercial aquaponic farming.

https://www.aquaponicdesign.it/

Scalabros

ScalaBox Farm is a new brand of Scalabros Srl, which started in 2021 as a Research and Development project on Circular Agriculture. The company specialises in the implementation of innovative agricultural technologies on shipping containers, including both facilities for mushroom production on innovative substrates (e.g., exhausted coffe ground) and indoor vertical farming with integration of Internet-of-Things (IoT) technologies. The ScalaBox systems were displayed at EcoMondo fair and were recently integrated into the sustainable food pilot of the Bologna City Council, realized within the project H2020-Food Systems in European Cities (FoodE).

https://scalaboxfarm.it/en/home-en/

Hangar Lab

Hangar, is an innovative start-up, born in Northern Italy in 2016. They have developed, in collaboration with research centres and universities, an innovative LED lamp system and software dedicated to different sectors, agriculture, entomology, algae and microalgae. Their mission is to help increase the quality and quantity of production, reduce mortality, extend seasonality and improve the well-being of the environment.

https://www.hangar-lab.com/

Tectum Garden

Tectum Garden's mission is to address the pressing need for sustainable urban spaces, playing a pivotal role in the transition to greener, decarbonized cities. It leverages the expertise of the Sostenipra research group in circular economy, urban agriculture, and life cycle analysis, aiming to share this valuable knowledge with society. This knowledge serves to tackle forthcoming sustainability challenges across three key dimensions: social, environmental, and economic.

https://www.tectumgarden.cat/en/

SILVER SPONSORS

Germina

Germina, founded in 2020, is a spin-off of the University of Genoa focused on developing its patented adaptive technology for cultivation systems. Its Adaptive Vertical Farm progressively adapts the cultivation environment following the growth of the cultivar, moving the shelves in the vertical space and changing the environment via controlled temperature, humidity and lighting. In respect to a fixed shelves VF, by minimising the LED distance from the leaves and reducing the volume of air to climatize, Germina solution is capable to reduce energy consumption up to 40%, as studies from the Energy Engineering Department of the University of Genoa demonstrated, while increasing the crop yield up to 80% in the same vertical space as demonstrated by simulations from Mechanical Engineering Department University of Genoa and CNR. The department of Agricultural and Food science of the University of Bologna is currently testing a prototype of Germina's technology after having studied this technology would translate in up to 190% increase of ROI@10y over a fixed-shelf equivalent Vertical Farm business endeavor for a 1500 m^2 plant. In 2022 Germina financed 2 PhD grants for scientific research of its technology over the next 3 years·

https://www.germina.bio/time-to-move-on/

Flytech

Flytech Srl is an electronic engineering company founded in 2006 as a spin-off of Eltec, an electronic manufacturing company. The company is specialized in the design and production of custom electronics for lighting systems in several contexts. It has an internal R&D department dealing with product design and engineering. The department also takes care of the creation of the testing tools before being shipped to the customer. Flytech also has an assembly department for SMD components with 4 production lines and a department for the assembly of traditional components. The company takes care of the entire electronic supply chain, with 35 employees in 2 production sites for a total of 2400 m^2. In collaboration with the University of Bologna, several research has been carried out for the definition of the optimal light characteristics for indoor cultivation (e.g. Vertical farms) of horticultural, aromatic and medicinal species, as well as for the adaptation of crop management practices (irrigation, mineral nutrition and climate management) in indoor cultivation systems, with the main aim of maximizing the resource efficiency. Flytech is a partner in FoodE project, under the EU Horizon 2020 research and innovation programme.

https://www.flytech.it/

TrolMaster

TrolMaster is a leading agriculture technology company specializing in advanced environmental controllers for the horticultural industry. With their extensive experience in horticulture and controller development, they have created a smart and interconnected platform that caters to the diverse needs of growers, from small-scale hobbyists to large industrial operations. Their platform is highly flexible, offering customized solutions for each grower. With remote access applications, customers can effortlessly manage their growth facilities from anywhere, at any time. Their comprehensive system provides automation, control, data collection, monitoring, and optimization, empowering growers to achieve optimal results. Furthermore, their commitment to continuous improvement ensures that their systems are always upgradable, delivering long-term value to customers. TrolMaster listens to growers and designs products specifically tailored to their needs.

