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III International Symposium on Innovation and New Technologies in Protected Cultivation

ORAL PRESENTATIONS

SESSION I: Greenhouse management and production systems

OS 1-1:

EFFECT OF DIFFERENT GREENHOUSE COVERING MATERIALS ON CUCUMBER GROWTH AND YIELD ON HOT CLIMATE

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The effect of three different covering materials on the production of cucumber, water use and climate conditions was tested. The experiment was carried out on the Sustainable Agriculture Research and Development center (ESTIDAMAH), Riyadh, Saudi Arabia using three different greenhouse covering materials clear glass Albarino zero crystal, diffuse glass Albarino high haze, and polycarbonate. Two cucumber (*Cucmis sativus* L.) varieties were used Khassib and Alfrid from RijkZwaan. The plants were grown in plant densities; 4 (high) and 3 (low) heads /m^2.
The average production, 57 days after transplanting, was 9.2 kg/m^2 under the polycarbonate, 14.5 kg/m^2 under the diffuse cover and 14.6 kg/m^2 under clear. The production was 58% higher in the diffuse greenhouse compared to the polycarbonate while no difference between clear and diffuse covering.
For the clear covering the high density produces more than the low density though the differences are not significant while for the diffuse and polycarbonate cover the higher density has no effect on the production. Water and light use efficiency were also investigated.

OS 1-2:

UV TRANSPARENT PLASTIC CLADDINGS PRODUCE WARMER CROPS AND IMPROVE WATER USE EFFICIENCY

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Advances in the manufacturing of plastic cladding for protected crop cultivation have resulted in wavelength selective plastics capable of manipulating the transmission of solar radiation to include ultraviolet (UV: 280-400 nm). Commercial growers already utilising these plastics report early maturity associated with warmer crops. We hypothesised that UV-B radiation causes partial stomatal closure that reduces stomatal conductance and transpiration rate, thereby increasing leaf temperature (relative to air temperature). We tested this hypothesis by investigating leaf gas exchange and temperature responses of individual tomato leaves to UV-B and UV-A radiation provided by UV lampsin a controlled environment. Transient (90 minutes) exposure to UV-B radiation decreased stomatal conductance but had minimal impact on photosynthesis, thus increasing leaf temperature and instantaneous water use

efficiency. Should this enhanced water use efficiency also occur at a whole plant/ canopy scale, these responses may benefit growers of protected crops in arid climates where plastic clad polytunnels are often utilised.

OS 1-3:

A COMPARISON OF TWO GREENHOUSE STRUCTURES (OPEN-ENDED AND FAN-PAD VENTILATED) UNDER SUB-HUMID CONDITIONS AND THE EFFECTS ON TOMATO PRODUCTION

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Ventilation is important for the reduction of solar heat gain in greenhouse structures, especially in the sub-tropics and tropics. The two main techniques used in the ventilation of agricultural greenhouses are natural and fan-pad evaporative cooling. The microclimate in a fan-pad evaporative cooled tunnel (FPVT) and an open-ended, naturally-ventilated tunnel (NVT) was investigated during the summer of 2012-2013. The effect of the microclimate on crop growth, yield and quality, using four tomato cultivars, was also investigated. The experiment consisted of two greenhouse ventilation systems, the FPVT and the NVT, without replications. Two microclimate variables, air temperature and relative humidity, were measured inside the tunnels. Crop growth was measured in terms of plant height, leaf number, leaf area and vegetative biomass. Crop yield was measured in terms of total yield (TY) fresh mass, total marketable yield (TMY) fresh mass and total unmarketable yield (TUY) fresh mass. The quality of the tomatoes was measured in terms of undersized (US), blossom end-rot (BER) affected, insect damaged (ID), cracked (CR) and deformed (DF) fruit mass. There were significant differences in the daytime air temperatures and relative humidity levels between the FVT, NVT and the outside. The temperature in the NVT was 4 to 5°C higher than in the FPVT at midday, when solar radiation was at its peak. The relative humidity was higher in the FPVT than the NVT. At night, there was no significant difference in temperature. The relative humidity differed significantly between the FPVT, NVT and the outside. The microclimate in both tunnels was non-uniform. During the daytime, the air temperatures were lower in the crop canopy than close to the cover. At night, air temperatures were lower close to the cover than within the crop canopy inside both tunnels. TY and TMY from the FPVT were not significantly different from TY and TMY from the NVT. TUY was significantly ($P<0.001$) higher in the NVT than in the FPVT. Under-sized and insect-damaged fruit were significantly higher in the NVT than in the FPVT. A cost benefit analysis for FPVT and NVT needs to be conducted for these two tunnels. Whitewashing and near infrared reflective screens could be investigated as tools to reduce the extreme solar heat gain of the greenhouses.

OS 1-4:

ENVIRONMENTAL ASSESSMENT OF A CLOSE HYDROPONIC GREENHOUSE SYSTEM

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The assessment of the environmental impact of agricultural production has received increasing attention over the last years, because agriculture appears to have a major impact on the environment. Modern, intensive crop production is regarded as a source of solid, liquid and gaseous emissions, which can be both a nuisance and environmentally harmful. Plastic, waste water and greenhouse gases, coming from direct or indirect sources, are the most important effluents for polluting the air, the ground and surface water (nitrates and phosphate emissions), causing climate change, acidification, eutrophication and ecotoxicity (soil enrichment with heavy metals). Regarding protected cultivations, there are some environmental studies that are restricted to the use of national or EU level guiding policy or in improving farm management by supplying information to the farmer or advisor. To reduce pollution sources from intensive agriculture production systems to the environment many technologies have been developed and applied, like close hydroponic systems, close greenhouse, degradable plastic covering materials etc. However, till

today information and studies concerning a complete environmental assessment of greenhouse cropping system are limited. Therefore, there is an increasing interest in product-oriented and life cycle based environmental assessments (LCA), because there is a need to evaluate global emissions and impacts from the whole production chain in relation to types and amounts of products consumed. Life cycle assessment (LCA) is a generally accepted method to evaluate the environmental impact during the entire life cycle of a product. In the present paper, we built upon the results of previous EU projects rational irrigation strategies in greenhouse and using the LCA method through the SIMAPRO software we evaluate the environmental impact on close, semi-close and open greenhouse hydroponic systems.

OS 1-5:

WINTER GREENHOUSE MICROCLIMATE AND ITS EFFECT ON BUTTERHEAD LETTUCE

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Greenhouse microclimate depends on the type of cover, ventilation type and prevailing microclimate. The winter microclimate in greenhouses and its effect on plant growth, yield and quality in the Pietermaritzburg area of KwaZulu-Natal is not documented. A study was undertaken to establish the microclimate conditions in tunnel greenhouses in Pietermaritzburg, KwaZulu-Natal, South Africa, during the winter period. In this study, open-ended naturally-ventilated and a fan-pad evaporatively cooled, polyethylene covered tunnels were used to study the microclimate conditions. Temperature and relative humidity were monitored from the 6th May 2013 to the 23rd June 2013, using Hoboware sensors and data loggers. Two butter-head lettuce cultivars, Ballerina and Nadine were used to determine the effect that the two microclimates have on crop growth, yield and quality. The results indicated that daytime temperature inside the tunnels was between 4 and 10°C higher in the tunnels than outside. The air temperature in the NVT was between 4 and 6°C higher than in the FPVT. Relative humidity was extremely low in the NVT, but within the crop optima for most crops, including lettuce in the FPVT. The high temperatures in the NVT did not negatively influence the growth of the lettuce. The growth of the cultivar Ballerina was faster than the growth of Nadine under both microclimates. The yield of Ballerina was enhanced by the optimum environmental conditions provided by the FPVT, but the cultivar was more susceptible to leaf tip-burn. Leaf tip-burn was more prevalent under the FPVT conditions, compared to the NVT conditions. These findings indicate that there is a need for extensive research, to establish the most cost-effective greenhouse design that will provide the optimum microclimate for the Pietermaritzburg conditions. With the right choice of cultivar, the NVT can be used during winter for lettuce production.

OS 1-6:

SOLAR THERMAL UTILIZATION AND STRUCTURE INNOVATION OF THE CHINESE SOLAR GREENHOUSE

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Chinese Solar Greenhouses (CSGs) with north heat storage walls with a thickness of 1-3m and thermal insulating coverings (straw mat, cotton blanket) are widely used for reducing energy consumption for heating during cold winter in north China. To further improve indoor nocturnal air temperature and increase land utilization efficiency of CSG, efficient energy saving technologies and new greenhouse structures were developed in the recent years. The energy saving technologies include active heat storage-release system with an efficiency of 24 (24kW solar energy gained while consuming 1kW electric-energy) for heating, the gravel wall and phase change materials with vertical air channels integrating solar concentrators for improving heat storage capability of CSG, energy releasing control for increasing heat energy utilization efficiency of north wall, etc. The recent developed greenhouse structures include structural design of greenhouses for increasing solar energy collection area and decreasing the energy loss

during nighttime, removable back walls with increased thermal insulation for the summer production of CSG, thin north wall with a thickness of 0.1-0.3m, which is one tenth of the traditional wall, large-scale structure for expanding effective indoor area for crop production with mechanical technology and decreasing the distance between two CSGs, etc. In this paper, the above technologies and related research progresses of CSG will be reviewed.

KEYNOTE 1

ROBOTICS AND INTELLIGENT AUTOMATION FOR PRECISION AGRICULTURAL TASKS IN PROTECTED CULTIVATION

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Robots are perceptive machines that can be programmed to perform a variety of agricultural tasks, such as cultivating, transplanting, spraying, monitoring, selective harvesting etc. Agricultural robots have the potential to enhance the quality of fresh produce, lower production costs and reduce the drudgery of manual labor. The inherent nature of agricultural robots make them suitable to perform precision agricultural tasks. However, in agriculture, the environment is highly unstructured. The terrain, vegetation, landscape, visibility, illumination and other atmospheric conditions are not well defined; they continuously vary, have inherent uncertainty and generate unpredictable and dynamic situations.
Extensive research has been focused on development of agricultural robots and intelligent automation systems to a variety of agricultural tasks in protected cultivation, and technical feasibility has been widely demonstrated. However, autonomous agricultural robots in still yield inadequate results and despite the tremendous effort, very few are operational in agriculture production systems.
Several gaps need to be investigated such as poor detection performance, inappropriate decision-making and low action success ratio. Research and development of versatile and adaptive algorithms with sensor fusion ability, integrated into a multi-sensor platform have to be conducted. The actual cycle time needs to be reduced to a rational value of a commercial agricultural production system and the production rate have to be increased to justify economic use. Focused research on each of these gaps and limiting factors is required in order to promote the field of robotics in precision agriculture one step toward commercialization.
Fundamentals, New concepts and approaches for the performance of precision agriculture tasks in protected cultivation by agricultural robots will be presented, and the current R&D, implementation and activities will be reviewed including several case studies conducted at the agricultural robotics lab at ARO including an autonomous robot for disease monitoring; a spraying robot for greenhouse specialty crops; a robotic sonar for yield assessment and plant status evaluation; and, a 3D modeling of greenhouse environments using a robotic platform.

SESSION II: Automation and Environmental Control

OS 2-1:

ENHANCEMENT OF BIOACTIVE COMPOUND ACCUMULATION IN RED LEAF LETTUCE BY UV LIGHT MANIPULATION BEFORE HARVEST

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In a plant factory with artificial light, accumulation of bioactive compounds can be enhanced via precise environmental control. Light is essential for growth and development, and for the production of bioactive compounds in plants. Ultraviolet (UV) light stimulates bioactive compound biosynthesis in plants including antioxidants. We developed a new and economical UV-rich fluorescent lamp (UV-FL), with the ability to adjust the ratio of UV-A and

UV-B. The objective of this study was to determine the effect of UV light on the accumulation of bioactive compounds in red leaf lettuce. Red leaf lettuce plants were grown in a plant factory with normal growing conditions under white light as light source (23/20°C, 70% RH, 16 h light period, PPFD 150 $\mu molm^{-2}s^{-1}$, 1,000 ppm CO_2) for 23 days. The plants were subjected to UV light under white light (low, middle, and high; 0.3, 0.6, and 0.9 Wm^{-2}) for 3 days before harvest. Fresh and dry weights of shoot, leaf area, total chlorophyll, total phenolic concentration, and ORAC for antioxidant activity were measured before and after the UV treatments. Middle and high UV treatments resulted in negative effects on the growth characteristics such as shoot fresh and dry weight, and leaf area. However, low UV treatment was not significantly different from the control for shoot dry weight. Total chlorophyll was higher in low and middle UV treatments than the high UV treatment and the control. In contrast, total phenolic concentration and ORAC value of lettuce plants grown under UV treatments were significantly higher than that of the control. This study suggests that short-term UV irradiation using economical UV-FL lamp before harvest was effective in improving the vegetable quality.

OS 2-2:

DEVELOPMENT OF NEXT-GENERATION LIGHT IRRADIATION TECHNIQUES FOR JAPANESE PLANT FACTOR SYSTEM POWERED BY LIGHT-EMITTING DIODE

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Food safety has become a matter of concern, and global climate change has made the agricultural supply unstable, so plant factories are expected to provide a stable source of chemically and biologically safe food. For the light source of a plant factory, the light emitting diode (LED) is expected to solve the cost problem as well as to promote plant growth and functionality efficiently. In this study, we examined the light condition created by using two different visible LEDs (blue, red) and an UV LED (central wavelength, 405nm), to provide irradiation to leaf lettuce. The result was that simultaneous red and blue irradiation promoted plant growth effectively rather than monochromatic irradiation and fluorescent light. Moreover, the alternating red and blue light accelerated plant growth significantly (almost two times heavier than with fluorescent light, and about 66% heavier than with simultaneous irradiation) even when the total light intensity per day was the same as with simultaneous irradiation. While, UV LED irradiation during dark period three days before harvesting increased vitamin C contents more than three folds as a control. The mechanism of physiological response and signal transduction pathways underlying the response to alternating and/or UV irradiations might be the issues for the next study.

OS 2-3:

IMPACT OF HEATING LOCATION, FORCED VENTILATION AND SCREENS ON THE ENERGY EFFICIENCY AND CONDENSATION RISKS INSIDE A CUCUMBER GREENHOUSE

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In western France, greenhouse cucumber production is largely developed. Heating makes it possible to maintain a high level of production, but with high energy costs. Growers therefore try to implement new crop management practices to increase the energetic efficiency while keeping good productivity and quality. In this prospect, two modalities were tested considering two greenhouse compartments ($307m^2$): one with heating tubes at the upper limit of the canopy and a thermal screen (control) and a second one with heating tubes at low position inside the canopy, mechanical ventilation (5 volumes per hour) and thermal+shading screens (innovative). These compartments were equipped with sensor chains, each with four pairs of temperature and humidity probes at four levels. Additional

thermocouples measured fruit temperatures. The energy consumption of the compartments was also assessed. Measurements were conducted over a three-month period. Results show that a better homogenization of the distributed climate was reached inside the innovative modality. Also, the innovative modality made it possible to significantly reduce risks of condensation on fruit compared with the control. Finally, in the innovative compartment, the energy efficiency was notably increased compared with conventional management, generating the same yield, but saving 17% of the energy. The innovative crop management therefore demonstrated the benefits of the fans combined with low level heating and double screens.

OS 2-4:

ANALYSIS OF AERODYNAMIC PROBLEMS OF DOMESTIC GREENHOUSES AND DEVELOPMENT OF EDUCATIONAL VR (VIRTUAL REALITY) SIMULATOR

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Due to the invisible characteristics of air, it was difficult to accurately analyze the air flow pattern, which affects generation, dispersion, and distribution of various variables related to the air quality. So, greenhouse workers have difficulties in controlling and monitoring micro-climates in a greenhouse. Internal air flow could be analyzed to solve this problem using CFD technique. However, the CFD-computed results still have limitation to help the workers understand more realistically. Virtual reality (VR) technology that allows users to experience various phenomena directly has been recently paid attention. However, there was no example applied to agricultural facilities. Therefore, purpose of this study was to develop an educational simulator using CFD and VR as a new method to understand the internal aerodynamic phenomena of an experimental greenhouse.
One of representative types of greenhouse was selected as the experimental greenhouse and seasonal problem in the greenhouse were surveyed. Aerodynamic analyses of the 3D CFD model were conducted for each problem using CFD. In order to link the CFD-computed results to VR, data such as air velocity, temperature, and humidity were extracted, and the 3D flow field, temperature, and humidity fields were implemented by linking them to the VR space. In addition, the user interface of the VR access system was designed and the educational simulator was also developed to enable users to experience various aerodynamic phenomena of the greenhouse in VR space.

SESSION III: Crop Management

OS 3-1:

OPTIMIZING CARBON DIOXIDE OFFTAKE BY COMMERCIAL UK TOMATO CROPS

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Carbon dioxide (CO_2) enrichment to a target concentration of 1000ppm has become ubiquitous in the UK tomato industry to promote high yields in vented glasshouses. This requires CO_2 dosage rates above 300 kg ha^{-1} h^{-1}, representing a significant economic cost. The lack of standard practice to quantify crop CO_2 uptake relative to venting losses has so far made growers cautious in any attempt to optimize the use of this resource at the potential risk of losing marketable yield. The objective of the work was to develop tools for the UK tomato industry to estimate crop CO_2 usage efficiency (CO_2 offtake) and to devise strategies for improved CO_2 management in long season crops. Ambient crop CO_2 usage was measured and used to generate a multivariate model for estimating crop CO_2 uptake using environmental and non-destructive crop measurements over four seasons. Data from four commercial cultivars was used to refine the model by incorporating data from diverse growth habits to establish CO_2 offtake in long season glasshouse grown crops. Supplementary interlighting was then trialed as a strategy for increasing CO_2 offtake by driving lower canopy uptake by providing additional stimulus for photosynthesis and

manipulating leaf aging. A method for determining crop CO_2 offtake was developed, which demonstrated that crop offtake varied between 5.3 – 19.6% depending on cultivar, season, glasshouse design and CO_2 dosage rates. For conventional crops, supplementary interlighting was able to increase CO_2uptake up to31%. Crop CO_2 use can be improved by two approaches: 1) optimizing dosage rates relative to achieved concentrations and 2) enhancing light penetration/availability in the lower canopy. Improving the efficiency of CO_2 assimilation by the crop represents additional route beyond engineering and energy market approaches to maximize returns on investment in CO_2 provision.

OS 3-2:

PRACTICAL IMPLEMENTATION AND EVALUATION OF OPTIMAL CARBON DIOXIDE SUPPLY CONTROL

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In state-of-the-art production of greenhouse crops, the air is enriched to higher than atmospheric carbon dioxide levels to increase photosynthesis and final yield. When there is ventilation, this means that some of the supplied carbon dioxide will be lost. Especially when the available carbon dioxide is not a by-product of heat production (e.g. pure liquid carbon dioxide), the enrichment has a significant cost. Commonly, controlling carbon dioxide level is a simple on/off control depending on the windows opening. Experienced growers try to increase the benefit-cost ratio by using more complicated strategies based on influences of climatic factors, e.g. sun irradiation and wind speed. The settings for the influences are made intuitively and it is hardly possible to get any feedback on the applied strategy; therefore they do not warrant optimal use of carbon dioxide. Stanghellini et al. (2011) developed a prototype of a model-based optimization algorithm estimating the carbon dioxide concentration where the difference between benefits and costs of carbon dioxide dosing is maximized. The greenhouse ventilation rate, as the major determinant of the costs, is estimated from the energy and vapor balance of the greenhouse. The photosynthesis, as the major determinant of the benefits, is simulated as a function of solar radiation and carbon dioxide. In this study, we describe the results of the model implemented in the process computer of a commercial tomato greenhouse, following the methodology of Tsafaras and de Koning (2017). This method allowed the model to run as a separate process, providing safety for the rest of the control processes. We show that the method gives a reasonable estimation of optimum carbon dioxide concentration in varying conditions. The estimated increase in margin compared to the strategy of the grower could be over 200 € ha^{-1}day.

OS 3-3:

INFLUENCE OF CO_2 CONCENTRATION ON TOMATO GROWTH AND YIELD GROWN IN CLOSED GREENHOUSE

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The experiment was carried out to determine the effect and use of carbon dioxide in relation to the production of tomato at two levels of concentrations. The experiment was done at the Sustainable Agriculture Research and Development center (ESTIDAMAH), Riyadh, Saudi Arabia. Two tomato varieties Forrester and Marenza from Enza Seeds were grown on high tech glasshouses (closed system). Forrester produces 20% more with a higher CO_2 concentration, Marenza 21% .In total 4.9 kg/m2 was supplied in the low CO_2 compartment and 7.6 kg/m2 in the high CO_2 compartment.

