1 Sweet pepper year round production with artificial light, Wageningen UR Greenhouse Horticulture
2 Gerbera flower with ultra-small temperature and humidity sensor, Wageningen UR Greenhouse Horticulture
3 Cucumber production with Light Emitting Diodes (LED), Wageningen University Horticultural Supply Chains
4 Anthurium production with High Pressure Sodium light (HPS), Wageningen UR Greenhouse Horticulture
5 Gerbera year round cut flower production with artificial light, Wageningen UR Greenhouse Horticulture
6 Spathiphyllum year round pot plant production with artificial light, Wageningen UR Greenhouse Horticulture
Proceedings of the 7\textsuperscript{th} International Symposium on Light in Horticultural Systems (ISHS Lightsym2012)

Convenors
S. Hemming
E. Heuvelink

14\textsuperscript{th}-18\textsuperscript{th} October 2012
Wageningen, The Netherlands
FOREWORD

The 7th International Symposium on Light in Horticultural Systems has been organized by Wageningen University and Research Centre in Wageningen, The Netherlands, from 14 to 18 October 2012. More than 180 symposium participants come from 27 countries involving scientists, greenhouse industry, advisors and growers.

Light plays an important role in market-oriented greenhouse production. Products have to be ready for the market on time with the desired volume and quality. In order to meet with these requirements, an optimal use of light as one of the most important production factors is of utmost importance. Natural light is free and its utilization in greenhouse horticulture is necessary for sustainable crop production. The addition of supplementary artificial light however, will remain necessary in several regions of the world. By manipulating light we are able to control and steer crop growth and development. Changing the factor light has a large impact on the total production system: microclimate and energy consumption are influenced, costs and benefits are affected. Research on light in horticultural systems is necessary for a sustainable and market-oriented greenhouse production in the future.

The symposium includes three days of scientific presentations, among which 7 invited speakers, 4 selected company presentations, 42 oral presentations and 129 poster presentations. During an one day excursion three different tours to modern greenhouse production facilities in different regions of The Netherlands are organized. We visit growers with artificial light, with modern LEDs, our research station in Bleiswijk and our research labs in Wageningen. All tours are combined with a touristic highlight in that region.

We hope that you all enjoy your stay in The Netherlands.

On behalf of the Organizing Committee
With lighting wishes,

S. Hemming  
Convenor

E. Heuvelink  
Co-convenor
Convenors

- Silke Hemming, Wageningen University and Research Centre
- Ep Heuvelink, Wageningen University and Research Centre

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- Theo Gieling, Wageningen UR Greenhouse Horticulture
- Silke Hemming, Wageningen UR Greenhouse Horticulture
- Ep Heuvelink, Wageningen University Horticultural Supply Chains
- Wim van Ieperen, Wageningen University Horticultural Supply Chains
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Overview of Wageningen
Detailed overview Forum

Oral programme: 2nd floor 222/221, 214, 217

Poster programme: 2nd floor left / right / bridge, 3rd floor left / right

Lunch
Sponsor exhibition
Registration and Helpdesk
ISHS business meeting 104
General overview ISHS Lightsym2012

Sunday, 14th of October
15:00-17:30 Registration desk (Hotel Hof van Wageningen, Wageningen)
18:00-22:00 Welcome reception (Hotel de Wereld, Wageningen)

Monday, 15th of October
07:30-10:00 Registration Desk/Presentation Delivery Desk (Forum hall)
07:30-08:30 Poster setup (Forum poster area)
08:30-09:00 Opening symposium (Forum 222/221)
09:00-09:45 Keynote 1 (Forum 222/221)
09:45-10:30 Keynote 2 (Forum 222/221)
10:30-11:00 Coffee/Tea
11:00-12:20 Orals 1 (Forum 222/221)
12:20-13:50 Lunch / Sponsor exhibition (Forum hall)
13:50-14:35 Keynote 3 (Forum 222/221)
14:40-15:50 Poster discussion groups A (Forum poster area)
15:50-16:10 Coffee/Tea
16:10-17:30 Orals 2 (Forum 222)
16:10-17:30 Orals 3 (Forum 214)

Tuesday, 16th of October
07:30-10:00 Helpdesk / Presentation Delivery Desk (Forum hall)
08:00-08:45 Keynote 4 (Forum 222/221)
08:45-09:15 Coffee/Tea
09:15-10:00 Orals 4 (Forum 222)
09:15-10:55 Orals 5 (Forum 214)
11:00-12:00 Poster discussion groups B (Forum poster area)
12:00-12:20 Group photo
12:20-13:20 ISHS business meeting incl. lunch (Forum 104)
12:20-13:50 Lunch / Sponsor exhibition (Forum hall)
13:50-14:35 Keynote 5 (Forum 222/221)
14:40-15:50 Poster discussion groups C (Forum poster area)
15:50-16:10 Coffee/Tea
16:10-17:30 Orals 6 (Forum 222)
16:10-17:30 Orals 7 (Forum 214)