https://www.trolmaster.eu/

BRONZE SPONSOR

PP Systems

Since 1984, PP Systems has been supplying quality, rugged, and reliable instrumentation to customers throughout the world for high-level research. PP Systems today is a global leader in the innovative design and manufacture of instrumentation for the measurement of photosynthesis, soil respiration, chlorophyll fluorescence, and CO2/H2O gas analysis. Customers come from a wide variety of scientific disciplines including agronomy, horticulture, biology, botany, crop and soil sciences, forestry, ecology, meteorology, oceanography, and plant physiology. Instruments produced by PP Systems are used in more than 100 countries.

https://ppsystems.com/

SAIS Sementi

S.A.I.S. Sementi is an Italian seed company, established in Cesena in 1941 and committed to the breeding, selection, production and marketing of vegetable and herbs seeds, with a specialized focus on species characteristic of the Mediterranean tradition, especially for indeterminate tomato, sweet and hot pepper, eggplant and basil. Reliability, research and innovation are the perfect combination in S.A.I.S., which has all the phases of its work cycle, starting from the activity of breeding and research and production, through the activity of selection and packaging, up to marketing, sales and distribution.

https://saissementi.it/en/

IVL Swedish Environmental Research Institute

IVL Swedish Environmental Research Institute is an independent, non-profit research organization established by the Swedish government and industry in 1966. The institute comprises Sweden's largest group of environmental experts for applied environmental research and consultancy services. IVL currently hosts the Sustainable Urban Food Lab, which leads a number of research projects working with understanding, improving, and assessing the sustainability and viability of urban and vertical farming systems. The SUF Lab bridges knowledge from the urban agriculture, horticulture, industrial ecology, circular economy, and sustainability assessment fields to promote sustainable food production and consumption systems in urban environments.

https://www.ivl.se/english/ivl.html

SUPPORTERS

Sherpa Space

Sherpa Space is a high-tech agricultural technology company, and since its inception in 2016, it has established itself as an integrated solution provider in agriculture, based on its R&D and international cooperation project capabilities, and commercialization capabilities. The best light for each crop variety is created on an Internet-based resource sharing server through its own research and demonstration using a variable film and a light source device that modifies the wavelength of light according to the plant variety and growth stage. It has created a database-based platform for autonomous precision control, which contributes in improving plant quality and productivity. Sherpa Space has been certified as a promising company and has laid the foundation for commercialization through guarantee and investment attraction based on patent competitiveness. It has also been certified as an environmentally friendly and sustainable company, having been named among the 'National Representative of Innovative Companies 1000'. Furthermore, continuous R&D is being carried out to develope a smart farm precision control platform based on optical editing technology, photo-exchange materials/films, recipes, and services. Addressing the energy and water overconsumption issues that are arising as challenges in existing agriculture, it will grow into a corporation that will lead the Next Green Revolution beyond the coming wave of climate change.

https://www.sherpaspace.co.kr/

Agricola Moderna

AGRICOLA MODERNA

Agricola Moderna is a vertical farming company based in Milano outskirts, founded in 2018. Since its establishment, Agricola Moderna targeted the optimization of its technology and growing capabilities. The company scaled up from a R&D lab to a fully operating 1,500 m² facility that produces 2,000 kg of leafy green crops per month. The main business model of Agricola Moderna is the sale of indoor farmed leafy green vegetable crops. Sales have been rapidly growing thanks to the superior taste and quality of the products as well as the sustainable cultivation protocols adopted. To keep up with demand, Agricola Moderna has started the development of a much larger and completely automated facility that will extend over 11,000 m², and - starting from Spring 2024 will deliver 30,000 salad bags per day.

https://agricolamoderna.com/

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VERTIFARM 2024

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