The production increase due to the higher CO_2 concentration is slightly lower as the theoretical value being 24%. 55% more CO_2 is dosed though the production is only 22% higher, the difference is caused by leakage.
The water use efficiency is extremely low and can be reduced by collecting also the condense water from the roof. The overall water use efficiency is 6.9 litres/kg.

OS 3-4:

PHOTOVOLTAIC GREENHOUSES IN THE MEDITERRANEAN BASIN: INVESTIGATION ON THESE INNOVATIVE COMBINED PRODUCTION SYSTEMS

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In the last ten years the photovoltaic (PV) energy applied to greenhouse systems has been massively observed in Mediterranean basin, due to the high natural irradiation and generous public incentives for PV energy production, leading to the spread of the "PV greenhouse", in which a percentage part of the greenhouse area is covered with PV panels. This an effective example of green energy application to agriculture: it can potentially contribute to improve the environmental sustainability and competitiveness of the greenhouse company, by producing both electricity and crops on the same area, without consuming further land for conventional agriculture. The PV greenhouse is peculiar of the European agriculture (80% of the area installed in Italy, followed by France, Germany and Spain), also characterized by large installations of more than 100 Ha each.
The solar radiation is the main parameter affecting the crop productivity inside PV greenhouses, due to the shading cast by the PV panels on the roof. The solar light is distributed heterogeneously on the greenhouse area, generating differences in growth and development among the plants.
In order to reach the optimal trade-off between electricity and crop production, new PV technologies and greenhouse designs have emerged in recent years to improve the transmission and the uniform distribution of the solar radiation received inside the PV greenhouses.
The aim of this study is to investigate on these innovative production systems in the Mediterranean basin. This survey provides an inventory of the current areas of PV greenhouses, an overview of trends in the used PV technologies and the crops grown. The data collected provides useful information for evaluating the development possibilities of this production system.

OS 3-4:

UNCERTAINTY ANALYSES OF THE VegSyst MODEL APPLIED TO GREENHOUSE CROPS

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Nowadays, roughly more than 70 % and 20 % of the Mexican greenhouses use low and medium technological levels, respectively. In order to increase yield, together with water and energy efficiency better control strategies of the root and shoot environments are needed. However, in looking for better control strategies such as the ones coming up from optimal control, reliable dynamic models of the greenhouses crops are required. The VegSyst is a discrete-time dynamic model that predicts dry matter production (DMP), thermal time (TT), Nitrogen uptake (Nup) and crop transpiration for greenhouse crops. The model has been used in developing a Decision Support System for Mediterranean greenhouse crops. Nevertheless, until now none uncertainty analysis (UA) of this model has been reported. Because an uncertainty analysis could increase the reliability of the VegSyst model, in the current research both a frequentist and also a Bayesian uncertainty analyses on the model parameters were carried out. In both approaches, firstly probability distribution functions for each model parameter were defined. Secondly, a Latin

Hypercube sampling procedure was applied in order to generate several thousands of parameters' values. Thirdly, Monte Carlo simulation was used in generating the outputs of the VegSyst model. Finally, several statistics were calculated and several plots generated in case of the frequentist uncertainty analysis whereas in case of the Bayesian uncertainty analysis, the Generalized Likelihood Uncertainty Estimation (GLUE) methodology was applied. In the second paradigm measurements of the predicted variables of the VegSyst model were also included. Several datasets from several greenhouse crops collected in Almeria, Spain and also data collected in two experiments with a tomato crop grown in Chapingo, Mexico were used to carry out the Bayesian uncertainty analysis. Main results that came up from both uncertainty analysis methods are that VegSyst predicts DMP and Nup better than crop transpiration.

OS 3-5:

IMPROVING COOLING/HEATING LOAD AND CONSTRUCTION COST OF INDOOR FARMING FACILITIES THROUGH THE USE OF ALUMINUM SHEET AS THE COVERING MATERIAL

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Integrated indoor farming facilities enable the production of horticultural crops throughout the year independent of the local climate and weather. The use of low price LED have reduced the energy cost for lighting and temperature control. However, the temperature control during high summer and winter is still challenging. In this study, we evaluated the use of heat shielding aluminum sheet as the covering material of the indoor farming facility. The facility has pipe house structure covered with synthetic fibre tent cloth and heat shielding alminum sheet set up under the tent cloth, no heat insulation material installed. The facility needs no foundation construction and can be built at low cost, but it showed high performance of heat shielding, especially during summer.

OS 3-6:

DEVELOPMENT OF 3D SHAPE MODEL OF TOMATO CROP FOR ESTIMATING AERODYNAMIC RESISTANCE IN CFD SIMULATION

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The crops have a great effect on the internal airflow, temperature patterns and natural ventilation. For this reason, a crop model including porosity of crop should be considered to study microclimate environment in greenhouse. For CFD simulation, porous media has been designed as the crops for more than 30 years because of computer capacity. However, the airflow patterns were different from the actual airflow patterns because this method simplified shape of crops. Over the last few decades, computers have undergone tremendous growth. The complex problems that could not be analyzed in the past could be solved in a short computation time. Therefore, the aim of this study was to develop the 3D shape model of actual tomato crop for estimating aerodynamic resistance in CFD simulation. The aero-resistance of tomato crops was measured through wind tunnel tests. The pressure drop was measured with the main factors of wind speed and density of plant canopy. 3D-Scanner were used to make the 3D shape model of actual tomato crop. The scanned data were processed into clear 3D shape model using various software such as VX element and Rhinoceros. This 3D shape model was input into CFD simulation, and CFD model was designed based on the size of test section in wind tunnel. The total number of meshes was approximately 1.30 million in the computational domain. The CFD-computed and wind tunnel-measured pressure drops were compared to validate the 3D shape model of tomato crop. The computed pressure drops exactly corresponded with the measured pressure drops according to the wind speed and density of plant canopy. From these results, the developed 3D shape model of tomato crop was highly appropriate for estimating aerodynamic resistance of tomato crop in CFD simulation.

OS 3-7:

ESTIMATION OF LIGHT INTERCEPTION, PHOTOSYNTHESIS, AND LIGHT USE EFFICIENCY WITH 3D SCANNED MODELS OF PAPRIKA BY GROWTH STAGE IN GREENHOUSES

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Light interception of crops is crucial for estimation of growth and development. The light interception changes over time and growth stage due to structural and optical changes. Functional-structural plant model(FSPM), which reflects structural and optical characteristics of crops, is advantageous in this aspect than process-based model. However, its reconstruction is indirect and the calculation of light interception involves home-built optical simulations. We constructed structural models of actual greenhouse and paprika plants in one- or two-week interval with 3D scanning and performed an optical simulation on it. The distributions of photosynthetic rate and light use efficiency were calculated with obtained light distributions and FvCB model. Temporal and spatial distributions of light and photosynthetic rate within the canopy were obtained with growth stage. Also transpiration rate and carbon dioxide consumption could be estimated from our results. This method would contribute to the comprehensive modeling of greenhouse operation and estimation of crop productivity in greenhouses.

OS 3-8:

PLANT PHOTORECEPTOR ABSORPTION AS A QUANTITATIVE MEASURE FOR PLANT PHOTOMORPHOGENIC CHARACTERISTICS OF INCIDENCE SPECTRA

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Higher plants alter their morphology in response to incident spectra as their specific compositions directly and indirectly indicate specific environmental conditions. These responses are evolutionarily developed under sunlight to best adapt to changing environments. As the emission spectra of electrical lightings are substantially different from that of sunlight, photomorphogenic responses of plants under electrical lightings can be anomalous. However, any method to quantitatively represent such characteristics of incident spectra is not available to date. Here we present the amount of lights absorbed by each of major photoreceptors can be used to quantitatively represent the plant photomorphogenic characteristics of incident spectra. We developed a method to normalize and represent photoreceptor absorptions. Artificial solar and three different light sources with identical photoreceptor absorptions were developed using conventional light sources such as high pressure sodium lamp, fluorescent lamp, light-emitting diodes, and incandescent lamps, of which exhibited substantially different spectra. Then cucumber (*Cucumis sativus* L.) plants were grown under the developed light sources and their morphology, photosynthesis, and growth were compared. Results clearly showed that the morphology of cucumber plants grown under the same photoreceptor absorptions showed indistinguishable photomorphogenesis despite of their substantially different spectra. Growth of the plants varied even though their morphology were similar due to the differences in leaf photosynthetic rate and resultant net assimilation. The plants grown under conventional light sources showed shorter stem and internode length, steeper leaf angle, and reduced growth which are consistent to previous reports. We conclude that the amount of light absorption of photoreceptors can be used as a quantitative measure for photomorphogenic characteristics of incident spectra with robustness and reproducibility.

OS 3-9:

ECONOMIC EVALUATION OF MANUAL AND ROBOTIC TRANSPLANTING OF PLANT CUTTINGS

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Transplanting of unrooted plant cuttings into propagation trays is a manufacturing process that requires considerable labor, especially during the peak season. The objective was to benchmark the labor efficiency of the manual transplant process and evaluate return on investment of automation. Data were collected on the transplanting process of 14 large U.S greenhouse companies. Manually transplanting required 6.4 ± 2.7 sec (mean ± st.err.) ata cost of $0.023± $0.003 per cutting. Differences in labor cost resulted from both the plant type produced in each location and the hourly wage which ranged from $9.23 to $18.66 and averaged $12.49 ± $0.78. To evaluate automation, data on labor, cuttings transplanted, and costs of automation were collected from five growers using transplant robots. A return on investment spreadsheet model was developed that allowed customized analysis of individual greenhouse businesses. The average of our sampled firms was31.8M cuttings transplanted per year, with a weekly peak of 2.1M cuttings. Four transplant robots capable of transplanting 2000 cuttings per hour operated for up to 76 hours per week during the peak and transplanted 19.5M cuttings per year (61% of the total).This equipment had a capital cost of $500,000. The average cost was $0.010 per cutting compared with $0.014 for manual transplanting. With these assumptions, the robotic transplanter would yield a yearly saving of $72,961, a payback period of 8.6years with a 5% discount rate, and would reduce labor requirement during the peak week by 9 full-time equivalents (15% of total workforce).Results will help growers highlight management practices to improve efficiency of the manual process, and evaluate how robotics could benefit producers in terms of labor cost and availability.

OS 3-10:

MICROCLIMATIC STUDIES IN A DOUBLE-SPAN GREENHOUSE UNDER WIND DRIVEN AND FAN VENTILATED CONDITIONS IN WEST COAST OF INDIA

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The microclimate in a double-span greenhouse (with screened vents on all four sides and roof) was studied under wind driven and fan ventilated conditions in 2014 -2017. The greenhouse air temperature, relative humidity and dew point temperature were monitored year round (ranged from 52.33±.0.17 to 13.5±0.0^{o}C, 100±0 to 18.17±1.64% and 32.33±0.25 to 10.83±0.31^{o}C in wind driven condition), while air velocities were measured for short periods with full grown tomato crop at various locations of the greenhouse under wind driven and fan ventilated conditions.. The air temperature, relative humidity and dew point temperatures in the fan ventilated greenhouse with tomato crop ranged from 41.13±1.80 to 15±0.41^{o}C, 98.63±2.06 to 38.71±3.71 % and 38.13±3.71 to 13.06±0.44^{o}C, respectively. The highly heterogeneous distribution of air velocities inside the structure even without crop under wind driven conditions (East span- 5.19-246.97% and West span-2.34-68.97%) were improved significantly by the installation of fans with a more homogenous distribution (East span -0.21-29.99%, West span-1.96-71.88%).

OS 3-11:

YIELD AND QUALITY PERFORMANCES OF TOMATO `CHERRY´ INOCULATED WITH BENEFICIAL MICROORGANISMS IN SALINE SOILS

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In order to evaluate the effects of beneficial microorganisms on greenhouse tomato “plum” grown under salinity conditions, research was carried out in Naples (southern Italy), by comparing three arbuscular mycorrhizal fungi (AMF) treatments (Micoseeds Plus by Msbiotech, Myco Apply DR by Sumitomo, non-inoculated control) in factorial combination with four soil electrical conductivities (1, 2, 3 or 4 mS cm^{-1} EC), by using a split plot design with three replicates. The mycorrhizal index increased from 1 to 2 mS cm^{-1} in plant roots inoculated with AMF, but decreased from 1 to 3 mS cm^{-1} in non-treated control; the latter attained lower values than AMF treatments at any soil EC. Harvest precocity was two days earlier in control plants than in those inoculated with AMF treatments and four days earlier under the 4 mS cm^{-1} soil EC compared to 1 mS cm^{-1}. Plants inoculated with beneficial microorganisms showed higher yield than the control ones at all soil ECs, and the best production performance under the 3 mS cm^{-1} soil EC due to both higher fruit number and mean weight; control plants attained the highest yield under both 2 and 3 mS cm^{-1} soil EC. The highest values of fruit dry residue and soluble solids as well as polyphenols, ascorbic acid and lycopene content were recorded under both AMF inoculation, regardless of the formulate applied, and 4 mS cm^{-1} soil EC. Beneficial microorganisms proved to be an effective environmentally friendly tool for improving tomato yield and quality performances both in normal and in soil salinity conditions.

OS 3-12:

ROLE OF ARBUSCULAR MYCORRHIZA IN ALLEVIATING THE EFFECT OF COLD ON THE PHOTOSYNTHESIS OF CUCUMBER SEEDLINGS

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Arbuscular mycorrhiza (AM) is known to enhance the rate of photosynthesis in plants, but there is little information on whether this effect is maintained at low temperature when the development of AM fungi is restrained. We therefore investigated the influence of AM on gas exchange, photosystem II fluorescence and some photosynthesis-related biochemical parameters in cucumber seedlings under cold stress. Cold stress decreased, as expected, the chlorophyll content, net photosynthesis rate and parameters related to photochemical quenching, while increasing nonphotochemical quenching and sugar contents in leaves. AM, in contrast, had opposite effects on most of the determined parameters, and improved therefore the efficiency of photosynthesis of the cucumber seedlings both at cold stress and at control ambient temperature. In addition, we recorded significant alleviation of the effect of cold stress on the sugar contents in leaves, which indicates that higher carbon-sink strength was an important factor maintaining higher efficiency of photosynthesis in mycorrhizal cucumber seedlings under cold stress.

KEYNOTE 2

MODELLING GREENHOUSE-GROWN VEGETABLE CROPS FOR OPTIMIZATION OF IRRIGATION AND NITROGEN MANAGEMENT

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The main simulation models and model-based decision support systems (DSSs) that have been adapted to or specifically developed to assist with irrigation and nitrogen management of greenhouse-grown vegetable crops will be reviewed. Models and DSSs will be presented that can be used with vegetable crops grown in soil and in substrate. The models and DSSs considered can be used to generate crop and site specific recommendations. Additionally, models that can be used for scenario analysis will be included. Mechanistic models such as EU-ROTATE_N, TOMGRO and CROPSYST have been used for scenario analysis applications of greenhouse-grown vegetable crops produced in soil or substrate. Several models have been developed for use in intensive greenhouse production in north-eastern Europe. The VegSyst simulation model calculates crop N uptake and crop evapotranspiration (ETc) for various vegetable species grown in low to medium technology greenhouses, in the Mediterranean Basin. The VegSyst-DSS decision support system incorporates the VegSyst simulation model and calculates daily recommendations of crop water and nitrogen requirements, and the applied N concentration in nutrient solutions where fertigation is used to apply all nutrients. VegSyst-DSS and similar DSSs can contribute to the optimization of irrigation and nitrogen management through the preparation of crop and site specific irrigation and nitrogen application plans for drip irrigated and fertigated crops. Practical considerations that need to be addressed when developing models for greenhouse crops such as level of complexity, number and types of inputs, selection of reference evapotranspiration equations, use of average versus measured climate data, and form of output will be discussed. Practical aspects related to the use of DSSs based on models for on-farm crop management will also be discussed.

SESSION IV: Greenhouse Management and Production Systems

OS 4-1:

PRECISION MODELLING OF DISTRIBUTED GREENHOUSE CLIMATE

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Climate heterogeneity is particularly important in controlled environment agricultural systems used for crop production. This variability severely effects plant activity and often leads growers to use more inputs. If climate distribution can be conditioned more precisely, energy can be saved and pressure of pests and diseases will be decreased, enabling pest and disease control in a more sustainable way, e.g. biologically. The knowledge of the distributed climate should help to improve its homogeneity by modifying the design of the greenhouse structure and climate air conditioning systems and by locally controlling these systems. This requires the characterisation and modelling of the processes, particularly of convective transfers, involved in its elaboration.
In the present paper a completely dynamic computational fluid dynamics model for greenhouse climate was developed and analysed. The simulations were carried out for an arc type tunnel greenhouse with a tomato crop representative of the greenhouses used in the Mediterranean region. The CFD code Fluent was used as a basis where the required external source code for the dynamic boundary conditions (written in C) was embodied. In the present paper the distribution of solar radiation during a whole day was incorporated in the crop model which is represented by the equivalent porous medium approach to model dynamic effects and a macro-model of heat and mass transfer to model the exchanges of heat and water vapour between leaves and air. Time step for the unsteady simulations was 1

sec. The results show the distribution of solar radiation and the exchanges of heat and mass between crop and air in for a whole day period and they compared with relative results from simulations carried out with steady state conditions.

OS 4-2:

MODELING TRANSLOCATION AND METABOLISM IN PLANTS

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I present a whole-plant model of movement of water and nutrients to predict growth. In this model, a plant consists of tissues; root, stem, and leaf, and each tissue has cells with compartments; apoplast, cytoplast, phloem, and xylem. Diffusion leads to rapid short-distance transport of water among compartments within cells. All metabolism of nutrients, such as sugar, nitrate, amino acid, protein, and structure, occurs in cytoplast, and follows the same Michaelis-Menten kinetics in each tissue. All transfers of water to and from cytoplast, phloem, or xylem, are through apoplast. Compartment volume and water content define water potential, and in combination with solute content, define turgor and osmotic pressure. Volume increases according to structure. Long-distance transport between tissues is in xylem and phloem. Nitrate is moved from roots to leaves in xylem by transpiration. Sugars are moved from leaves to roots in phloem by translocation. Nitrate is transformed into ammonium and amino acids. Protein and structure are synthesized in the cytoplast, and cannot move between tissues. Linear relations describe water potential, and short-distance movement among compartments within one tissue, and long-distance transport in xylem and phloem between tissues, and metabolism with each tissue. These relations are programmed in VENSIM (Ventana Systems). I examine the effect of external nitrate, and sunlight, on movement of water and nutrients in xylem and phloem, and on water content and metabolites in organs of an idealized plant.
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OS 4-3:

ENERGY SAVING MEASURES IN OPTIMALLY CONTROLLED GREENHOUSE LETTUCE CULTIVATION

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Efforts to increase the energy use efficiency (EUE) of greenhouses are made in various fields, e.g., crop management and breeding; greenhouse design and technology; and climate control, including optimal control. Quantifying and comparing the influence of the different system components on EUE is important for improving greenhouse energy efficiency.
In this study, we examined an optimally controlled greenhouse lettuce system during a winter cycle in the Netherlands. A model sensitivity analysis of the optimal control problem aimed at minimizing heating was performed to investigate which of the system components have the strongest influence on EUE.
The results were compared with a previous study examining energy saving measures in lettuce cultivation. It was found that a reduction in indoor temperature, an increase in roof transmissivity, and to a lesser extent, an increase in insulation, improved the EUE of an optimally controlled greenhouse in a similar way as a conventionally controlled greenhouse.
A 10% increase in EUE of the optimally controlled greenhouse was achieved by each of the following: a0.2°C decrease in minimum indoor temperature; a 7% decrease in heat loss through the cover; a 13% increase in yield factor; and a 13% increase in net photosynthesis.
The results suggest that finding ways to decrease the indoor temperature without reducing yield has the highest potential for increasing EUE. In addition, optimal control may be combined with known energy saving measures to achieve a higher EUE than previously found.