Wednesday, 17th of October
07:30-10:00 Helpdesk / Presentation Delivery Desk (Forum hall)
08:00-08:45 Keynote 6 (Forum 222/221)
08:45-09:15 Coffee/Tea
09:15-10:15 Poster discussion groups D (Forum poster area)
10:20-11:40 Orals 8 (Forum 222)
10:20-11:40 Orals 9 (Forum 217)
11:40-12:00 Sponsor presentations
12:00-13:30 Lunch/Sponsor exhibition (Forum hall)
13:30-14:15 Keynote 7 (Forum 222/221)
14:20-15:40 Orals 10 (Forum 222)
14:20-15:40 Orals 11 (Forum 217)
15:45-16:15 Closing symposium (Forum 222/221)
18:00-23:00 Congress Dinner (Openluchtmuseum, Arnhem)

Thursday, 18th of October
7:30-19:00 Excursions (Westland, Gelderland, Venlo/Eindhoven)
Oral Program

Monday, 15th of October

**Room 222/221**

07:30-08:30
**Poster setup** *(Forum poster area)*

07:30-10:00
**Registration Desk/Presentation Delivery Desk** *(Forum main hall)*

08:30-09:00
**Opening symposium by Ernst van der Ende, director Plant Sciences Group, Wageningen UR**

09:00-09:45
**Session chair: Ep Heuvelink**

**Keynote lecture 1**: Plant Lighting in Controlled Environments for Space and Earth Applications [167]

*C.A. Mitchell*

09:45-10:30
**Keynote lecture 2**: Plant Production in a Closed Plant Factory with Artificial Lighting [263]

*E. Goto*

10:30-11:00
Coffee/Tea

**Session chair: Leo Marcelis**

**Light in horticultural systems**

11:00-11:20
Continuous Light as a Way to Increase Greenhouse Tomato Production: Expected Challenges [163]

*A.I. Velez-Ramirez, E. Heuvelink, W. van Ieperen, D. Vreugdenhill, F.F. Millenaar*

11:20-11:40
Improving Sweet Pepper Productivity by LED Interlighting [165]

*K. Jokinen, L.E. Särkkä, J. Nääkkilä*

11:40-12:00
UV Radiation as an Exploitable and Diverse Tool in the Regulation of Crop Quality and Yield [134]

*E.M. Elfadly, J.J. Wargent, W. Sobeih, J.P. Moore, N.D. Paul*

12:00-12:20
Influence of Diffuse Glass on the Growth and Production of Tomato [147]

*T. Dueck, J. Janse, T. Li, F. Kempkes, B. Eveleens*

12:20-13:50
Lunch/Sponsor exhibition *(Forum main hall)*
Oral program - Monday, 15th of October

Room 222/221

Session chair: Ep Heuvelink

13:50-14:35
Keynote lecture 3: Plant Morphological and Developmental Responses to Light Quality in a Horticultural Context [139]
W. van Ieperen

14:40-15:50
Poster discussion groups A (Forum poster area)

15:50-16:10
Coffee/Tea

Session chair: Wim van Ieperen

Light influences on photosynthesis, morphogenesis, development

16:10-16:30
Growth and Photosynthesis of Ornamental Plants Cultivated under different Light Sources [103]
K.J. Bergstand, H.K. Schüssler

16:30-16:50
Photosynthetic Light Responses in Relation to Leaf Temperature in Sun and Shade Leaves of Grapevines [146]
D.H. Greer, M.M. Weedon

16:50-17:10
The Effect of Irradiating Adaxial or Abaxial Side on Photosynthesis of Rose Leaves [209]
R. Paradiso, L.F.M. Marcelis

17:10-17:30
Effects of Continuous Lighting with or without a Diurnal Temperature Difference on Photosynthetic Characteristics of Tomato Leaves [214]
R. Matsuda, N. Ozawa, K. Fujiwara

Room 214

Session chair: Tom Dueck

13:50-14:35
Light in horticultural systems – company presentations

H. Plaisier, P. Arkesteijn, H. Andersson, P. Holgerson

14:40-15:50
M. Vitali

15:50-16:10
Coffee/Tea

Session chair: Tom Dueck

Light in horticultural systems – company presentations

BASF: Photomorphogenic Effects on Tomato Crop from Blue Light Manipulation through Photoselective Greenhouse Films [244]
M. Vitali

16:10-16:30
Light in horticultural systems – company presentations

Philips: Growing Value with LEDs in Horticulture [292]
E. van Echtelt, J. Dai, S. Gao, N. Lu, D. van Tuijl, U. van Slooten

16:30-16:50
Light in horticultural systems – company presentations

Guardian: Diffuse Glass and Modern Glass Developments for Horticultural Applications [299]
S. Billon
Oral program - Tuesday, 16th of October

Tuesday, 16th of October

Room 222/221
Registration Desk / Presentation Delivery Desk (Forum main hall)