OS 4-4:

ESTABLISHMENT OF 3D SCANNED PARAMETRIC MODEL DATABASE OF PAPRIKA PLANTS (*Capsicum annuum* L.) WITH GROWTH STAGE

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Simplified estimation of light interception in process-based model (PBM) exhibits decreasing accuracy due to complicated structures of plants. Functional-structural plant model (FSPM) includes the structural features required for estimation of light interception, which results in improved accuracy over PBM. However, accuracy is still a problem the model is constructed in an indirect ways. We created high resolution models of paprika plants using 3D scanner every 1 or 2 weeks during growing season. The scanned models were converted into parametric models to enable the optical simulation on developed models. The error between the scanned and parametric models was less than 0.1 mm, indicating that the scanned model well reflected the actual plant. The data of the parametric models were separated by organs for detail analysis. The analysis with growth stage could be performed more accurately. In addition, by combining each plant organ into the existing crop modeling tool, it was possible to visualize the plant model close to the actual one.

SESSION V: Crop Management

OS 5-1:

MODELLING TOMATO CROP GROWTH AND DEVELOPMENT IN RELATION TO NITROGEN FERTILIZATION UNDER HIGH ALTITUDE COLD TROPICAL CONDITIONS

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Nowadays, crop models are a widespread tool for both research and production activities. However, most of the models were developed and calibrated for potential conditions at places where there is a narrow gap between potential and actual yields. The objective of this work was to incorporate the effect of nitrogen (N) supply in a tomato crop growth model calibrated for high altitude tropical conditions. We carried out field experiments to determine the effect of N fertilization on plant parameters such as leaf area (LA) and allocation of dry matter (DM) in fruits. A total of 10 treatments ranging from 196 to 1114 N kg ha-1 were evaluated, six of them were used in the model calibration and the remaining four were reserved for validation. Plant development was determined by means of accumulated thermal time (ATT) using a base temperature of 10ºC. LA results were fitted with a nonparametric model to predict the changes in LA as response to N supply. This N-model was introduced as a module within the tomato model. The N-module calculates LA for a given amount of soil N available and ATT. Simultaneously, a nitrogen stress factor (NSF) was calculated as the ratio between daily available soil N per plant and N demand to reach the potential growth. If NSF is less than one, a leaf area reduction factor (LARF) was calculated as the ratio among LA estimated by the nonparametric model and that calculated by the potential model. In this way, a deficient N-supply affects plant growth by correcting the leaf DM produced at the end of each day by LARF. The performance of the model was satisfactory as shown by statistics such as the root mean square error, model efficiency and coefficient of determination.

OS 5-2:

DESIGNING A SUSTAINABLE AND RESILIENT PRODUCTION SYSTEM FOR GLASSHOUSE STRAWBERRIES

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The area of strawberries cultivated in glasshouses is currently expanding. Glasshouse strawberries can guarantee a secure supply and a high fruit quality level, but several aspects of this production system may conflict with today's societal demands for sustainability, such as the avoidance of the use of pesticides, prevention of residuals on fruits, lowering the energy demand and avoiding negative effects on environmental water quality. The goal of this five-year project is to develop a sustainable, robust, resilient and competitive cropping system for strawberries, with high resource use efficiency and without use of high risk pesticides. For this we are redesigning the integral propagation and production system of strawberries in cooperation with, and inspired by, the ministry of Economic Affairs and a stakeholder platform consisting of growers, policy makers, advisors, breeders and other chain partners. Following design requirements and socio-economic boundaries, a new sustainable strawberry production system is designed. These steps are discussed here. The following steps, testing and evaluation, take place in 2018-2021 and are not within the scope of this paper.

OS 5-3:

EFFECT OF ANTAGONISM OF Trichoderma spp ON SOIL BACTERIAL POPULATIONS IN JALAPEÑO PEPPER SYSTEMS (*Capsicum annuum* L.*var. annuum* L.cv. Jalapeño)

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Biological control of diseases is based on the use of pathogen antagonistic microorganisms, such as fungi, yeasts, and bacteria, through various mechanisms of action including the production of antimicrobial substances, parasitism, competition for space and nutrients, induction of resistance and opposition To oxidative stress. *Trichoderma* sp has been characterized as an effective biological control agent due to interactions with the pathogen and the plant, however, it is unknown whether the treatment with this biological agent changes the microbial populations of the rhizosphere. The aim of this work is to analyze the distribution and abundance of bacterial populations of the rhizosphere, by establishing the treatment with the biological control agent *T. atrivoide* and *T. virens*, directed to the pathogen *Fusarium oxysporum*, in a culture system of chili pepper (*Capsicum annuum*) and the use of microbiological techniques and metagenomic analysis, to identify taxonomically the presence of microorganisms present in the rhizosphere.

OS 5-4:

OPTIMIZING VERTICAL LIGHT SPECTRAL DISTRIBUTION TO IMPROVE YIELD AND QUALITY IN GREENHOUSE FRUIT VEGETABLE PRODUCTION

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Different spectra of light trigger different plant growth processes. Therefore, the optimum light spectrum for various plant growth processes, such as leaf and fruit growth, may be different. Greenhouse fruit vegetables, such as tomatoes, cucumbers and sweet peppers are of tall crops, with most leaf growth occurring in the top and middle canopy and fruit growth occurring in the middle and bottom canopy. Therefore, optimized vertical light spectral distribution profiles could be developed for improving both vegetative and generative growth, and fruit quality. The availability of light emitting diodes (LEDs, narrow spectral compositions and low surface temperature for intra-canopy application) has made this possible. A research project was initiated in 2013 to optimize the vertical spectral distribution of supplemental lighting for greenhouse fruit vegetable production. Four winter experiments (Oct. to May) were conducted from 2013 to 2017 in a large greenhouse (200m^2). The greenhouse was divided into 4 sections (50m^2/section) so that 2 different overhead (above crop canopy) light spectral compositions can be applied with 2 replications. Four different intra-canopy light spectral compositions, provided by LEDs, were applied to 4 plots inside each section. A total of 8 vertical light spectral distribution regimes were tested in these experiments. Same amount of overhead light and intra-canopy light was applied to all 8 vertical regimes. The vertical regimes resulted in significant differences in leaf photosynthesis, leaf size, fruit yield and quality in greenhouse tomatoes, mini-cucumbers and sweet peppers. Proper vertical light spectral distribution regimes were identified for hybrid light systems (overhead high intensity discharge (HID) light and intra-canopy LEDs) and for pure LED light systems (Overhead LEDs and intra-canopy LEDs). This study has clearly demonstrated that optimized vertical light distribution profiles can be developed for improving both plant growth and fruit yield & quality in year-round greenhouse tomato, mini-cucumber and sweet pepper production with supplemental lighting.

OS 5-5:

THE RELATION BETWEEN PRE-HARVEST LIGHT LEVELS AND POSTHARVEST PERFORMANCE OF LETTUCE

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The effects of pre-harvest lighting (last days before harvest) on quality and shelf life of (fresh-cut) lettuce was investigated. Lettuce was grown in soilless culture in a vertical farm under 240 µmol m^{-2} s^{-1} PAR from Red+White LEDs. Five days before harvest, different light intensities were applied (50, 240 and 500 µmol m^{-2} s^{-1} PAR from Red+White LEDs) and quality at harvest and subsequent postharvest performance of intact leaves and fresh-cut product in darkness at 10°C was determined. The high light pre-harvest treatment significantly prolonged the shelf life of both the intact leaves and the fresh-cut product. This longer shelf life was related to increased levels of soluble sugars, starch and ascorbic acid at harvest. During the dark storage, levels of carbohydrates and ascorbic acid decreased over time, but at any time point, the highest levels were present in the product derived from plants that received high levels of light during cultivation. The roles of carbohydrates and ascorbic acid in postharvest tissue browning and senescence is discussed.

OS 5-6:

PULSED LIGHT-EMITTING DIODES FOR HIGHER CONTENTS OF MINERAL ELEMENTS IN MUSTARD MICROGREENS

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In this study the effects of monochromatic pulsed light-emitting diode (LED) lighting on accumulation of mineral elements in mustard (*Brassica juncea* L., 'Red Lion') microgreens were evaluated. Plants were grown indoors under the main high-pressure sodium (HPS) lighting supplemented with 20±2µmol m^{-2} s^{-1}photosynthetic photon flux density (PPFD) ofmonochromatic455-, 470-, 505-, 590-, or 627 nm LED(total PPFD 200±20µmol m^{-2} s^{-1};16 h day^{-1}). For pulsed light treatments, the frequencies at 2-, 32-, 256-, and 1024 Hz with a duty cycle of 50% of monochromatic LED were applied.The results were compared with those under the continuous light (0 Hz) condition in terms of mineral elements. The contents of macro- and microelements were determined by microwave assisted digestion combined with inductively coupled plasma optical emission spectrometry (ICP-OES). The significant differences in the response of mineral elements between pulsed light at several frequencies and continuous light were determined. The highest content of potassium under the treatment of blue 455 nm and yellow 590 nm at 2 Hz frequency was determined. All the supplemented monochromatic wavelengths affected the higher content of calcium at 32- and 256 Hz frequencies. The similar tendencies for accumulation of phosphorus and sulphur were determined. The pulsed LED light had negative effect for accumulation of magnesium. The significantly higher contents of iron and zinc were measured in mustard, grown under all supplemental pulsed LED (except blue 470 nm) at 2-, 32-, 256 Hz frequencies. In general, the supplementation of common used HPS lamps with pulsed LED lighting improves the nutritional value of mustard microgreens due to increased content of mineral elements.

SESSION VI: Efficient Use of Resources

OS 6-1:

PHOTOSYNTHETIC ELECTRON TRANSPORT CHAIN IN CHRYSANTHEMUM LEAVES UNDER DIFFERENT LIGHT SPECTRUMS

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Light is one of the most important environmental factors that can affect plant growth and development. Previous studies indicated that plants under different light qualities exhibit different photosynthetic characteristics. However, the regulation mechanisms underlying related photosynthetic electron transport remained largely unclear. To unravel the effects of light quality on photosynthetic electron transport chain, chrysanthemum (*Chrysanthemum morifolium*) plants were grown under four different light qualities including white (400-730nm), blue monochromatic light (450 nm), red monochromatic light (635-665 nm) and a combination of red and blue (R:B =70:30), with the same PPFD (250 µmol $m^{-2}s^{-1}$). The results showed that using monochromatic light during growth of Chrysanthemum led to some defects on electron transport chain, while using full visible spectrum (white light) or combination of red and blue lights resulted in normal performance of electron transport chain. Between monochromatic lights, using red light significantly increased dissipated energy flux, absorption and energy trapping fluxes per reaction center when compared with other light treatments. On the other hand, red light caused a significant decrease in the performance index for energy conservation, maximal quantum yield of primary photochemistry, quantum yield of electron

transport and maximum quantum yield of photosystem II than other light treatments. Maximal quantum yield of primary photochemistry in monochromatic lights was considerably decreased when compared to white or RB lights. In conclusion, monochromatic lights can decrease efficiency of electron transport chain in the photosynthetic apparatus of the chrysanthemum plants.

OS 6-2:

FORECASTING ROOT-ZONE ELECTRICAL CONDUCTIVITY OF NUTRIENT SOLUTIONS IN CLOSED-LOOP SOILLESS CULTURES USING A RECURRENT NEURAL NETWORK

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Soilless cultures can improve crop yield and quality compared to soil cultures. In existing closed-loop soilless cultures, nutrient solutions are controlled by the electrical conductivity (EC) of the solution. However, the EC of nutrient solutions is affected by both growth environments and crop growth, so it is hard to predict the EC of nutrient solution. The objective of this study was to predict the root-zone EC of nutrient solutions in closed-loop soilless cultures using recurrent neural network (RNN). In a test greenhouse with sweet peppers (*Capsicum annuum* L.), data were measured every 10 sec from Oct. 15 to Dec. 31, 2014. Mean values for every hour were analyzed. Validation accuracy (R^2) of a single-layer long short-term memory (LSTM) was 0.92 and root mean square error (RMSE) was 0.07, which was the best results among the different RNNs. The trained LSTM predicted the substrate EC accurately at all ranges. Test accuracy (R^2) was 0.72 and RMSE was 0.08, which were lower than values for the validation. Deep learning algorithms were more accurate when more data were added for training. The addition of other environmental factors or plant growth data improved model robustness. A trained LSTM can be applied to control nutrient solutions in closed-loop soilless cultures based on predicting future EC. Therefore, the algorithm can make a planned management of nutrient solutions possible, reducing resource waste.

OS 6-3:

A DECISION SUPPORT SYSTEM TO AUTOMATICALLY CALCULATE AND READJUST NUTRIENT SOLUTIONS IN COMMERCIAL SOILLESS CULTIVATIONS

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A major technological component of the modern greenhouse industry is the soilless cultivation. However, the management of nutrition in soilless cultivations poses serious difficulties to growers, because the calculation of the fertilizers needed to prepare a nutrient solution (NS) requires a good background in chemistry and is time consuming. Furthermore, the composition of the NS supplied to the plants needs modifications at different cropping stages. The calculations are specific for each grower and cropping stage, because of differences both in the mineral composition of the irrigation water used to prepare NSs,and in cropping conditions, which entail individual decisions about adaptations in nutrient supply during the cropping period. Thus, there is a need for modern computational tools operating as decision support systems (DSS) which can provide easy and accurate calculation and adaptation of NSs in each commercial enterprise whenever needed. In the present paper, a DSS for soilless cultivations is presented, which can be used to automatically calculate NSs based on desired characteristics given as target values, and adapt them during the cropping period after chemical analyses of the root-zone or the drainage solution. The primary input data to this DSS include desired NS characteristics, particularly: (i) electrical conductivity, (ii) pH, (iii) concentrations or mutual ratios of macronutrients except P and Sand (iv) P and micronutrient concentrations. Further essential input data to this DSS is the mineral composition of the water used to prepare the NS, the season of the year, the mean drainage fraction in substrate-grown crops, the type of the soilless cultivation system (e.g. open or

closed-loop), etc. The DSS includes a database with targetNS characteristics, which are specific for each cropspecies and plant developmental stage. This DSS could operate also on-line to readjust automatically the NS composition in real time, if the concentrations of some nutrients in the root zone are monitored using ion specific electrodes.

OS 6-4:

ENHANCING RESOURCE USE EFFICIENCY IN PLANT FACTORY

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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. The main focus with the existing system designs has been using the internal building space to achieve higher biomass production without considering detailed engineering design fundamentals for air conditioning systems, uniformity of the environment, efficient delivery of CO2, shelf spacing, smart lighting system and shelf designs, and interaction of crop and surrounding climate in terms of heat and mass-transfer processes. Therefore, lack of detailed engineering analysis in the system design can lead to inefficient use of resources (i.e. energy, CO2, water), non-uniform environment, higher system costs, and limit production quality, yield, and profitability. 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. This presentation will discuss about some of the challenges and opportunities for growing food in indoors with artificial lighting, with special focus on climate control and environmental uniformity. Potentials of using Computational Fluid Dynamics based simulation for air distribution systems and analysis of climate uniformity and EnergyPlus based building energy simulation on energy consumption in a plant factory is presented. Discussions will also include on potential climate control strategies which could lead to resource savings.

OS 6-5:

PHOTOSYNTHETIC EFFICIENCY OF HYDROPONICALLY-GROWN TOMATO PLANTS TO DECENTRALIZED WASTEWATER TREATMENT SYSTEMS (DEWATS) EFFLUENTS AND NITRIFIED URINE CONCENTRATE (NUC) AS NUTRIENT SOURCES

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There is increasing interest and wide recognition of the potential use of human-excreta derived materials (HEDM) as fertiliser to supply essential nutrients needed for crop production. This has additional benefits as part of a reuse-oriented sustainable sanitation approach in efforts aimed at addressing sanitation challenges in many parts of the developing world. However, most work on HEDMs has focussed on yield responses when compared to chemical commercial fertiliser sources using soils. Not much work has considered different systems such as hydroponic production. The physiological responses of plants to different HEDM when used in a hydroponic system is currently not well understood. This study evaluated the effect of Decentralized Wastewater Treatment System (DEWATS) effluents and Nitrified Urine Concentrate (NUC) as nutrient sources on hydroponically grown tomatoes. The study was conducted in a polyethylene tunnel located at Newlands-Mashu Research Station under eThekwini Municipality, KwaZulu-Natal, South Africa. The experiment was laid out using a complete randomised block design and comprised of three treatments, namely, DEWATS effluent, NUC and commercial hydroponic fertilizer mix (CHFM). Each treatment was replicated three times giving nine experimental units of five plants each planted in a 5 L polyethylene pot. Data was collected on the following physiological variables: leaf area index (LAI), chlorophyll content index (CCI), stomatal conductance (*gs*), net CO_2 assimilation rate (*A*), intercellular CO_2 concentration (C_i)

and instantaneous water-use efficiency (WUE_{ins}), were evaluated at vegetative stage. Results showed that tomato plants receiving CHFM had the highest LAI (2.00), followed by NUC (1.17) and DEWATS (0.87). CCI was significantly higher in the NUC treatments (38.67) compared to the CHFM (34.08) and DEWATS effluent (31.22). A similar trend was observed in *A* where NUC had the highest *A* value (17.39 µmol CO_2 m^{-2} s^{-1}) followed by CHFM (15.28 µmol CO_2 m^{-2} s^{-1}) and the DEWATS effluent (13.97 µmol CO_2 m^{-2} s^{-1}). The value of *gs* was higher in the DEWATS effluent (0.13) compared to the values of 0.12 and 0.09 observed for NUC and CHFM, respectively. Further, C_i was higher using DEWATS effluent compared to NUC and CHFM while the reverse trend was observed with WUE_{ins}. The current study demonstrated that the use of HEDM such as NUC and DEWATS effluent as nutrient sources have comparable effects with commercial fertilizer mix with respect to the physiology of hydroponically grown tomatoes.

OS 6-6:

POSTHARVEST RESPONSES OF OREGANO AND MARJORAM LEAVES GROWN UNDER THE RED AND PEARL PHOTO-SELECTIVE SHADE NETS

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This study was conducted to see the influence of modified spectral quality under the photo-selective nets on the retention of antioxidants in fresh cut oregano and marjoram leaves after postharvest storage. Oregano and marjoram fresh cut leaves obtained from the plants grown under red net [40% shading and 0.57 blue/red ratio; 0.85 red/far-red ratio; 221.67 (µmol $m^{-2}s^{-1}$)], pearl net [40% shading; and 3.88 blue/red ratio; 0.21 red/far-red ratio; photosynthetic radiation (PAR) 233.24 (µmol $m^{-2}s^{-1}$)] and black net [25% shading; 3.32 blue/red ratio 0.96 red/far-red ratio; 365.26 (µmol $m^{-2}s^{-1}$)] were stored at 0 °C, 10 days, 95% RH and thereafter at the retailers' shelf 15 °C for 4 days, 75% RH (postharvest storage).
Oregano and marjoram fresh cut leaves obtained from the plants grown under red and pearl nets (40% shading) showed reduced weight loss and retained higher total phenols, flavonoids (quercetin) and antioxidant scavenging activity after postharvest storage. Both oregano and marjoram fresh cut leaves obtained from the plants grown under the pearl nets showed retention of ascorbic acid content and visual quality after postharvest storage. Typical aroma was higher in both oregano and marjoram fresh cut leaves obtained from the plants grown under the red nets. Results suggest that spectral quality under the pearl net improves the retention of overall visual quality, marketable yield, antioxidants and major aroma components in oregano and marjoram fresh cut leaves during postharvest storage.

OS 6-7:

APPLE FRUIT CARBON PARTITIONING AS AFFECTED BY DIFFERENT LIGHT ENVIRONMENTS

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To evaluate the effect of the light spectrum on apple fruit carbon partitioning, five light environments were created in a Rosy Glow orchard, in spring 2017. A standard black anti-hail net (serving as control) and four photoselective nets (red, blue, white, yellow) were used to cover 6 trees each. Every treatment was replicated twice; shading was 20% for all nets. Growth of 32 fruit, their bourse shoots and 32 extension shoots was measured twice a week, from the end of April to the end of May, and once a week, until the end of June. Nets induced differences in both fruit and extension shoot growth, but not in bourse shoots. The yellow and the black nets tended to increase growth, while blue appeared to slow it down in absolute terms, but not on a per gram basis. The red and white nets were mostly intermediate. As fruit grew at different rates, whereas bourse shoots did not, different source-sink relations between the two are hinted. The bourse shoots borne on the spurs with the more active fruit might have been more efficient, in terms of photosynthate production. On the other hand, fruit might have been stronger sinks, able to draw a higher

amount of photosynthates. The light spectrum might induce differences in the carbon loading processes, but the potential applications in the field still need to be tested and further investigations are required.

KEYNOTE 3

PLANT BIOSTIMULANTS IN GREENHOUSE HORTICULTURE: RECENT ADVANCES AND CHALLENGES AHEAD

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Interest in plant biostimulants is on the rise, compelled by the growing interest of greenhouse growers and private industries in natural substances and beneficial microorganisms able to boost vegetables and ornamentals productivity in a sustainable way. Protein hydrolysates (PHs) and arbuscular mycorrhiza fungi (AMF) are two important groups of plant biostimulants. PHs are generally applied as foliar sprays or near the roots, whereas, AMF are applied as powder, pellet, gel and seed coating. PHs and AMF are widely used in greenhouse crops largely for improving plant nutrient uptake, growth, yield and fruit quality, and also for their ameliorating effect on crop tolerance to abiotic stressors. In the current review article, we give an update about the recent advances in the biostimulant properties of PHs and AMF on vegetables, flower and ornamental crops performance. The agronomical and physiological processes conferring tolerance and/or resistance to several environmental stresses in biostimulant-treated plants will be also elucidated.

SESSION VII: Greenhouse management and production systems

OS 7-1:

ADAPTING CONTROLLED ENVIRONMENT FOOD PRODUCTION TECHNOLOGY FOR HUMAN LIFE-SUPPORT ON OTHER PLANETS

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Bioregenerative Life Support Systems (BLSS) based on crop production will play a central role in the establishment of future Lunar and Martian outposts. Such systems will be designed to a) revitalize the habitat's atmosphere; b) recycle the crew's water; and c) generate a portion of the crew's total caloric intake. This will reduce resupply requirements. One of the most important components of the BLSS is represented by the greenhouse subsystem. The University of Arizona-Controlled Environment Agriculture Center (UA-CEAC), UA-Systems and Industrial Engineering (UA-SIE), Sadler Machine Co. (SMC), and our European partners of Thales Alenia Space-Italy (TAS-I), Aero Sekur SpA (A-S), National Research Council Institute Agro-environmental Biology & Forestry, Italy (CNR), and DLR Department of Space Systems Analysis, Institute of Space Systems (Germany) supported by the NASA Ralph Steckler Human Space Exploration Grant through the University of Arizona Space Grant Consortium, have developed the BLSS Mars-Lunar Greenhouse (MLGH) with the ultimate goal of constructing and operating a full-sized space greenhouse that addresses the challenges of air revitalization, waste water recycling and crop

production to supply a portion of the overall crew caloric needs. The NASA Steckler Space Grant project goal was to enable crop production in full-scale structures that have a high degree of mission fidelity and could represent a space structure applicable to a future Mars or Lunar Habitat. Tests within a closed system of plant production whereby nutrient water and atmospheric gasses were recycled within short term tests demonstrated the viability based on the productivity per resource (water, energy, labor) input. The results of testing will be presented, and their relationship to Earth-based food production will be contrasted.

OS 7-2:

EVALUATION OF POLLEN STORAGE STRATEGIES IN *Cucurbita pepo* L.

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Male flower shortage is a major reason of insufficient pollination in zucchini (*Cucurbita pepo* L.), leading to pointy fruits that rot quickly in the post-harvest phase. Harvesting pollen grains early in the season, when male flowers are abundant, followed by storage and subsequent manual pollination, could be a solution, provided that high pollen viability is maintained. Therefore, insight in parameters affecting pollen viability during anthesis and under storage are needed to advice growers on the most successful pollination strategy. Pollen viability was determined using Fluorescein Diacetate (FDA) and digital image analysis performed with Image J. Under practice conditions, viability started to diminish three hours after anthesis. At flower closing, only 60% of pollen grains remained viable and the next morning no more than 10%. In order to assess the impact of storage on pollen viability, pollen grains were subjected to different relative humidities and storage times. Stored at 20°C and 80% RH or lower for four hours, at least 90% of the pollen turned out to be non-viable. At 20°C and 90%, RH pollen viability remainedabove 50% for eight hours. When female flowers were pollinated with stored pollen (five days or longer), none of the fruits set sufficiently to be marketable, while fresh harvested pollen resulted in 90% marketable fruits. Therefore, pollen should be harvested and applied on the stigma within three hours after anthesis in order to assure good fruitsetting. Pollen could not be stored longer than eight hours without severe loss of viability or pollinating capacity.

OS 7-3:

PRELIMINARY EVALUATION OF THE IMPACT OF PREHARVEST UV-C ON LETTUCE: POTENTIAL FOR THE CONTROL OF *Xanthomonas campestris*

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Two lettuce (*Lactuca sativa*) cultivars, the susceptible ‘Chief’ and the tolerant ‘Little Gem’, were used to study the effect of ultraviolet-C (UV-C) light on bacterial leaf spot (BLS) development. Potted plants were irradiated every 48 h with UV-C to obtain a cumulative dose of 1.6 kJ m^{-2} over a period of 8 d. Inoculation with *Xanthomonas campestris* pv. *vitians* was performed 2 d after the last UV-C treatment. Then, 14 d after inoculation, the severity of BLS was assessed on the lettuce seedlings using a six-point scale (0–6). Lettucenin, a known antimicrobial molecule of lettuce, was extracted from controlled and treated tissues and assayed by ultra-performance liquid chromatography. For the susceptible cultivar ‘Chief’, the severity of BLS was markedly reduced on the UV-C-treated plants in comparison with the non-UV-C-treated plants. The BLS severity scores for ‘Chief’ were 2.66 and 5.16 in the UV-C-treated plants and the controls, respectively. Ultraviolet-C treatment did not significantly affect the

BLS severity index (<2) in the tolerant cultivar 'Little Gem'. The lettucenin A content in the leaves was significantly higher in the tolerant cultivar than in the susceptible cultivar. Ultrastructural changes induced by UV-C on the surface of lettuce leaves were observed by scanning electron microscopy. These observations revealed the occlusion of the stomata of UV-C-treated leaves by a wax-like matrix that remains to be fully characterized. This occlusion seemed partial in the susceptible cultivar and more complete in the tolerant cultivar. The results of this preliminary work suggest a potential antibacterial role of lettucenin in the natural tolerance of lettuce against *X. campestris*. However, the beneficial effect of UV-C treatment on BLS severity seems to be related at least in part to ultrastructural modifications that restrict the access of the pathogen to the stomatal chamber.

OS 7-4:

DAILY EVAPOTRANSPIRATION (ET) MODELING FOR GREENHOUSE TRAY SEEDLINGS IRRIGATION UNDER DIFFERENT SUBSTARE CONDITIONS

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This research evaluated three ET different models under combinations of three irrigation conditions (20%, 50%, 80% relative volumetric water content) and four root zone volumes (6,10,23,33 ml for each plant) to study the effects of different factors on daily ET prediction of greenhouse tray seedlings. The predicted value was compared with the actual value obtained by the continuously weighting. Crop coefficient (Kc) curves were obtained and adjusted for the seedlings under different conditions. The results of this research show that the daily evapotranspiration rate of seedlings could be calculated by ET models and this method is promising for greenhouse seedlings irrigation management.

OS 7-5:

IMPROVED RED AND BLUE RATIO IN LED LIGHTING FOR INDOOR CULTIVATION OF LEAFY VEGETABLES

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Plant cultivation is greatly influenced by environmental conditions. Light is one of the most important environmental factors affecting photosynthesis and morphogenesis. While in open-air cultivation is difficult to regulate natural light, plant factories with artificial light (PFAL) enable to fully control environmental factors, including the light environment. Between the different light sources' adaptable to indoor cultivation, light emitting diodes (LEDs) are increasingly common due to their good cost performance, relatively high electricity-to-light energy conversion factor, adaptable spectrum colours, relatively low surface temperature, long lifetime, solid-state construction without gas. The present work assess the effects of different ratio of red (R) and blue (B) spectral components in LED lights used for hydroponic cultivation of lettuce (*Lactuca sativa* var. Rebelina) and basil (*Ocimum basilicum* var. Genovese). Fifteen days after sowing, plants were transplanted in plastic pots filled with nutrient solution constantly aerated and placed in isolated boxes where artificial light treatments were applied. Five LEDs treatments (R:B=0.5, R:B=1, R:B=2, R:B=3, R:B=4) and a fluorescent light were compared, with 240 mmol m^{-2} s^{-1} PPFD and 14/10 hours of light/darkness photoperiod. During the plants' cycle, stomata conductance, leaf temperature and N leaf content were measured. At the end of cycle, nutrient solution was sampled in order to identify differences in the uptake of macro- and micronutrients. At harvesting time (18 and 21 DAT, respectively for lettuce and basil), fresh and dry weight, ions content, total phenolic and flavonoids content, total antioxidant capacity and nitrates content were

determined. Greater yields were associated with higher portions of red light (R:B=3 and R:B=4, respectively for basil and lettuce).

OS 7-6:

PILOT-SCALE AQUAPONICS IN A SEAWATER-COOLED GREENHOUSE: EXPERIMENTAL RESULTS, WATER USE, AND PRODUCE WATER FOOTPRINT

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A pilot-scale aquaponics unit was installed and operated for one year inside a controlled environment agriculture building cooled by the evaporation of seawater on the campus of King Abdullah University of Science and Technology in Thuwal, Saudi Arabia. Results collected from the operation included crop water use, water quality parameters, dissolved ion concentrations, outdoor and indoor climate data and crop output.Seawater-based evaporative cooling did not provide adequate indoor temperatures for cultivation of lettuce during the hot and humid summer season. However, the combined aquaponics with seawater evaporative cooling was effective for fall, winter, and spring cultivation with a mixed crop of lettuce and tomatoes. Opposite to the vegetable production cycle, water temperatures favored production of sabaki tilapia during the warm summer season rather than the cool winter season. Because of this dichotomy, the system showed promise for management and balancing of nutrient levels on an annual basis rather than a daily basis. From a fresh water use perspective, the average daily fresh water use totaled only 4.6 L day^{-1} m^{-2} or 19 L kg^{-1} of crop harvested during the peak winter/spring growing season. These results demonstrate that an aquaponics system in combination with a seawater based evaporative cooling system is capable of saving ~90% of fresh water as compared with traditional forms of agriculture in the region.

OS 7-7:

EFFECT OF UV LIGHT ON THE ACCUMULATION OF BIOACTIVE COMPOUNDS AND THE EXPRESSION OF THEIR BIOSYNTHESIS GENES IN RED PERILLA

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Red perilla (*Perilla frutescens*) is used as food and a crude drug, and in cosmetics. The major bioactive compounds of red perilla are perillaldehyde, rosmarinic acid, luteolin and anthocyanin. In this study, we evaluated the effect of UV light on the accumulation of its bioactive compounds under controlled environments. To this end, we measured its bioactive compounds and the expressions of the genes encoding related enzymes. Red perilla was cultivated in a controlled-environment room for 35-42 days after germination. The growing conditions were as follows: air temperature 25/20 °C (light/dark), R.H. 70%, light period 16 h, PPFD 200 $\mu mol \cdot m^{-2} \cdot s^{-1}$ and CO_2 concentration 1000 ppm. The plants were exposed to UV-B light of various wavelength ranges under white LED light for 3 days. UV intensity was set at 0, 0.5, and 1.0 $W \cdot m^{-2}$. The concentrations of the bioactive compounds and oxygen radical absorbance capacity (ORAC) as antioxidant capacity were measured every day after the start of treatment. Expressions of the genes encoding phenylalanine ammonia-lyase, tyrosine aminotransferase (TAT), rosmarinic acid synthase (RAS) and chalcone synthase were analyzed by RT-RT-PCR. UV-B light of 290-315 nm wavelength with intensity 0.5 $W \cdot m^{-2}$ decreased the fresh weight and leaf area at Day 3, however, UV-B light of 310 nm alone with 1.0 $W \cdot m^{-2}$ did not decrease the fresh weight and leaf area. Concentrations of perillaldehyde and rosmarinic acid and the ORAC values were significantly high under the 310 nm UV-B light treatment with 1.0 $W \cdot m^{-2}$. Anthocyanin concentration did not differ among the treatments. *TAT* and *RAS* expressions under 310 nm UV-B light at Day 2-3 were significantly higher than those of the control. The results indicate that irradiation with UV-B of proper

wavelength for 3 days stimulated gene expression resulting in the biosynthesis and enhanced accumulation of the bioactive compounds.

OS 7-8:

EFFECTS OF BENEFICIAL ORGANISMS UNDER DIFFERENT IRRIGATION PROGRAMS IN GREENHOUSE CUCUMBER PRODUCTION

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This study was conducted in order to determine the effects of beneficial organisms under water deficit with different leaching rates in greenhouse cucumber production grown substrate culture. Two beneficial microorganisms, namely mychorriza (*Glomus* species) and *Trichoderma harzianum* and their combination mychorriza + *T. harzianum* were tested comparing with control (no treatment) under two irrigation programs based on indoor integrated solar radiation levels of 1 MJ m^{-2} and 2 MJ m^{-2} with a two different leaching rates of 20% and 40%. Cucumber plants were grown at autumn (22 October 2015-5 January 2016) and spring (16 March-10 July 2015) growing cycles in unheated greenhouse conditions. Perlite was the growing substrate with a volume of 8 liters per plant. Yield was lower due to the shorted growing period in autumn, however, total yield and water use efficiency ranked between 18.36 and 33.31 kg m^{-2} and 40 and 66 kg m^{-3} in spring season, respectively. Among the tested treatments the highest yield was obtained under frequent irrigation application of 1 MJ m^{-2} x leaching rate of 40% x mychorriza interactions.

OS 7-9:

PLASTICULTURE: ECONOMY OF RESOURCES

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Plastic in agriculture is essential for farmers, growers and the agriculture production... The plastic allows a better production in quantity and quality, while using less input: water, pesticides, fertilizers... Therefore, agri-plastics has an important contribution for an intensive ecological agriculture (agro-ecology). Then plastic reduce the environmental impact of the agriculture production. Every year, the world is using 6,1MT of agri-plastics: greenhouses, small tunnels, mulching, silage, stretch films, irrigations pipes, nets and many more. Without plastics, 60% of the vegetable and animal production will be jeopardized.
After use, if collected, agri-plastics are recycled and contribute then to the circular economy.
By 2030, the world will consume 9,5MT of plastic to face the growing demand of the increasing population. Due to the contamination (sand, earth, water, organic matters) the used agri-plastic will represent the equivalent of 17,5 MT of waste to be managed. To often, all over the world, agri-plastics are not properly managed: plastics left on the field, accumulation in the soil, wild storage, with dramatic damage for the environment and jeopardizing the production itself.
The plasticulture community (users, industry, distributors, scientific community) must be concern about the end-of life of agri-plastic and therefore take individuals and collectives initiatives to ease sustainable solutions for users and the environment.

IHC2018-Symposium 17
III International Symposium on Innovation and New Technologies in Protected Cultivation

POSTER PRESENTATIONS

S17-P1:
DYNAMIC TEMPERATURE CONTROL STRATEGY WITH A TEMPERATURE DROP IMPROVED RESPONSES OF GREENHOUSE CUCUMBERS TO LONG PHOTOPERIODS OF SUPPLEMENTAL LIGHTING

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Supplemental lighting is essential for year-round greenhouse crop production in regions with low natural light conditions. Supplemental lighting for increasing the daily light integral can be added via lengthening photoperiods or increasing light intensity. Light addition via long photoperiods is preferred because of the lower light fixture capital costs in comparison to the use of high light intensity. However, long photoperiods cause photo-injury such as leaf chlorosis in greenhouse fruiting vegetables such as cucumbers, and yield is no long increasing with extended photoperiods. In our previous study, we found that a pre-night temperature drop with dynamic temperature integration (TI) can promote photo-assimilate translocation from leaf to fruit and thus has the potential to reduce photo-injury. This study was conducted from 2016 to 2017 with the aim to test this temperature control strategy for improving the response to long photoperiods including both overhead HPS (high pressure sodium) lighting and LED intra-canopy lighting. The study was conducted in 8 greenhouse compartments, each with 50 m^2 of growing area. Two photoperiods (Control (17h) and Long Photoperiod (20h)) of overhead HPS lighting and two temperature integration strategies (Control TI – no temperature drop, and Dynamic TI with a pre-night temperature drop to 12.5°C at the end of photoperiod) were applied in the 8 compartments (2 replications). Three intra-canopy light treatments (control – no intra-canopy LED, 17h or 20h of intra-canopy LED light) were applied inside each greenhouse compartment. The dynamic TI with a pre-night temperature drop significantly increased fruit yield at the long photoperiod but did not reduce photo-injury for greenhouse cucumbers. Therefore, dynamic temperature integration with a proper pre-night temperature drop can be used to improve fruit production in greenhouse cucumbers grown with long photoperiods of supplemental lighting.

S17-P2:
GROWTH ANALYSIS OF TOMATO PLANTS UNDER ENVIRONMENTALLY CONTROLLED GREENHOUSES

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Greenhouses are used to maintain an ideal plant growth by controlling environmental conditions. Two polycarbonate covered greenhouses; automated (G1) and normally operated (G2) were used to evaluate plant growth, yield and quality traits. An automated system was applied to control shading, natural ventilation, and thermal screens during hot conditions, moderate conditions, and cold winter nights, respectively. Four weeks tomato (cv. Valouro RZ F1) seedlings were transplanted in Rockwool blokes. Vegetative (leaf area, stem length, fresh and dry weight of leaves and stems, stem diameter)were measured at 14 days intervals. Fruit and yield traits (Fruit length, diameter, fresh weight andnumber and total yield) were recorded at each harvest time. The following growth indices were

calculated: leaf area index (LAI), leaf area duration (LAD), leaf weight ratio (LWR), stem weight ratio (SWR), fruit weight ratio (FWR), specific leaf area (SLA), leaf area ratio (LAR), net assimilation rate (NAR), relative growth rate (RGR) and crop growth rate (CGR). Plants grown under G1 were superior in vegetative growth traits. In addition, tomato fruits from G1 had the highest quality traits (vitamin C content, total soluble solids and total acidity). Growth analysis data indicated that tomato plants in G1 had faster growth rate than plants grown under G2 due to the optimum environmental conditions provided by the automation system. As a result, they had the best growth, yield and quality traits. Growth indices can be used as tools to explain morphological and/or developmental plant responses under greenhouse conditions.

S17-P3:

THE HORTSYS MODEL EXTENDED TO PHOSPHORUS UPTAKE PREDICTION FOR TOMATOES UNDER SOILLES CULTURE

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Phosphorus (P) is one of the essential nutrients required by all plants to complete their life cycles. P is involved in all growth phases in every living cell. In horticulture, P is vital in nutrient management for achieving maximum crop yields. There is an intimate relationship between the state of nitrogen (N), P and carbon metabolism. Therefore, deficiency of N and P in plants induces changes in the synthesis of carbohydrates and degradation pathways. The progressive phosphorus deficiency stops root and shot growth of the plant, decreases the concentration of P in the dry matter, and decreases the photosynthetic activity. The aim of this research was toextend and calibrate the HortSyst model for the prediction and management of P uptake by a tomato crop under soilless culture in order to increase the efficiency of this nutrient linked to the irrigation management through the crop transpiration. The HortSyst model is a discrete time model for describing the dynamics of dry matter production, N uptake, leaf area index and crop transpiration. Two experiments with tomato *cv* "CID F1" were carried out under greenhouse conditions, during the autumn-winter and spring-summer seasons growing in hydroponic systems using volcanic tuff as substrate. Plants were distributed with a density of 3.5 plants·m^{-2}. The temperature, relative humidity and solar radiation were measured inside of the greenhouses. P concentration was determined by the method of yellow molybdovanadate reading the absorbance at 470 nm with a spectrophotometer. The parameters were calibrated using nonlinear least square estimation and thestatistics of goodness of fit between simulated and measured data were the root mean square error (RMSE), bias (BIAS), and modelling efficiency (EF). The model showed effectiveness and good performance, so the HortSyst model could be used to predict P uptake besides the N uptake theby tomato crop.

S17-P4:

A REVIEW OF ROOTSTOCK USAGE IN EGGPLANT AND RECENT ADVANCES

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The reduction of chemical quantity usage is very important to human and environmental health and next generation. Rootstock usage provides many advantages such as resistance or tolerance to biotic and abiotic stress factors, thus, increasing yield. Rootstock usage in eggplants was started in early 1950's. Currently, it is used worldwide, especially in Asia, Europe, Africa and America. In order to choose the best performing rootstocks in eggplants, many resources have been carried out until now. Verticillium, Fusarium, Nematode resistance, salt, drought, chilling, low

temperature tolerance, reduction of heavy metals (cadmium, nickel, chrome), yield increases, quality and scion-rootstock compatibility subjects are the most important topics for the researchers. Some wild ancestors of eggplants and, tomatoes were tested as rootstocks in these topics.
In this study more than a hundred and fifty research articles were reviewed to determine the best performing rootstocks for eggplants in the subjects mentioned above. Thus, practical information may be provided for future studies to be used by both researchers and breeders in order to stimulate new researches on this subject.

S17-P5:

PRELIMINARY STUDY OF GREEN LED ON LETTUCE GROWTH UNDER INDOOR ARTIFICIAL LIGHT CULTIVATION

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Red and blue light-emitting diodes (LEDs) have been the typical mixtures of light spectra applied on the indoor cultivation of leafy crops in Singapore. This preliminary study, on the use of green LED in combination with blue and red LEDs, is an attempt to improve lettuce (*Lactuca sativa*)growth under indoor controlled environment. The first experiment involved local Chinese lettuce grown in garden compost-filled pots under 4 artificial light sources of cool-day fluorescent light, high red/blue LEDs, low red/blue LEDs and red /blue/green LEDs with photosynthetically active radiation (PAR) ranging from 26 - 47µmolm^{-2}s^{-1}. Higher shoot fresh weights (FW) from greater PAR of approximately 50 µmolm^{-2}s^{-1} tend to promote growth efficiency. Green and blue lights seem to influence a photomorphogenic response on local lettuce plant development in particular the stem and leaf. In the second experiment, multi-leaf lettuce was grown for 50 days at 18^{o}C in a deep flow hydroponic growth chamber under 2 lighting conditions (red/blue/green and red/blue) with similar spectral intensities at higher PAR levels of 85-87 µmol m^{-2}s^{-1}. Overall plant size and structure of multi-leaf lettuce grown without green light were greater than the compact heads of the red/blue/green plants. Effects of green light in the presence of blue and red lights on plant growth (i.e. FW gain) remained inconclusive but it had elicited stem and leaf development.

S17-P6:

EFFECT OF BLUE LIGHT PERCENTAGE ON MINERAL ELEMENTS CONTENT IN *Brassica* MICROGREENS

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The objective of our studies was to determine changes of mineral elements and nitrates content in *Brassica* microgreens depending on different percent of blue light in light-emitting diodes (LED) lighting. Experiments were performed in controlled environment growth chambers. Microgreens of mustard (*Brassica juncea* L. 'Red Lion'), red pak choi (*Brassica rapa* var. chinensis 'Rubi F1'), and tatsoi (*Brassica rapa* var. *rosularis*), were grown in a peat substrate (pH 5–6) in 0.5 l plastic vessels for 10 days, from sowing to harvest. Day/night temperatures of 21 ± 2/17 ± 2 °C were established with a 16-h photoperiod and relative humidity of 50–60%. A system of five high-power, solid-state lighting modules with standard 445-, 640-, 660-, and 735-nm LEDs was used in the experiments. The spectral composition was changed by adding a blue component – 0, 8, 16, 25 and 33%– changing the PPFD level of red (640 nm) light. ICP-OES method was used for determination of mineral elements, potentiometric method – for nitrate content. Our results revealed that an increase of various mineral elements content was mostly caused by higher

percentage of blue light. However, the changes on contents of mineral elements depended on microgreens species and percentage of blue light. The highest content of macro- and microelements was determined at 25% of blue light in mustard and at 33% – in red pak choi and tatsoi. The absence (0%) of blue light led to lower content of macroelements in red pak choi and tatsoi. The percentage of 25% led to significant lower nitrates content of all investigated microgreens.

S17-P7:

PROTEIN HYDROLYSATE-BASED BIOSTIMULANT IMPROVE YIELD AND FRUIT QUALITY OF GREENHOUSE FRESH TOMATO

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The use of natural plant biostimulants has been proposed as one of the most promising and innovative approach to address the challenges to sustainable greenhouse horticulture, to ensure optimal nutrient uptake and crop yield. Very limited information are available concerning the effect of natural biostimulants on yield and quality attributes of vegetables. Accordingly, it is in the best interest of growers, extension specialists and scientists to elucidate how biostimulant applications can modulate quality and yield of greenhouse vegetables. A greenhouse experiment were carried out to assess the crop productivity and fruit quality traits of tomato (Solanum lycopersicum L.) in relation to foliar protein hydrolysate-based biostimulant applications (untreated or treated at a concentration of 3 ml L^{-1}). Foliar application of the protein hydrolysate-based biostimulant enhanced marketable yield and mean fruit weight by 15.4% and 19.8%, respectively compared to untreated tomato plants, with no significant effect on the fruit number. Similarly to crop performance, the foliar application of protein hydrolysate incurred a significant increase in total soluble solids, total ascorbic acid and by 10.2%, 22.9% and 37.5%, respectively compared to untreated tomato plants.

S17-P8:

CONTROLLED-RELEASE FERTILIZER TYPE AND GRANULATED SOIL ACTIVATOR COMBINATIONS MODULATE GROWTH AND ORNAMENTAL QUALITY OF TWO BEDDING PLANTS

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Sustainable production in the nursery cultivation has gained consumer and trade interest during the last two decade. The goal of sustainable production is to reduce environmental degradation, maintain agricultural productivity, promote economic viability, as well as reduucing energy losses. Bedding plants are an important part of the nursery industry. Improving cultivation practices that increase the performance of potted ornamentals may become a promising and effectively sustainable strategy to be adopted in nursery. Among the important group of plant biostimulants soil activator complexes obtained by combination of brown macroalgae, zeolites, humic acids and soil bacteria enduring improvement of the chemical-physical and microbiological properties of the substrate. The aim of this study was to assess the effect of the addition of a granular soil activator (Agrosil® Turf Algin) to two commercial controlled-release fertilizers (CRF) on growth, ornamental value, leaf gas exchanges and mineral composition of two bedding plants: *Begonia semperflorens* and *Salvia splendens*. The plant growth parameters and the ornamental quality recorded in Agrosil-treated bedding plants were dependent on the species, but also on the CRF type. Our results also indicated that in general the activator application enhanced several growth and quality parameters: plant height, canopy volume, leaf area and color, number of flowers in both the species. The increased

crop performances recorded were related to an increased photosynthetic rate and to a better nutritional status (N, P, K, Mg).

S17-P9:

THE DETERMINATION OF SPECIFIC COMBINING PERFORMANCES OF CAPIA PEPPER (*C. annuum* L.) INBRED LINES AND DEVELOPMENT OF HYBRID PEPPER VARIETIES FOR PROTECTED CULTIVATION

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Pepper (*Capsicum annuum* L.) is one of the most important vegetable species produced in both open fields and protected cultivation in Turkey. There is a need for new hybrid varieties with various fruit types because of changing market demands. This study was carried out to determine both specific combining performances of capia pepper inbred lines and promising hybrids during two single seasons in 2013, 2014 at the Vegetable Department of Batı Akdeniz Agricultural Research Institute (BATEM). A total of 16 capia pure lines within twenty five lines were selected by considering heterotic patterns and were crossed as 8 male and 8 female to obtain specific hybrid combinations in spring term of 2012. Sixty four hybrids and four commercial hybrids were tested in randomized complete block design (RCBD) with two replications in the single crop-growing season in 2013 in unheated glasshouse. The performance of total fruit yield ranged from 815 to 2006 g per plant. The selected 30 hybrids and 4 commercial hybrids were tested again in single season in 2014 in protected cultivation and morphological characterizations of hybrids were done. The performance of total fruit yield ranged from 1007 to 1896 g per plant. As a result of this study, two sweet and one hot superior capia pepper hybrids were determined as candidate varieties for demands of market. The hybrids were also presented to private sector during growing season. The candidate capia pepper hybrid cultivars and 5 inbred lines were introduced to the private and public sector in “Products Catalog” and some inbred lines were sold to private sector.

S17-P10:

PHOTOSYNTHESIS IN *Ranunculus asiaticus L.*: CHARACTERIZATION IN TWO MEDITERRANEAN HYBRIDS UNDER FLUORESCENT WHITE LIGHT

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Ranunculus asiaticus L. is a quantitative long-day species, originating from Mediterranean area, grown in cold greenhouse for cut flowers and potted plants. Flowering in ranunculus is a complex process, strongly steered by the and photoperiod. Vernalization of rehydrated tuberous roots, used as propagation material, anticipates sprouting and leaf rosette formation and flowering. It is known that the time for flowering and the sensitivity to cold treatment vary in the numerous commercial hybrids, while no information seems to be available on the influence of vernalization on the photosynthetic process.
The aim of the experiment was to investigate the influence of two hybrids, MDR (medium earliness) and MBO (early flowering), and two preparation treatments of tuberous roots, only rehydration (Control, C) and rehydration plus vernalisation (V), on photosynthesis and photochemistry and photosynthetic pigments content in plants grown in pot in climatic chamber, under controlled environment.
In control plants, photosynthesis was higher in MDR-C than in MBO-C, while the maximal PSII photochemical efficiency (Fv/Fm) slightly decreased in the first hybrid. MBO-C developed more leaves and a consequent higher plant leaf area.
Compared to only rehydration, vernalization of rehydrated tuberous roots increased the number of leaves and the plant leaf area in both the hybrids. The preparation treatment did not affect photosynthesis while it decreased the

maximal PSII photochemical efficiency (Fv/Fm) in both the hybrids. A significant interaction was found between the hybrid and the preparation treatment in the content of photosynthetic pigments, which decreased in plants from vernalized tuberous roots compared to those from only rehydrated roots in MDR, while increased with vernalization in MBO.

S17-P11:

RAINFED PRODUCTION OF WINTER WHEAT ON THE SEMI-ARID LOESS PLATEAU OF CHINA: IMPROVEMENTS IN PRODUCTIVITY AND SOIL FERTILITY WITH PROTECTED CULTIVATION

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A three-year field trail was conducted from 2015 to 2017 to evaluate the effects of six different protected cultivation systems on winter wheat productivity and soil fertility in the rainfed agriculture of the semi-arid Loess Plateau. The six protected cultivation systems were: (i) conventional cultivation (CK); (ii) straw mulching (SM); (iii) plastic-film mulching (PM); (iv) ridge-furrow without mulching (RF); (v) ridge-furrow with mulching [i.e. plastic-film mulched ridges and straw mulched furrows] (RFPS); (vi) green manuring (GM). The results show that compared to CK, the grain yields under RFPS, PM and SM were significantly ($p < 0.05$) increased by 51.8%, 41.3% and 13.7%, and water use efficiency (WUE) was increased by 40.9% ($p < 0.05$), 34.0% ($p < 0.05$) and 11.19%, respectively. Grain yields and WUE were not significantly affected by RF and GM. The grain yields and WUE under RFPS were significantly ($p < 0.05$) higher than those under the other treatments. Compared to CK, RFPS substantially increased the contents of soil organic C (5.1%) and easily oxidizable C (15.1%) and C pool management index (17.9%). Moreover, RFPS also increased the contents of soil total N, total P, available N and P (6.5%, 4.5%, 46.1% and 37.1%, respectively) and raised the levels of soil microbial biomass C (57.0%), microbial biomass N (75.7%) and their respirations (25.1%), followed in the older by SM and GM, but not under PM and RF. Our result suggest that the ridge-furrow mulching system with plastic-film mulched ridges and straw mulched furrows significantly increases winter wheat productivity and soil fertility in rainfed agriculture on the semi-arid Loess Plateau of China.

S17-P12:

PLANT GROWTH, YIELD, FRUIT QUALITY AND RESIDUAL BIOMASS COMPOSITION OF TOMATO AS AFFECTED BY GENOTYPE AND MULCH TYPE

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With the aim to assess the effects of biodegradable mulch on fruit yield and quality performances of greenhouse grown tomato, research was carried out in southern Italy by comparing four mulching treatments (two MaterBi biodegradable black films, MB N2/12 and MB N8, having 15 and 12 µm thickness respectively; black polyethylene film, LDPE, 50 µm thick; non-mulched control), using a randomized complete block design with three replicates. LDPE resulted in higher harvest precocity than non-mulched control. The biodegradable MB N8 and the plastic LDPE films led to the highest fruit yield, total crop biomass and leaf area index, whereas the non-mulched control showed the worst overall performances. Fruit dry residue and soluble solids were highest under the biodegradable films MB N2/12 and MB N8, and lowest in the control berries. Titratable acidity was highest under MB N8 and lowest in the control, similarly to the colour component “a”. MB N8 and LDPE grown berries attained the highest levels of colour components “L” and “b” respectively, the biodegradable mulch MB N8 also leading to the highest

fruit firmness. The biodegradable films MB N2/12 and MB N8 resulted in the highest values of both the antioxidant concentration and activity. Biodegradable mulch proved to be as effective as the plastic film in terms of tomato yield, but it better affected fruit quality and antioxidant content, also showing environmentally friendly features.

S17-P13:

INFLUENCE OF A PASSIVE HEATING SYSTEM THAT COMBINES HEAT ACCUMULATORS AND THERMAL SCREEN ON THE GREENHOUSE MICROCLIMATE

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The Mediterranean horticulture currently uses low technified greenhouses, which means that the productive results are far from their potential in relation to the climatological characteristics of the area. During the periods when minimun temperatures are a limiting factor for yield of the horticultural crops under greenhouse, the heat accumulation by water filled NIR absorbing polyethylene sleeves have showed a positive effect. In this work the combination of this system with the use of thermal screen is evaluated. A positive effect of both installations has been observed which leads to an increase in nighttime air temperature higher than 3 °C. A good linear relationship has been shown between the daily global radiation and the maximum increase in water temperature in the heat accumulators. The sustainability of this alternative system for heating makes it interesting for its implementation in the Mediterranean greenhouse.

S17-P14:

EFFECTS OF OXYFERTIGATION AND PLANT GROWTH PROMOTING RHIZOBACTERIA ON GREENHOUSE LETTUCE GROWN IN PERLITE

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This study was conducted in order to determine the effects of oxygen enrichment of nutrient solution coupled with plant growth promoting rhizobacteria on soilless grown iceberg lettuce (cv. Papiro) production. Seeds were treated with *Bacillus subtilis*, *Pseudomonas putida*, *P. fluorescens*, *P. punonensis* and combined application of *B. subtilis* + *P. fluorescens* and were sown into vermicompost:peat (1:1.5, v/v) mixture on January 14th, 2015. After germination in growth chamber, seedlings were moved to a greenhouse for seedling growing till they were ready for planting. Seedlings were transplanted to the PE greenhouse 35 days after sowing. Perlite as growing medium was used in open-system soilless culture. Nutrient solution was aerated with an air compressor and applied to plants 2 days after planting with drip irrigation. To diffuse oxygen into nutrient solution in large bubbles, a circular air-stone commonly used in fisheries was used. The nutrient solution without oxyfertigation and plants not treated with bacteria constituted the control treatment. Experiments were conducted in randomized plots design with 2 factors and 3 replications. Heads were harvested 2 months after transplanting. Yield and head quality parameters of head were determined. It was concluded that oxygen enrichment of nutrient solution through a compressor (aeration) provided increases in yield and plant growth. Especially root development, head size and leaf number were higher in plants grown with aerated nutrient solution. Among the tested bacteria, *P. fluorescens* and *B. subtilis* + *P. fluorescens* were found promising due to the their higher performance.

S17-P15:

IMPROVEMENT OF NEW TOMATO VARIETIES RESISTANT TO *Fusarium oxysporum* f.sp. *radicis lycopersici*

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Tomato is the most important vegetable and produced more than 160 million tons of every year. Pests and diseases are reducing yield and quality of the crop so breeding of resistant new tomato cultivar is necessary. Fusarium crown and root rot, incited by *Fusarium oxysporum f.sp. radicis lycopersici* (FORL), causes significant yield losses in tomato. The objective of this study was to develop new tomato cultivar which is resistant to FORL. Plants were tested against fusarium crown and root rot in root with dip inoculation method. Four weeks after the inoculation, resistant and susceptible plants were scored 0 and 1, respectively. Also tomato cultivars were screened Frl gene for FORL with SCARFrl marker. Hybrids were evaluated for yield, colour and shape. As a result, FÇ154, FÇ99 and FÇ131 hybrids were selected as a beef type, and FÇ85, FÇ140 and FÇ89 were selected as a cheery and cocktail type.

S17-P16:

EVALUATION OF SOME QUALITATIVE TRAITS AND YIELD OF GREENHOUSE CUCUMBER GRAFTED ON DIFFERENT CUCURBITA ROOTSTOCKS

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Grafted seedling has become a common practice in many parts of the world in protected cultivation. Use of grafted seedling increased in greenhouses due to enhance yield and fruit quality. The objective of this study was to examine the effects of grafting and the kinds of rootstocks on plant growth, yield and some qualitative traits on cucumber fruits. The tongue approach grafting method was used. The greenhouse cucumber cultivar Gordion was grafted on ten rootstocks. Non grafted plants were used as control. The results showed that total yield, early yield and total number of fruits were significantly influenced by grafting. The highest total yield was obtained from Maximus. The plants grafted with the other some rootstocks gave also higher yields, plant height, fruit length, fruit diameter than non-grafted plants.

S17-P17:

DIFFERENT ROOTSTOCK/SCION COMBINATIONS EFFECT ON YIELD, FRUIT QUALITY PROPERTIES IN PROTECTED CUCUMBER (*Cucumis sativus* L.) GROWING

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This study was carried out to investigate the effects of using grafted seedlings on plant growth, yield and compatibility of Termessos F1 variety and different rootstocks in the greenhouses between 2007 and 2008. Seedlings of cucumber (*Cucumis sativus* L.) cv. Termessos were used as scion and control non-grafted and self-grafted. Thirteen different rootstocks, of which three were wild type, were used as rootstock. In both 2007 and 2008 grafted and non-grafted plants were grown in the greenhouse of Bati Akdeniz Agricultural Research Institute. While survival rate was low (70%) in *Cucumis hardwickii*, *Cucumis metuliferus* and *Cucurbita ficifolia*, it was high (83%) in

Cucurbita and *Lagenaria* type rootstocks. Control plants produced female flowers earlier than the grafted ones. In both years, yield per plant was affected by grafting.

S17-P18:

THE EFFECTS OF GRAFTING AND MeBr ALTERNATIVES ON PEPPER (*Capsicum annuum* L) PRODUCTION IN GREENHOUSE

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Effects of grafting and MeBr alternatives on pepper production were investigated in a greenhouse of Bati Akdeniz Agricultural Research Institute located in Antalya. Trials were set in the split plot design with 3 replications. Solarization (S), Solarization+Metham sodium (S+Ms), Solarization+Condor (S+Cr), Solarization+ Basamid (S+Bs) and Control (C) without solarization and chemical were determined as main treatments .Kusak F1 was grafted on 5 different rootstocks (Atlanta F1, AG 9306, BATEM-PR, Snoker F1 and Troser F1) and non-grafted Kusak F1 used as control.Observations were taken for the properties such as plant length, fruit weight, early yield and total yield in trial plots. In conclusion; grafting was not a good option to grow pepper on different rootstocks; however, Solarization plus Condor always provided better quality and higher yields in pepper production regardless of the rootstocks used.

S17-P19:

EFFECTS OF DIFFERENT ARTIFICIAL LIGHT SPECTRA ON GROWTH OF LETTUCE IN A CONTINUOUS LIGHT PLANT FACTORY SYSTEM

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Nowadays plant factory systems have been proposed as a viable alternative to increase productivity per unit area of cultivated land by extending crop production in vertical dimension along with efficient resource consumption, without environmental pollution. To investigate productivity of lettuce plants in plant factory systems, plants were cultivated in closed three layers vertical cultivation systems where they exposed to continuous lighting of LEDs (light-emitting diode). The LED light wavelengths were in the range of 660 to 680, 420 to 440 nm and 730 to 750 nm for red, blue and far-red lights, respectively. Plants were grown under three lightning spectra: (Full red; R), (75% red and 25% blue, RB), and (50% red, 25% blue and 25% far-red; RBF), provided continuous light with 250 µmol m^{-2} s^{-1} PPFD and 21±1 °C. Growing of the plants under continuous light resulted in some necrotic spot on the plant leaves exposed to R and RB treatments. Highest fresh and dry weights and also leaf area were obtained in full R treatment. However, Plant under this treatment showed deformed leaves (strong epinasty). RBF treatment resulted in very tall plants with limited number of necrotic spots than the R treatment.

S17-P20:

EFFECTS OF LIGHT QUALITY DURING CULTIVATION ON THE FLOWERING AND FLORET ARRANGEMENT IN PHALAENOPSIS

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More than 70% of the potted phalaenopsis currently produced in Japan are white large floret variety which is mainly used as gifts. Therefore, a better cultivation technology is necessary for increasing the size and number of florets to achieve the high quality. The flowering of phalaenopsis can be induced in the temperature range of 20-25^{0}C, and the sufficient quantity of light is necessary to produce high-quality potted plants. Although the technology of temperature control in the greenhouse has progressed, strong shading is necessary for the hot summer. There is a shortage of sunshine during the cloudy weather such as rainy and winter season in Japan. LEDs as a low-heat generating light source will be effective to compensate the insufficient sunshine for the appropriate temperature. However, it is still unknown which type of light should be supplemented for the phalaenopsis production. Therefore, we examined the influence of light quality on the flowering of *Phalaenopsis amabilis* using various LEDs. Each plant was irradiated at 80 μmol·m^{-2}·s^{-1} PPFD with blue, green, yellow, red or far-red LED (the peak wavelength of 470, 525, 590, 660, and 735 nm, respectively). The temperature of each chambers was maintained at 23± 2^{0}C and lighting time was set to 16 hours (8:00 - 24:00). The flower stem under blue LED rose up, and each of florets was arranged at an acute angle against flower stem axis. As a result, the whole inflorescence was compact, and the ornamental value was high. On the other hand, the flower stem under red LED elongated sideways, and the pedicels were longer and obtuse against flower stem axis, so the ornamental value decreased significantly. There were also differences in the reaction under other LEDs, and it was discussed from the viewpoint of quality for potted plant.

S17-P21:

SIMULATION AND VALIDATION OF THE AIRFLOW INSIDE A NATURALLY VENTILATED GREENHOUSE DESIGNED FOR TROPICAL CONDITIONS

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In the Colombian high altitude tropics, comercial protected horticulture is carried out in low cost greenhouse structures, ventilated in a natural way. Still nowadays, the current knowledge about the performance of these structures under tropical climate conditions is scarce. The present work presents a combined methodology for the study of the natural ventilation of a Colombian greenhouse through 3D computational fluid dynamics numerical simulation and 2D sonic anemometry. The experimental work was developed in a multispan greenhouse consisting of five spans with a ground covered area of 3025 m^2 located in the Sabana de Bogota. This methodological approach allowed to obtain the airflow patterns in the experimental greenhouse under the prevailing wind and temperature conditions of the study region. Measurements and simulations were made for the predominant conditions of the daytime period (6 to 18 hours) in which the following three ventilation configurations were considered: side ventilation, roof ventilation and a combination of both. The results showed a high efficiency of the roof ventilation for low-speed wind conditions (-1). The airflow pattern simulations showed a high correlation with the wind direction and speed measured through sonic anemometry.

S17-P22:

HOW INTELLIGENTLY CONTROLLED LEDS CAN BE USED TO MORE EFFICIENTLY MANAGE SUPPLEMENTAL LIGHTING IN GREENHOUSE PRODUCTION SYSTEMS

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In greenhouse production, high pressure sodium (HPS) and light emitting diode (LED) supplemental lighting systems are normally controlled in an on/off manner according to user-programmed photoperiod and ambient light thresholds. While not practical with HPS, fixture-dimming strategies and automatic control are technically feasible with LEDs. Dimming could allow supplemental LED intensity to be modified, in real-time, in response to varying levels of natural light. Further enhancements are possible by combining additional input factors like upper/lower thresholds of photosynthetic photon flux density (PPFD), target daily light integral (DLI; the amount of PPFD received by the crops over 24-h), time-of-day electricity pricing, latitude and historical PPFD data into a predictive algorithm. These control strategies have the potential to enhance crop productivity by attenuating fluctuations in canopy-level PPFD, while simultaneously minimizing energy cost. The present study investigated cut gerbera production under threshold-controlled HPS compared with intelligently controlled LED using Heliospectra's HelioCORE™ DLI-controller to manage their LX602G multichannel intelligent grow lights. Each treatment had four replications within a common growing area, during the supplemental lighting season in Ontario, Canada. Both controllers were programmed to target total DLI of 7 mol m^{-2} d^{-1}. The overall mean canopy-level DLI were 8.40 and 7.77 mol m^{-2} d^{-1} for HPS and LED treatments, respectively. There were no treatment effects on number of flowers initiated, harvested, and % marketability. HPS-grown flowers developed 5% faster but had 7% lower fresh mass and 4% shorter stems versus LED. The DLI-controlled LED treatment had reduced supplemental light usage but similar crop productivity.

S17-P23:

SUPPLEMENTAL LIGHTING IN TOMATO CROP ON SUBSTRATE IN SWISS CONTEXT

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In recent years, Light-Emitting Diodes (LED) have strongly developed, especially for use in greenhouses. They have various advantages including their efficiency, their lifetime, and wavelengths ranging from ultraviolet to infrared. The use of LEDs inside the crop seems to be an interesting approach to increase the productivity of greenhouse tomato crops. At the moment, supplemental lighting is not used on tomato in Switzerland for various reasons including the protection of the market for part of the year and the price of electricity. In order to provide some answers in the Swiss context, an experiment was carried out by Agroscope in 2015 and 2016 to evaluate the interest of LED interlighting in combination or not with High-Pressure Sodium (HPS) lighting in tomato crop on substrate. The interlighting LEDs significantly increased the yields compared to the control without lighting in 2015 (+ 9%), with continuous operation from 5 a.m. to 9 p.m. This gain was not repeated in 2016 with a reduced duration of lighting. The combination of HPS lighting over and LED interlighting did not result in the increase of the yield compared to the modality with HPS lighting alone. Lighting has an effect on the diameter of the plants, which must be taken into account when conducting the crop.

S17-P24:
THE NUTRITIONAL VALUE OF BRASSICA LEAFY GREENS IN DIFFERENT GROWTH STAGES

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In this study the nutritional value of *Brassica* leafy greens in different growth stages was investigated. Mustard (*Brassica juncea* L., 'Red Lion') and tatsoi (*Brassica rapa* var. *rosularis*) were grown indoors under light-emitting diodes (blue 447 nm, red 638 nm, red 665 nm, far red 731 nm LEDs) lighting (total PPFD 300±10 µmol m^{-2} s^{-1}; 16 h day^{-1}). The contents of saccharides, phytochemicals, nitrates and mineral elements at microgreen (7 days), baby-leaf (21 days) and technical maturity (mustard – 31 days, tatsoi – 40 days) growth stages of leafy greens were evaluated. The significantly higher contents of glucose and fructose in baby-leaf mustard and tatsoi were determined, in comparison with microgreens and technical maturity plants. Also, the higher total phenolic content, total anthocyanin content and DPPH free radical scavenging activity in both species baby-leaf plants were determined. The mustard microgreens accumulated the significantly higher contents of nitrate and nitrite, and the lower contents of macro and microelements, in comparison to baby-leaf and technical maturity plants. The same tendency on mineral elements in tatsoi was determined, however, the significantly higher contents of nitrate and nitrite in technical maturity tatsoi were determined. In conclusion, the contents of antioxidant properties having metabolites, nitrates, nitrites and mineral elements in *Brassica* leafy greens varied depending on age, and the baby-leaf plants showed higher nutritional value, in comparison to microgreens or mature plants.

S17-P25:
EFFECTS OF ARBUSCULAR MYCORRHIZAL FUNGI (AMF) ON ABSCISIC ACID (ABA) METABOLISM AND CARBOHYDRATE METABOLISM IN CUCUMBER SEEDLINGS UNDER COLD STRESS

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The influence of symbiosis with Arbuscular mycorrhiza fungi (AMF; *Glomeromycota*), *Rhizophagus irregularis*, on cucumber growth, carbohydrate content, function of the photosynthetic apparatus, ABA content and expression of ABA metabolism were studied under cold stress. AMF alleviate the damage of cold stress by decrease the content of some carbohydrate and H_2O_2 in plant leaves and increasing root dry weight, net photosynthetic rate and chlorophyll. Cold stress reduced photochemical quenching parameters, including maximum photochemistry efficiency of photosystem II, quantum yield of linear electron flux, coefficient of photochemical quenching (qP), and de-epoxidation state of the xanthophyll cycle, but elevated non-photochemical quenching (NPQ). Concentration of ABA was not increased in inoculation plants, the genes of *NCEDs* may plan more important role in the ABA metabolism. These results indicate that AMF can alleviate the growth inhibition caused by cold stress in a complex way.

S17-P26:
AN INTEGRATED SIMULATION AND DECISION SUPPORT SYSTEM FOR GREENHOUSE CLIMATE CONTROL (InfoGrow 2.0) BASED ON AN OPEN SOURCE GREENHOUSE MODELLING PLATFORM

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Infogrow 2.0 is a model-based multi-source decision support system for energy and production management, which can help greenhouse nurseries continue to increase the energy efficiency achieved over the past years. So far, energy savings are the result of investments in energy saving measures, production of less heat consuming cultivars and, to some extent, the use of energy saving climate control regimes and simple or model-based decision support systems. Building upon the latter, the next step is optimizing model-based decision support through new compilation of models and introduction of data from new data sources (e.g. production planning and weather data). This system integrates existing tools for on-line monitoring of resource use and plant growth (InfoGrow) with a greenhouse simulator (Virtual Greenhouse), which simulates the effects of physical changes in the greenhouse and changes in climate control. In this paper, we present the overall concept of the integrated simulation and decision support system, showing the workflow of the different components in the system and presenting a design example of the user interface.

S17-P27:

VEGETABLE EXTENSION CENTER CULTIVA UCHILE, AN INDUSTRY-UNIVERSITY-GOVERNMENT PARTNERSHIPS MODEL

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In a context of knowledge-based economies, a key factor for regional development are the new institutional arrangements that allow the interaction of virtuous channels, between private actors (industry), government and universities. These interactions can be considered in themselves as a social innovation if they are framed in models such as the Innovation Triple Helix. This model tends to generate a climate and attitudes that allow coordination between industry, government and academia to create an environment of innovation that allows the development of emerging companies. In this context, the role of the Academy faces new challenges to its traditional role of generating knowledge and training, developing a more effective role of transmission and collection of innovation opportunities for the private sector, but also being a link between the government and the private company. The Vegetable Extension Center of the University of Chile, represents an example of implementation of this model, where in its two years of operation has positioned itself as a linker and facilitator among the actors of the vegetable industry of the Central Valley of Chile on the one hand and on the other hand, it has developed an extension methodology that allows to bring the knowledge generated from research centers in an applied way to respond to the productive needs. The lessons learned relate to the need to promote applied research, reinforce a spirit of collaborative work among the different agents and the need to include topics related to rural extension in professional training.

S17-P28:

MICROCLIMATE AND TOMATO PRODUCTION UNDER CANARIAN GREENHOUSE EQUIPPED WITH FLEXIBLE PHOTOVOLTAIC PANELS

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The photovoltaic greenhouses are mixed systems, combining the electricity and the agricultural production on the same surface area. Moreover, the photovoltaic greenhouse conserves all the properties of a conventional greenhouse, but in addition it offers the possibility of producing and reselling electricity.
The presence of the photovoltaic panels on the roof reduces the solar radiation received inside the greenhouse. However, the consequence of such decrease in the incident radiation on the fruit production and the greenhouse climate is still being discussed within this kind of agrosystem.
In this context, the aim of the present study is to assess the impact of the shadow caused by the photovoltaic panels on the microclimate and the tomato yield in the canarian greenhouse. Experimental measurements were carried out in experimental canarian type greenhouse covered with flexible photovoltaic panels on 10% of its total roof area. The PV panels were installed on the roof with a checkerboard pattern. We have chosen this configuration because it improves the unbalanced spatial distribution of the solar radiation received in the greenhouse.
Results illustrate that this occupancy rate of the flexible photovoltaic panels arranged in checkerboard pattern, does not have a significant effect on the microclimate and tomato production under canary greenhouses in the southern Mediterranean climate.

S17-P29:

USE OF BIODEGRADABLE AND COMPOSTABLE POTS FOR GREENHOUSE VIOLA X WITTROCKIANA PRODUCTION: EFFECTS ON PLANT GROWTH AND SHELF LIFE

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The use of biocontainers, made by biodegradable or compostable materials, is an effective solution for reducing the amount of waste plastic from greenhouse pot plant growing, an environmental problem especially for short-term crops e.g. annual bedding plants. Market research has shown that pots from recicled matetials, plantable or compostable, have a positive impact on green conscious consumers and their higher price is acceptable for the market niche of environmental friendly ornamental plants, currently increasing in Italyas well. The differences in physical properties of biocontainers, depending upon the used material, can however affect agronomic practices, quality of flowering pot plant and lenght of shelf-life in trolley. In the research five commercially available biocontainers, including pots made from 80% cedar wood fiber and 20% peat and lime (Fertil Pot), peat fiber (Jiffy), rice hull fiber with natural starch-based binder with solid or slotted side and bioplastic (PLA; D-grade) were evaluated for greenhouse production of *Viola* x *wittrockiana* 'Balto Eyed Yellow', in comparison to traditional black plastic pot (PP). Their diameter was similar (9-10 cm) but volume ranged from 300 to 460 mL for bioplastic and peat fiber, respectivelly, because of limited commercial availability. Biocontainers performed as well as the plastic control during greenhouse phase from transplanting to flowering, though different irrigation, on an as-needed bases. Plants in 80% wood fiber pots even showed a larger diameter (+ 10.3%) and a increased leaf surface (+28.0%) than control. Pot type did not influenced plant height (17.6 cm on average), flower numer and dry weight (3.6 and 0.44 g/plant). Only solid rice hull fiber pot seemed to have a negative influence on leaf dry weight and conversely a positive effect on shelf life. With this pot type leaf drying (leaf Ψ_w = 15-17 atm) occurred 2 days later than in plastic and bioplastic pots. Water retention of pots and substrate are reported.

S17-P30:

EFFECTS OF AIR CIRCULATION FANS ON THE ENVIRONMENTAL UNIFORMITY AND THE OIL CONSUMPTION IN A CUT ROSE GLASSHOUSE WITH A HOT AIR HEATING SYSTEM

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In this study, the effects of the number and location of horizontal airflow fans on the environmental uniformity in the nighttime and the oil consumption in a cut rose glasshouse (9.8 m wide and 34.1 m long) equipped with a hot air heating system were investigated. The rose plant rows oriented north-south. To distribute hot air from a hot air heater installed in a northwest corner of the glasshouse, the polyethylene ducts were installed on the floor between the plant rows. Hot air was exhausted toward the south from the outlet on a duct end. The hot air heater was operated by on-off control with a temperature set point of 17 °C. Different combinations of the fan (36 cm in diameter and 1.42 m^3/s in airflow rate) number up to five and the fan location were tested. The results of the horizontal air temperature distribution measured at a height of 1.5 m in the nighttime without the fans in operation showed that the average temperature in the north region of the crop space was 1.4 °C lower than the down stream region from the duct outlets. When two fans were operated in the locations adjacent to the south side of the glasshouse, the temperature difference between those regions was reduced to 0.5 °C. The vertical temperature variation with two fans was improved to 0.2 °C from 0.5 °C without fans. While the airflow velocity without fans was approximately 0.06 m/s throughout the crop space, the airflow velocity with two fans was 0.2-0.3 m/s, indicating that more number of fans might be required. The oil consumption increased linearly with increasing the nighttime heating degree-hour. It was surprising that the average oil consumption with fans was approximately 19 % greater than without fans at equal heating degree-hour.

S17-P31:
BLUE LIGHT DIFFERENTIALLY STIMULATES LEAF ANTIOXIDANTS IN BRASSICA VEGETABLES

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Brassica vegetables contain many antioxidants such as vitamin C, phenolic and flavonoid compounds. Light emitting diodes (LED) give to possibilities for a spectral control in urban farming and greenhouse conditions. An optimized spectrum offers possibilities to enhance the antioxidant content in leafy vegetables. We investigated the effect of an increasing percentage of blue in the light spectrum on leaf development, plant biomass and accumulation of antioxidant compounds in *Eruca vesicaria, Diplotaxis tenuifolia* and *Brassica rapa* subsp. *nipposinica* (mizuna). Seedlings were grown at ± 100 µmol $m^{-2}s^{-1}$, a photoperiod of 14 hours and a temperature of ± 20°C. Five combinations of red and blue LEDs were investigated, namely 100 % blue (B), 100 % red (R), B:R 25:75, B:R 50:50, B:R 75:25 and as control solar plasma lamps (24 % B and 26 % R. For *Eruca* 24-25% B resulted in the highest leaf area, while highest leaf area was obtained under 100 % red and plasma lamps for mizuna and the highest leaf area was found if the blue ratio was higher than 50% for *Diplotaxis*. However, leaf area and biomass were not strongly correlated. For *Diplotaxis* highest yield, pigment content and flavonoids were found for B:R 50:50, while vitamin C peaked at 100 % blue. For mizuna and *Eruca* the highest antioxidant levels were found under plasma lamps and under 100% blue. Light quality can be used to enhance the antioxidant content of the leaves but the reaction to a given spectral combination is clearly species dependent.

S17-P32:
POSSIBILITIES OF IMPROVING PRODUCTIVITY IN MEXICAN GREENHOUSES BY APPLICATION OF OPTIMAL CONTROL STRATEGIES

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Nowadays, roughly more than 70 % and 20 % of the Mexican greenhouses use low and medium technological levels, respectively. In order to increase yield, together with water and energy efficiency, better control strategies of the root and shoot environments are needed. That would imply the introduction of heating, CO_2 enrichment and active cooling systems. However, the use of those control systems would increase the investment cost. It has already been demonstrated, by simulation based on dynamic crop growth and greenhouse climate models, that high-tech greenhouses with glass cover, heating system, CO_2 and active cooling, can get the higher gross and net income, though the larger payback time. Thus, to explore possibilities of improving the productivity of Mexican greenhouses, while maintaining profitability of the whole system, in this work the optimal control approach is applied. In the dynamic optimization framework it is required to determine control variables in such a way that the dynamic system follows admissible trajectories which maximizes a performance measure. A basic assumption is the existence of accurate models of the crop system and the greenhouse climate. Until now, dynamic models of the greenhouse climate of Mexican greenhouses have been developed, analyzed and calibrated. Also dynamic models of typical greenhouse crops have been analyzed by sensitivity and uncertainty analyses and calibrated using experimental data. In the current work a two-state TOMGRO model is used. A suitable seasonal criterion for a greenhouse tomato crop can be the maximization of the income from selling marketable produce minus the cost of greenhouse heating and ventilation. Because in greenhouse cultivation there are constraints not only on the control variables but also on the states, the numerical solution of the optimal control problem has been tackled by using the method of orthogonal collocation which is available in the TOMLAB toolbox for Matlab.

S17-P33:
DEVELOPMENT AND EVALUATION OF THE SENSOR SYSTEM FOR MEASURING THE THERMAL AND AIR ENVIRONMENT IN GREENHOUSES

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Many combustion heaters and air-source heat pumps are used in Japanese greenhouses. Temperature in the greenhouse is controlled based on the value measured at one or two points in the greenhouse. Both heaters and heat pumps generate warm wind to warm air in the greenhouse. It is more difficult to keep air temperature uniformly in the greenhouse using the heaters than using hot water pipe lines. Therefore, in order to make the air in the greenhouse uniform by the heaters or heat pumps, the proper arrangement of air circulation ducts and fans, and adjustment of the air volume is required. However, methods for measuring the variation of air temperature in the greenhouse comprehensively and continuously have not been established. We have developed a small and accurate sensor system with low cost and easy installability. The system consists of two parts. One is a sensor to measure air temperature and humidity, the other is a telecommunication device with a photovoltaic cell (PV). The sensor is in a plastic 15 mm cube. The telecommunication device is in a box (45 mm x 90 mm x 12 mm), one surface of which is the PV. The measured value obtained every 1 minute is sent from the telecommunication device to a PC that is located more than 60 m away. In order to accurately evaluate the performance of the sensor system, 50 sensor systems were installed in a greenhouse (5000 m^2) in which tomatoes were grown and the temperature distribution was examined. Most of sensor systems worked well, however, some sensor systems did not send the data to the PC. The reason was thought to be that the power generation by PV was insufficient because particular spaces in the greenhouse had a short time of sunlight irradiation.

S17-P34:
STUDY ON THE CHANGES OF FRUIT CUCUMBER LEAVES AND PHOTOSYNTHESIS OF DIFFERENT POSITION LEAVES IN GREENHOUSE

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Adequate greenhouse plants management is very important for improving vegetable growth and development. To study the changes of unit leaf area quality, leaf length, leaf width, leaf area, leaf chlorophyll and carotenoids contents from the 1th to 15th leaves, and to study the changes of the air exchange parameters for different position leaves of fruit cucumber, a fruit cucumber variety Deltastar was grown in greenhouse in spring. The results showed that unit leaf area quality of cucumber gradually decreased from the 2th to 15th leaves. The cucumber leaf length, leaf width, leaf area changed as quadratic equation from the 1th to 15th leaves. The model equation which we had built for the changes of different leaf length, leaf width and leaf area can fit the measured data very well with R^2 values of 0.951, 0.925, and 0.952, respectively. From the 1th to 15th leaves, the leaf chlorophyll a, b and carotenoids contents increased first and after reached to the highest value, then decreased gradually. The cucumber net photosynthetic rate (P_n) in saturated light intensity also changed as quadratic equation from the 1th to 15th leaves. But the stomatal conductance (G_s) increased from the 1th to 12thleaves and then dropped from the 12th to 15th leaves. The intercellular CO_2 concentration (C_i) improved from the 1th to 15th leaves and the transpiration (T_r) enhanced from the 1th to 14th leaves. The experiment had concluded the leave changes and its photosynthetic capacity of different position leaves. The results of this study would help us better understand cucumber growth and development.

S17-P35:

TIME-DEPENDENT RESPONSES ON GROWTH AND PHOTOSYNTHESIS OF FIVE LETTUCE CULTIVARS GROWN UNDER CONTINUOUS LIGHT DELIVERED BY RED AND BLUE LEDs

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Five lettuce cultivars were hydroponically grown in an environmentally-controlled plant factory equipped with red plus blue LED lamps to analyze growth and photosynthesis in responses to light condition. All cultivars were subjected to two light treatments: normal light (12/12h, 240 μmol·m^{-2}·s^{-1}, NL) and continuous light (24/0h, 240 μmol·m^{-2}·s^{-1}, CL). The results showed that, compared with NL, CL significantly increased the fresh and dry weight of five lettuce cultivars in 15 days after transplant, while merely significantly improved the dry weight when transplanted for 30 days. The shoot dry weight ratio was significantly higher under CL, especially in 30 days after transplant. The chlorophyll contents of CL in all five cultivars were significantly higher than those of NL treatment in 15 days after transplant, while the chlorophyll content of CL declined when transplanted for 30 days except ‘Ziyue’ and ‘Zishan’ cultivars. The photosynthetic rate (P_n), stomatal conductance (g_s), intercellular CO_2 concentration (C_i) and transpiration rate (T_r) of four cultivars except ‘Lvluo’ cultivar grown under CL were significantly lower than those grown under NL in 15 days after transplant. The P_n of five cultivars and the g_s and T_r of ‘Yidali’, ‘Lvluo’ and ‘Ziyue’ cultivars were extremely decreased by CL in 30 days after transplant, but the C_i of ‘Dasusheng’ and ‘Zishan’ cultivars were significantly higher than that of NL. In short, the adaptability of five cultivars to CL was different and time-dependent, indicating that the adaptability to CL at harvest was significantly weaker at the early growth stage. ‘Lvluo’ cultivar was the most adaptable cultivars among five lettuce cultivars.

S17-P36:

SIMULATION AND OPTIMIZATION OF AIRFLOW AND TEMPERATURE IN PLANT FACTORY WITH ARTIFICIAL LIGHT BASED ON CFD

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Three cases of air ventilation and circulation systems were designed to improve velocity and temperature value and their uniformity. CFD (computational fluid dynamics) was applied to create a three-dimensional model, the whole plant factory was divided into grids and simulated. CFD model was validated through comparison of experimental data of the distribution of air flow and air temperature in a plant factory. The maximum absolute error, average relative error and root mean square error of wind speed and temperature are 0.12 m/s, 1.1 °C; 11% , 4 ‰; 0 1.3 °C, respectively, Case 0: control treatment, conventional air supply with upper (in the ceiling) air inlet and both side wall outlets; Case1: one side wall inlet, the other side wall outlet; Case2: one side wall inlet, the other side wall and upper outlet; Case3: both sides inlet, upper outlet. Results show that Case1~Case 3 could improve velocity and temperature value and their uniformity compared with Case0.By comparing wind speed and temperature value of plant canopy surface, Case1 increased average wind speed by 0.51 m/s, reduced coefficient of variation(CV) by 17% , reduced average temperature by 0.46 °C, was the best air circulation system in plant factory.

S17-P37:

NUMERICAL ANALYSIS AND PROPER DESIGN OF AN ACTIVE HEAT STORAGE AND RELEASE SYSTEM USING IN SOLAR GREENHOUSE

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This paper aimed to investigate an active heat storage-release system (AHS) using circulating water which was developed to supplement heat to raise air temperature in Chinese Solar Greenhouse (GSG) during cold winter. A numerical model was developed to predict its internal flow and the properties of heat transfer. And Model results agreed with experimental data after model simulation. The investigation results indicated that the introduction of baffles could strengthen the convective heat transfer process and lessen the radiation heat loss, which contributed to efficiency improvement. The influence of water flow rate, baffle number, baffle size, the thickness of water gap and the number of top film cover on the collector performance was also analyzed, and the results showed that as for a special scale collector, there existed an optimal baffle number and baffle size. The operating parameters such as the solar radiation intensity and surrounding temperature had significant influence on the water temperature rise but had little influence on the collector efficiency, which indicates that this kind of AHS could be applied in different kinds of solar greenhouses in a wide range of geographical latitude.

S17-P38:

PREDICTION MODEL ON AIR TEMPERATURE IN LARGE-SPAN GREENHOUSE WITH DIFFERENT ORIENTATION BASED ON CFD

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In order to increase the land utilization efficiency and decrease the necessary distance between two adjacent greenhouses to prevent shading, a south – north large scale greenhouse was designed substituting for conventional east-west direction greenhouse. To assess the performance of this type greenhouse a prediction model on temporal and spatial variation of air temperature based on the computational fluid dynamics (CFD) technique was established. The discrete ordinates (DO) radiation model was used to simulate the radiation heat transfer of the greenhouses. The solar radiation values were calculated by solar ray tracing method. In order to validate the effectiveness of the prediction model, the spatial and temporal distribution values of air temperature were measured and compared with the simulated data. The results showed that the errors between simulated and measured air temperature varied from 0.3 to 2.0 °C and the predi analyze the temperature differences in new type greenhouses with south-north and east-west direction at different

time. The simulated results showed that when at 10:00 am and 14:00 pm the average indoor air temperature difference in both greenhouses was very small. Despite both sides of the south-north direction greenhouse cover are lighting surface compared to the east-west greenhouse with only one side lighting surface. When at 12:00 the air temperature in south-north greenhouse was 2.8 ℃ higher than in the eastwest greenhouse. Relative standard deviation (RSD) was also used to evaluate climate uniformity based on the air temperature distribution. The data clearly showed that the south-north greenhouse with lower RSD values compared to the east-west greenhouse. It means that the south-north greenhouse with more climate uniformity.

S17-P39:

INVESTIGATION OF HIGH LIGHT-INDUCED OXIDATIVE STRESS FOLLOWING ROSE PLANT GROWTH AT DIFFERENT LIGHT SPECTRUMS

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Light is the original source of energy for plant photosynthesis. Plant responses to light depend on different attributes of intercepted light. Exposure to high light intensities causes damage to the photosynthetic apparatus. According to the intercepted light intensity, plants modify their metabolites and enzyme activities. To investigate the effects of prior exposure to different light spectrums on the high light-induced oxidative stress, after growth of rose plants under different light spectrums [including red (R), blue (B), 70:30% red:blue (RB) and white (W)], they were further exposed to a 12 h high light intensity (HL;1500 µmol m^{-2} s^{-1}). The results showed that superoxide dismutase activity was increased while ascorbate peroxidase and catalase activities were decreased following exposure to HL. This resulted in the accumulation of H_2O_2 following HL-exposure. The highest malondialdehyde (MDA) content was observed in RB-grown plants. Anthocyanin content was increased by HL-exposure; the highest anthocyanin content was observed in W-grown plants following exposure to HL. In conclusion, HL causes oxidative stress in rose plants and light spectrum during growth can influence the subsequent plant responses to the HL-induced oxidative stress.

S17-P40:

EFFECTS OF DIFFERENT INTENSITIES OF RED AND BLUE LIGHTS AND FAR RED LIGHT ON GROWTH, DEVELOPMENT AND PHOTOSYNTHETIC ELECTRON TRANSPORT OF LETTUCE (*Lactuca sativa*)

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Previous studies have demonstrated that combination of red and blue lights is the most effective light spectrums for plant growth and development in artificial growing environments. Light intensities can be controlled in artificial production of plants. In the current study growth, development and photosynthetic electron transport were investigated in lettuce (*Lactuca sativa*) plants exposed to different light spectrums and intensities. To do that, lettuce seedlings were grown under three different red (635-665 nm) and blue (450 nm) lights (75:25) treatments (RB). To study the effects of high light intensity plants were exposed to two different light intensities including 350 (RB) and 1400 µmol $m^{-2}s^{-1}$ [high light treatment (RB+HL)] and RB with Far red (RB+Fr) with a PPFD of 120 µmol $m^{-2}s^{-1}$. The highest leaf fresh weight and leaf number were observed in RB treatment, the highest root fresh weight and root volume were measured in RB+HL and the tallest plants were observed in RB+Fr. Absorption flux and energy trapping flux per reaction center were increased in RB+Fr, while they were decreased in RB+HL treatment. Quantum yield of electron transport was significantly lower in RB+HL than other treatments. Dissipated energy flux was

higher in RB+HL and RB+Fr than its value in RB plants. Performance index for energy conservation was highest for RB plants and was lowest for RB+HL plants. In conclusion, RB (70:30) is the best treatment for increasing photosynthetic performance and growth of lettuce plants. Continuous Fr would result in lower use of absorbed light by photosystems. HL condition would result in lower photosynthetic performance and lower yield in lettuce plants.

S17-P41:
EFFECTS OF FERTIGATION METHODS ON GROWTH, YIELD AND QUALITY OF SOIL CULTIVATED SWEET PEPPER IN SOLAR GREENHOUSE

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Water and nutrient managements are important techniques for protected vegetable cultivation. Long intervals between irrigations or fertilizations lead to imbalance between supply and vegetable demand for water and nutrients. To establish a new precision fertigation method, the experiments were carried out by six treatments: CK1-traditional furrow irrigation with periodic topdressing; CK2-conventional drip irrigation with periodic fertilization; T1- daily fertigation with 1/4 strength Yamazaki sweet pepper nutrient solution; T2-daily fertigation with 2/4 strength nutrient solution; T3-daily fertigation with 3/4 strength nutrient solution; T4-daily fertigation with 1 strength nutrient solution. Universal formula of trace elements was used in T1-T4. The volume of nutrient solution supplied in T1-T4 was variable depending on growth stages and greenhouse environments. The results showed that: Compared with CK1 and CK2, daily fertigation promoted growth of soil cultivated sweet pepper, increased plant height and dry matter weight in both shoot and root, and the length, surface area, volume, apex number and activity of roots were significantly higher; Daily fertigation with 2/4 strength nutrient solution resulted in most fruits and highest yield, increasing by 31.11 % and 22.44 % for winter-spring crop when compared to CK1 and CK2, and by 35.52 % and 16.29 % for autumn-winter crop, respectively, fruit quality was also improved; Compared to CK1 and CK2, fertilizer application of T2 was reduced by 59.71%, irrigation water was saved by 30.92% and 12.51% for winter-spring crop; 64.59%, 25.83% and 9.45% respectively for autumn-winter crop.

S17-P42:
EFFECT OF DIFFERENT GLASS GREENHOUSE COVERING MATERIALS ON BASIL AND MINT PRODUCTION AND QUALITY

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The covering material used on a greenhouse is essential to provide a suitable environment for plant growth. Glass has long been one of the most widely used material in greenhouses but there are increasing attempts to replace it by other cladding materials. This survey focuses on how four different glass cover materials affect the growthand production of basil (*Ocimum basilicum*) and mint (*Mentha piperita*) plants which are both of high economic importance due to their powerful antioxidant capacity. The experiment reported in this study was conducted in four small scale-structures covered with either floatglass or three low-iron soda glasses with different anti-reflectance coatings (Interfloat Corporation, Ruggell, Switzerland), yielding different patterns of light scattering. The mini-greenhouses were arranged in a randomised block design with four replications per cladding material. Six basil and six mint plants grown in pots with soil and sand substrate respectively, were included in each mini-greenhouse. Three different doses of manganese (0.0, 1.0, 2.0 ppm) were imposed in the mint plants for several days. Non-destructive measurements (plant height, leaf nitrogen balance index and chlorophyll content) were performed. The antioxidant activity of the leaves was also quantified. Furthermore, another aspect that was tested was the effect of the excess of

manganese treatment on the monoterpene content of the mint plants. This works aims to provide more insight into the modification of the greenhouse claddings and their impact on crop productivity.

S17-P43:
EXPERIMENTAL CULTIVATION OF PEPPERS IN GREENHOUSES INTEGRATED PHOTOVOLTAICS (GIPV)

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Energy demand of greenhouses is an important factor for their economics and photovoltaics (PV) can be considered an alternative solution to cover their electrical and heating needs. On the other hand, Infrared (IR) radiation heating systems possess the advantage of high directional control and focused compensation of energy losses, appropriate for creating local temperature conditions in open or thermally unprotected spaces resulting in an overall reduction of heat losses and consequently heating energy needs. The objective of this research is to develop a low energy demand greenhouse by using IR heating and the cover of remaining energy needs by the installation of PV panels on the greenhouse's roof. Also, to investigate the effect of PV panels induced partial shading on growth parameters and physiological characteristics of plants. Experimental results are presented from a full cultivation period inside two greenhouses, with and without PV correspondingly. Pepper (California Wonder L.) is used as the test crop for a three months period. The results include electrical energy output, radiation fluxes (incoming solar radiation and PAR) and temperature and plant growing. Results are compared to conventional cultivation. The design and energy performance of the above PV installation modes is analyzed and results are presented.

S17-P44:
MICROCLIMATE AND CUCUMBER CROP TRANSPIRATION IN A GREENHOUSE COOLED BY PAD AND FAN SYSTEM

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The microclimate and cucumber soilless crop response in an evaporativelly cooled greenhouse were studied in Cyprus during spring. Measurements were carried out in two greenhouse compartments: (1) a compartment where a wet pad and fan system for evaporative cooling of the greenhouse environment was operated and (2) a compartment where greenhouse cooling was performed by means of forced ventilation. Compared to forced ventilation, evaporative cooling reduced mean air temperature by about 7.5ºC and maintained greenhouse air temperature below 28ºC, while mean air temperature without cooling reached values higher than 34ºC. Furthermore, evaporative cooling reduced air vapour pressure deficit by about 60% and maintained mean greenhouse air vapour pressure deficit below 1.6kPa. In addition, evaporative cooling resulted in an about 4ºC lower leaf temperature values compared to the case of forced ventilation. The cucumber crop transpiration rate was about 20% higher in the compartment cooled by forced ventilation than in the one with evaporative cooling. Finally, it was estimated that the crop stomatal conductance was about 25% higher for the crop cooled by the evaporative cooling system than the crop cooled by forced ventilation.

S17-P45:

THE MICROCLIMATE IN A MONO-SPAN GREENHOUSE UNDER COASTAL CONDITION OF WESTERN INDIA AND ITS EFFECT ON BIOTIC STRESS IN CUCUMBER

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Forcing vegetable production under inclement conditions of moderately high temperature and high humidity is the focus of research under greenhouse structures for the western coast of India. Modified tunnel type greenhouses are an option for the small farmers to produce vegetables during the long monsoon. The microclimate under a 12^{o} NE-SW oriented, mono-span, naturally ventilated greenhouse (200 sq m area, 4.5 m ridge height), with continuous screened vents along roof ridge, sides and southern end was analysed in empty condition and with Cucumber crops from 2014 to 2016 . The results indicated that apart from being a good rain shelter, the structure marginally improved the microclimate in the greenhouse, but the high humidity could not be controlled under naturally ventilated conditions. Significant velocity reductions at the centre of the structure as compared to ambient (on west -up to 26% with crop, up to 31% without crop and on East up to 80.32% with crop and up to 33.33% without crop). Significant gradients in temperature and humidity were recorded across the structure. The introduction of horizontal axial flow fans improved the homogeneity of the temperature and humidity but still failed to reduce the humidity which during the monsoon season had a maximum value between 92-94.7% and minimum 43.5-91%. Reasonably good production was achieved inside the greenhouse (1.35-2.2 kg/plant yield). The biotic stress events *viz*., foliar disease and pest incidence in the crop were regressed against daily maximum and minimum greenhouse temperature, humidity and dew point temperature using stepwise multiple logistic regression and result showed that daily minimum temperature, maximum RH and minimum dew point temperature ($p < 0.01$) were having significant influence on disease development. The R^2 of the model was found to be 0.47 ($p < 0.01$). The reason behind the moderate R^2 value may be due to the effect of other soil related variables like soil reaction, soil moisture content which have significant influence on disease development and not included in our study. Modified tunnel type mono-span greenhouses provide a scope for crop production under western coast of India, but need to be tested under fan ventilated conditions for better microclimate.

S17-P46:

EFFECTS OF ARBUSCULAR MYCORRHIZAL FUNGI ON MICROBIAL COMMUNITY AND FUNCTION IN THE RHIZOSPHERE SOIL OF CUCUMBER PLANTS

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Microbial population and function, physical and chemical properties, as well as enzyme activity in rhizosphere soil of cucumber (*Cucumis sativus* Linn, “Zhongnong 26”) seedlings inoculated with arbuscular mycorrhizal fungus (AMF) *Funneliformis mosseae* were investigated under sterilized pot experiment condition in solar greenhouse. The result showed that, the population density of bacteria and fungi in the rhizosphere soil of AMF-inoculated plants was significantly higher than that in the soil of untreated plants (CK). The population density of actinomycetes in the experimental soil was lower than that in CK; on the contrary, Rhizosphere microbial functional diversity analysis showed that the average color change rate (AWCD), Simpson index and Mclntosh index in the experiment soil were significantly lower than those in CK. AMF inoculation could improve the available nutrient content, physical properties of soil, and phosphatase, aminopeptidase and oxidase activity of soil. RDA analysis showed that there was a positive correlation between fungal infection rate and available P content (r=0.65, properties and soil enzyme activity through improving microbial community and function of the rhizosphere soil of cucumber.

S17-P47:

EFFECTS OF CUCUMBER YIELD, QUALITY AND SOIL FERTILITY RECOVERY BY ADDING DIFFERENT CROP RESIDUES INTO ORGANIC SOIL SUBSTRATE WITH CONTINUOUS CULTIVATION IN SOLAR GREENHOUSE

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Organic soil substrate composed of straw, manure and field soil, which physical and chemical properties become better than field soil. The decline changes of organic soil substrate can be found with the cultivation years increasing. By add vegetable residue or crop straw to organic soil substrate, the effects of soil fertility recovery and cucumber growth were measured. The results showed that by adding vegetable residue into continuous organic soil, the cucumber plants grow better than CK and adding crop straw organic soil, which increase leaf area, cucumber yield and nutrient quality. So it is possible to adding vegetable residue into soil to recovery soil fertility after continuous vegetable cultivation.

S17-P48:

EFFECTS OF LIGHT QUALITY MODIFIED BY DYE-SENSITIZED SOLAR CELLS AND LIGHT-EMITTING DIODES ON GROWTH AND DEVELOPMENT OF COLEUS AND LISIANTHUS

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Dye-sensitized solar cell (DSSC) can be applied as a greenhouse covering material because it is translucent with various colors and produces electricity. However, light quality under DSSC is different to that of natural sunlight and its transmittance of visible light is low. Therefore, we compared the growth and physiological responses of coleus and lisianthus, very sensitive plants to light condition, under transparent glass and red-colored DSSC. Coleus and lisianthus seedlings were grown in transparent (T, the control), shading (S), and DSSC (D) chambers maintained at 23±2 °C and [illegible] white (W), B+G, and R+B+W colors for 16 hours from 06:00 to 22:00 with 60 μmol·m^{-2}·s^{-1} PPFD. In both plants, S and D reduced number of leaves, chlorophyll content, fresh and dry weights compared with the control (T), whereas increased plant height and leaf size. Supplemental lighting using LEDs with higher portion of blue light such as B, B+G and R+B+W increased number of leaves, chlorophyll content, fresh and dry weights compared with D, whereas green LED lighting in D chamber increased plant height, leaf size and shoot growth. In conclusion, coleus and lisianthus plants grown under DSC had stretched stems and less leaves, and lighter biomass compared with T. Supplemental lighting by LEDs with blue wavelength under DSC improved growth and plant quality.

S17-P49:

FARM SCALE STRATEGIES FOR REDUCING THE ENVIRONMENTAL FOOTPRINT IN INTENSIVE CROP PRODUCTION SYSTEMS

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The present economic situation in European crop production forces producers to focus on improving efficiency in order to increase their competitiveness. Among the important factors in achieving improved efficiency is the

provision of an optimal building environment with low Greenhouse Gases (GHGs) emissions. In paper we present our recent research efforts and ongoing projects results aiming to assess the environmental footprint of greenhouse and other intensive crop production systems through a sustainable reduction of released air pollutants and GHGs along with a decrease in energy consumption. This has been achieved through efficient design of the greenhouse facilities construction and selection of appropriate electromechanical (E/M) systems, through the energy demand reduction and through the use of innovative emission reduction technologies. The paper is focused in the follow areas:

Microclimate: The internal microclimate in greenhouses can be controlled either passively by natural ventilation building systems wherein appropriate construction geometry and materials are designed prior to construction or actively by the ventilation system and electromechanical equipment operation during building operation. Therefore, an important requirement is to examine the effect of the above parameters on the internal microclimate and consequently on the final concentration of the air pollutants and GHGs from the greenhouse and to determine best practices and designs that will eventually contribute to better air quality.

Modelling approach: Numerical modelling techniques such as Computational Fluid Dynamics (CFD) can offer an effective way of accurately quantifying the influence of structures/machinery design, environment parameters and weather conditions within a virtual environment. Such a tool is used in order to assess the influence of different structural specifications and designs on internal environmental of a greenhouse.

Environmental footprint assessment (LCA): An agricultural activity is considered to be ecologically sustainable if its polluting emissions and its use of natural resources can be supported in the long term by the natural environment. The first step in the assessment of ecological sustainability is assessment of its environmental impact. A cradle-to-farm-gate' Life Cycle Assessment approach was applied in order to examine the effect of alternative systems (mainly on the water and nutrient supply) on the Carbon Footprint in a greenhouse crop.

S17-P50:
PLANT GROWTH REGULATION BY ROOT-ZONE TEMPERATURE CONTROL USING NEW ROOT-ZONE ENVIRONMENTAL CONTROL SYSTEM (N.RECS)

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The new root-zone environmental control system (N.RECS) was developed by combining floor heating panels, an air-source heat pump cold/hot water supply system, and heat-insulating pot container. N.RECS has 2 modes, which are heating and cooling modes of root-zones. The heating mode was able to maintain the root-zone temperature at 25°C at a 10°C air temperature during the winter season, and the cooling mode could provide a 23°C root-zone temperature at a 40°C air temperature during the summer season.

The effects of root-zone heating during the winter season on growth and flowering in Tuberous begonias (*Begonia* × *tuberhybrida*) were investigated. The plants were grown in plastic houses with minimum air temperatures/root-zone temperatures of 16°C/non-heating and 12°C/24°C. The growth and flowering of plants cultivated at 12°C/24°C was promoted compared with that of 16°C/non-heating. The cost of the consumption of energy for heating was estimated to be 32% lower at 12°C/24°C compared with that of 16°C/non-heating. Cyclamen (*Cyclamen persicum*), with poor heat tolerance, was used to investigate the effects of root-zone cooling on growth and flowering. When the plants were cultivated at 20 °C cooling of the root-zone during the summer season, the growth and flowering was promoted compared with that of non-cooling. Thus, it is indicated that N.RECS is useful for the growth regulation of pot flowers year round.

S17-P51:
ESTIMATION OF WATER STRESS IN TOMATO AND CUCUMBER SEEDLINGS USING THERMAL IMAGING

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The temperature during nursery period affects the growth and development of crops such as flower breeding, photosynthesis, and absorption of inorganic nutrients. Leaf temperature is closely related to plant photosynthesis, rate of evaporation, and stomatal resistance. Therefore, studies have been conducted to estimate the amount of evaporation and to analyze the stress of crops using leaf temperatures of crops, and to utilize them for irrigation of crops. The purpose of this study was to obtain the thermal image of tomato and cucumber seedlings and to estimate the water stress by measuring leaf temperature by thermal image analysis. Thermal images were taken continuously on the top of plug tray using an infrared camera (A325sc, FLIR systems USA), and the images were stored in a notebook at 1 minute intervals. Moisture stress was estimated by the difference between leaf temperature and temperature. Experimental results show that there is a strong correlation between leaf temperature and water stress. The leaf temperature of a crop is related to various factors such as solar radiation, temperature, humidity, wind speed, and stomatal aperture as well as soil water contents. Therefore, the study including the other factors should be carried out in next experiment.

S17-P52:
LIGHT AND NITROGEN CONTROL FOR GROWTH OF DORITAENOPSIS QUEEN BEER `Mantefon´

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Light and nitrogen control is needed to increase leaf growth and flowering quality under CO_2 enriched conditions. To investigate the effect of nutrient and light control under CO_2 enrichment, plants were placed in growth chamber under 150 μmol·m^{-2}·s^{-1} PPF (LL) and 300 μmol·m^{-2}·s^{-1} PPF (HL) with different nitrogen content of 20N (200 ppm N, 200 ppm P, 200 ppm K), 40N (400 ppm N, 200 ppm P, 200 ppm K), 60N (600 ppm N, 200 ppm P, 200 ppm K), or 80N (800 ppm N, 200 ppm P, 200 ppm K) in *Doritaenopsis* Queen Beer 'Mantefon' under 800 μmol·mol^{-1} CO_2 enriched condition. Plant leaf initiated more under HL compared with LL condition in the plants watered with 40N, 60N, and 80N. Leaf size of new leaf increased more in the plants grown under HL than the plants grown under LL, regardless of nitrogen content. Photosynthetic rate (P_n) was higher in the plants grown under HL than the plants grown under LL, regardless of nitrogen content. Plants watered with 20N and 40N had the highest P_n under HL. No significant differences were observed between light intensities in minimum saturating irradiance, F_v/F_m, Φ_{PSII}, qP, qN, and ETR, regardless of nitrogen content. Plants grown under HL with 20N or 40N enhance growth and photosynthetic characteristics of *Dtps*. 'Mantefon' under 800 μmol·mol^{-1} CO_2. This work was carried out with the support of "Cooperative Research Program for Agri. Sci. & Tech. Dev. (Project No. PJ012069)" Rural Dev. Admin. and a grant (NRF-2015R1C1A1A02037704) from Nation Res. Fdn. of Korea.

S17-P53:

PHOTOSYNTHETIC PHOTON-FLUX DENSITY DISTRIBUTION MEASUREMENT IN CULTIVATION SHELVES IN ARTIFICIAL-LIGHT'BASED PLANT CULTIVATION

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In recent years, Japan, South Korea and China have seen an increase in vegetable production in plant factories that use LEDs as the main light source. In many plant factories that use artificial lights, cultivation shelves are equipped with LED-based illumination and a hydroponics system. The plant grower needs to correctly measure the distribution of the photosynthetic photon-flux density (PPFD) of the cultivation area of each cultivation shelf. Because plant cover rate varies according to the cultivation stage, the spectral reflectance and PPFD on the upper surface of cultivation panels change considerably. Although PPFD measurement of cultivation shelves is performed only in the vertical direction, plants are irradiated with LED light not only along the perpendicular direction but also along other axes. We assembled a PPFD sensor that can perform simultaneous measurements along five axes (perpendicular, before, after, left, right), and measured the maximum and minimum PPFD, for which a white panel and a black panel were used, respectively. We first performed measurements on a cultivation shelf in which only the ceiling was equipped with LEDs. For the case with the black sheet, the horizontal PPFD was found to be 40% of the perpendicular PPFD or lower. For the case with the white panel, owing to reflection, the perpendicular PPFD increased to approximately 15% and the PPFD of the inner sides of the measurement space increased to approximately 45% of the horizontal PPFD. Next, we performed measurements on a cultivation shelf in which both the ceiling and the sides were equipped with LEDs. The horizontal PPFD increased owing to the effect of the side LEDs, and it was shown that strong direct light reaches by arranging especially below the side. We also discuss the measurement result obtained using the five-axis PPFD sensor on vegetable cultivation conditions.

S17-P54:

PHOTOSYNTHETIC PERFORMANCE OF CUCUMBER TRANSPLANTS ACCLIMATIZED TO LIGHT WITH HIGHER RED TO FAR-RED RATIO THAN SUNLIGHT

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Transplant quality should be evaluated based on the plant’s growth potential, including photosynthetic ability, after transplantation. The growth potential is strongly affected by eco-physiological responses to physical environmental factors. In transplant production, controlling the environmental factors might therefore improve the growth potential of transplants. Light is one of the most important factors for eco-physiological acclimatization of plants. This study investigated the effect of the red to far-red ratio (R:FR) of light, which is known to be involved in shade-avoidance responses, on the photosynthetic performance of cucumber (*Cucumis sativus*) transplants. The cucumber seedlings were acclimatized to light with high or normal (similar to sunlight) R:FR, and then their photosynthetic properties were compared. The maximum photosynthetic rate of leaves acclimated to high R:FR was greater than that of the normal leaves. The heightened photosynthetic ability of the high-R:FR leaves reflects physiological and morphological responses that are opposite to those that are typical of shade avoidance and tolerance. This acclimatization may be advantageous when plants are to be transplanted under high light intensity. On the other hand, high-R:FR illumination inhibits leaf enlargement and subsequent whole-plant growth during acclimatization. This indicates that the high-R:FR seedlings took a long time to equal the size of the normal-R:FR seedlings, despite their increased photosynthetic ability. Thus, there may be a trade-off between growth rate during transplant production and photosynthetic performance after transplantation. In selecting light quality for transplant production, growers may need to consider which of the two advantages is most important.

S17-P55:
ENVIRONMENTAL CONDITIONS INFLUENCE THE OVIPOSITION RATE OF THE TWO-SPOTTED SPIDER MITE THROUGH HOST-PLANT RESPONSES

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The two-spotted spider mite (TSSM), *Tetranychus urticae* Koch, is the most important tetranychid pest in greenhouse cultivation and attacks many horticultural crops. Predicting its occurrence is therefore important for effective pest management, particularly because of its rapid reproduction. Many studies have investigated the relationship between environmental conditions and TSSM reproductive behaviors. Environmental conditions can also influence TSSM behavior indirectly through host responses. For example, oviposition can increase through an increase in the host leaf's trichome density at low humidity. In this study, we hypothesized that light intensity and CO_2 concentration would influence the oviposition rate of TSSM through the host plant's responses, and particularly through changes in leaf mass per unit area (LMA), which is positively correlated with TSSM reproduction. We grew cucumber seedlings at different combinations of light intensity and CO_2 concentration in growth chambers until the first true leaves expanded. Adult TSSM females were released on the adaxial surfaces of leaf squares cut from the first true leaves, and held under the same conditions. Eggs were counted every 24 hours for 4 days after release. Leaf squares were also cut to evaluate LMA and trichome density. The oviposition rate of TSSM, and the LMA and trichome density of host leaves, tended to increase with increasing light intensity and CO_2 concentration. A linear regression model with oviposition rate as the dependent variable and LMA and trichome density as independent variables shows that both variables significantly influenced the oviposition rate. These results indicate that higher light intensity and higher CO_2 concentration, which can both promote plant growth, indirectly increase TSSM oviposition through increased LMA and trichome density of the host plant's leaves.

S17-P56:
A PRELIMINARY STUDY ON LEAF YELLOWING SYMPTOM IN GRAFTED EGGPLANT

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Leaf yellowing symptom observed in the eggplant grafted in to rootstock in Sichuan province in last few years, which caused considerable yield loss. According to the symptoms of grafted seedling in the fields and the preliminary results of the soil and plant samples, it was considered lack of magnesium. In order to investigate the cause of symptom, four treatments with combining base fertilizer with magnesium fertilizer on leaf on self-root and grafted eggplant were performed. In this study, *Solanum melogena* cv.tianjiao was grafted on *Solanum torvum*. And magnesium contents of self-root eggplant at the different position leaves as control and grafted eggplant were tested at three different fruit development stages. The results showed that magnesium content and change trend in leaves were completely different between self-root eggplant and grafted eggplant during the different periods. Under the same treatment conditions, magnesium content of self-root eggplant was always significantly higher than grafted eggplant in different position leaves at different stages. Magnesium content in grafted eggplant leaves presented a tendency to drop sharply at the full fruit period, which in self-root eggplant was opposite to it. And the gap continued to widen until fruit gained end stage. The self-root eggplant had higher magnesium contents by treated with magnesium fertilizer than those contents in the self-root seedlings without magnesium treatment, but it were not found in the grafted plant. In addition, treatments of magnesium fertilizer didn't effectively improve the leaf yellowing symptom in grafted eggplant. According to the results, we presume that the grafting affects the absorption, translocation and utilization of magnesium, which lead to magnesium deficiency, and eventually cause leaf yellowing symptom in grafted eggplant.

S17-P57:
GOOD AGRICULTURAL PRACTICES IN GREENHOUSE CROPS

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In many regions of the world, and parallel to the development of economic activities in these countries and of the international trade of their agricultural products, greenhouses are increasingly used for vegetable production as well as for cultivation of ornamental plants, due to their ability to allow a qualitative and quantitative control of production through a direct management of the growing environment. Especially in these areas, where seasonal excursions of temperature are almost negligible and no need exists for artificially heating protected crops, greenhouses may be realized with relatively simple means, which allow obtaining higher yields with comparatively modest investments. Compared to similar situations in regions of the temperate areas of the world, greenhouse productions face a series of totally different challenges in tropical and subtropical regions. First of all, high temperatures often represent a limiting factor for vegetable protected cultivation and, if heating the greenhouses is not necessary in these areas, cooling may become a priority. Therefore, site selection and correct orientation of the greenhouses become important choices, in order to manage positively the incidence of solar radiation and the flow direction of prevailing winds. Ventilation capacity of the greenhouses is also a critical factor, aimed at reducing the humidity and temperature inside the structure. Through a control of environmental factors and the application of simple methods for achieving a mechanical exclusion, greenhouses also play an important protective function from many biotic agents (pests and diseases) attacking vegetable crops and reducing their production. Promotion of greenhouses is considered as a component of a broader approach for 'Integrated Production and Protection Management' (IPPM), with the final objective of reducing the spraying of pesticides and increasing quantity and quality of crop production all year round. Pests and diseases management in greenhouse crops is probably the practice with the greatest impact, not only on the environment and consumer's health, but recently, also on public opinion in many countries. Due to the increasing development of protected cultivation (especially for vegetables), crops are becoming progressively susceptible to pests and diseases for multiple reasons, including monoculture cultivation and the use of selected cultivars with high yields, which may also stimulate pest/disease development. Therefore, various new control methods are being developed to face the increasingly aggressive pests and diseases, and new management practices are being incorporated into the production systems.

S17-P58:
SPECTRAL EFFECTS OF LEDs ON GROWTH, MORPHOLOGY, PIGMENTATION AND CHLOROPHYLL FLUORESCENCE IN BASIL, CORIANDER AND OREGANO

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The aim of the study was to evaluate the growth and physiological status of green basil 'Genovese', red basil 'Basilico Rosso' (*Ocimum basilicum* L.), coriander (*Coriandrum sativum* L.) and oregano (*Origanum vulgare* L.) cultured in greenhouse under different spectra of LED lighting and the same PPFD (200 µmol/m^2 s) at plant height for 12 h per day. Four LED light treatments with different colors mixing blue, green, red and far-red, including G (high blue and high red), LV (high blue, high green and low red), S (low blue and high red) and F (low blue, high red and far-red) were used. The experiment was held for 9-12 weeks during the period from November 2017 to January 2018. Total biomass was the highest under LV for green basil, under S and F for coriander and under LV and F for oregano, and the lowest under G treatment. Red basil showed no significant differences in biomass production under varied light spectra. Plants grown under G and LV treatments (high blue light share) had reduced internode length and more compact growth compared to S and F treatments (high red or far-red share). The chlorophyll biosynthesis was favored under G and LV treatments for green basil and coriander and under G and F treatments for oregano. Photosynthetic activity of plants was overall higher under G and LV than under S and F treatments. The maximal photochemical activity (Fv/Fm) of plants grown under G and LV was significantly higher (0.76) than under S and F (0.73) treatments, which indicated a permanent downregulation of PSII in the red and far-red treatments. Our results

have also shown that the potential efficiency of photosynthetic apparatus (Yield) of plants grown under G (high blue and high red) treatment was overall 15% higher than under other treatments.

S17-P59:
THE INFLUENCE OF A SOLAR AIR COLLECTING WALL COMBINED WITH PHASE CHANGE HEAT EXCHANGER ON THE GROWTH AND YIELD OF TOMATO IN CHINESE SOLAR GREENHOUSE

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A solar energy collecting/storage system contributes to the diurnal thermal performance of greenhouse for the off-season tomato production was discussed. At the northern latitudes of China, although the solar radiation levels may be acceptable on plant growth, high thermal load during the winter result in poor temperature environment in greenhouses. A flat-plate solar air collecting wall combined with a heat exchanger filled with phase change materials have been used as a solar collecting/storage system, a series of pipes near the root region were set for heat releasing during the night. Tomato plants were cultivated on coir slab grow-bags. Another greenhouse chamber was set without heating as a control treatment. During the period of observation (November 2017-April 2018), microclimatic data were recorded concerning the: 1) air temperature and humidity, 2) temperature of the root region, 3) intensity of solar radiation. Also, the following plant growth parameters were measured: a) tomato plants growth rate, b) total number of tomato fruits per truss and c) total yield, for both greenhouses. The solar heating system leads to a higher room temperature and higher soil temperature. The improvement of the microclimate conditions also showed significant improvement on tomato growth yield and the quality.

S17-P60:
DEVELOPMENT OF METHOD TO IMPROVE FRUIT SETTING RATE FOR STABLE PRODUCTION OF MIDDLE AND SMALL TYPE SEEDLESS WATERMELON

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The preference of consumers on middle and small-sized seedless watermelon is rising due to increase of nuclear family. Seedless watermelon is resistant to high temperature compared with diploid general watermelon. Therefore, farmers tend to prefer seedless watermelon in high temperature season. However, there is a disadvantage that the fruit setting rate falls because of strong plant vigor. The aim of this study was to improve the productivity of seedless watermelon by developing method to increase the fruit setting rate and studying the optimum planting distance. 2 cultivars which are sold in the domestic market were used; ‘Uniquegem’(Bayer), ‘Style’(Bayer). The planting date was June 20. The treatment (topping) to increase the fruit setting rate was cutting the stem growth point before the third female flower is bloomed. The planting distance was 25, 30, 35, 40cm. As a result, in the non-treatment (non-topping), the fruit setting rate of ‘Uniquegem’ and ‘Style’ were 15.6%, 24.4%, respectively. On the other hand, in the treatment (topping), the fruit setting rate of ‘Uniquegem’ and ‘Style’ were 84.4%, 93.3%, respectively. Since the plant vigor of seedless watermelon is strong in the high temperature season, there is a lot of the amount of photosynthate translocation near the growth point. Therefore, it is considered that the growth of the embryo is inhibited because the assimilation products can not migrate to fruits. Also, the wider planting distance, the better the growth of plant and fruit weight. Although each variety showed differences, in the fruit setting rate, ‘Uniquegem’ was the highest when planted at a 40cm spacing and ‘Style’ was the highest when planted at 30 cm spacing. These results suggested that when growing seedless watermelon in high temperature season, it is possible to improve the productivity by cutting the stem growth point and setting the planting distance to 30~40cm.