07:30-10:00
Session Chair: Nicolas Castilla
Keynote 4: Light Transmission through Greenhouse Covers [259]
E. Baeza, J.C. López

08:00-08:45
Coffee/Tea

08:45-09:15
Session Chair: Nicolas Castilla
Light manipulation by coverings, nets, screens

09:15-09:35
Solar Transmittance of Greenhouse Covering Materials [173]

09:35-09:55
Solar Radiation Distribution in Screenhouses: A CFD Approach [238]
T. Bartzanas, N. Katsoulas, E. Kitta

09:55-10:15
The Effect of Gutters and Roof Openings on Light in a Multi-Span Greenhouse [152]
M. Teitel, M. Deriugin, M. Barak, A. Antler, Y. Gahai, J. Tanny, V. Haslavsky

10:15-10:35
Radiometric Properties of Plastic Films for Vineyard Covering and their Influence on Vine Physiology and Production [148]
G. Vox, G.S. Mugnozza, E. Schettini, L. de Palma, L. Terricone, G. Gentilesco, M. Vitali

10:35-10:55
Yellow and Red Sweet Pepper Quality Under Photoselective Screens And Field Crop Conditions [246]

11:00-12:00
Poster discussion groups B (Forum poster area)

12:00-12:20
Group photo

12:20-13:20
ISHS business meeting Commission Horticultural Engineering and Commission Protected Cultivation incl. lunch (Room 104)

12:20-13:50
Lunch / Sponsor exhibition (Forum main hall)
Oral program - Tuesday, 16th of October

**Room 222/221**

*Session Chair: Sadanori Sase*

13:50-14:35

**Keynote lecture 5:** Light and Energy Saving in Modern Greenhouse Production [264]

*H.R. Gislerød, L.M. Mortensen, S. Torre, H. Pettersen, T. Dueck, A. Sand*

14:40-15:50

Poster discussion groups C *(Forum poster area)*

15:50-16:10

Coffee/Tea

*Session Chair: Sadanori Sase*

**Lighting systems in plant factories and greenhouses including energy aspects**

16:10-16:30

Energy-efficient, Uniform, Supplemental Plant Lighting for Research Greenhouses [151]

*L.S. Albright, D.S. de Villiers, R. Tuck*

16:30-16:50

Effects of Light Quality and Light Period on Flowering of Everbearing Strawberry in a Closed Plant Production System [120]

*H. Yoshida, S. Hikosaka, E. Goto, H. Takasuna, T. Kudou*

16:50-17:10

Flexible Spectra LED Arrays for Sole Source Lighting and Growth Comparisons with Conventional High Pressure Discharge Lighting using Arabidopsis thaliana [110]

*C.L. Norling, H.N. Wiggins, J.I. Crawford, A.W.M. Wotton*

17:10-17:30

Developing LED Light Recipes for Multi-layering Systems: LED as an Alternative for HPS in forcing of Rhododendron simsii [188]

*B. Schamp, E. Lauwels, B. Gobin*

**Room 214**

*Session Chair: Dennis Greer*

**Light influences on photosynthesis, morphogenesis, development III**

16:10-16:30

Control of Plant Morphology by UV-B and UV-B-Temperature Interactions [137]

*S. Torre, A.G. Roro, S. Bengtsson, L.M. Mortensen, K.A. Solhaug, H.R. Gislerød, J.E. Olsen*

16:30-16:50

Short Main Shoot Length and Inhibition of Floral Bud Development under Red Light Can Be Recovered by Application of Gibberellin and Cytokinin [257]

*N. Fukuda, T. Yoshida, J.E. Olsen, C. Senaha, Y. Jikumaru, Y. Kamiya*

16:50-17:10

Red and Blue Light Effects during Growth on Hydraulic- and Stomatal Conductance in Leaves of Young Cucumber Plants [258]

*W. van Ieperen, A. Savvides, D. Fanourakis*

17:10-17:30

Vegetative Growth Response to Light and Temperature, Interpreted by Carbohydrate-Pool Dynamics [166]

*I. Seginer, M. Gent*
Wednesday, 17th of October

**Room 222/221**

07:30-10:00
Registration Desk / Presentation Delivery Desk (*Forum main hall*)

*Session Chair: Jorunn Olsen*

**08:00-08:45**

**Keynote lecture 6:** Prospecting the Use of Artificial Lighting for Integrated Pest Management [216]

*I. Vänninen, D. Pinto, A. Nissinen, N.S. Johansen, L. Shipp*

08:45-09:15
Coffee/Tea

**09:15-10:15**

*Session Chair: Erik Runkle*

**Light effects on crop growth and production I**

10:20-10:40
Effect of Overnight Supplemental Lighting with Different Spectral LEDs on the Growth of some Leafy Vegetables [105]

*S. Sase, C. Mito, L. Okushima, N. Fukuda, N. Kanesaka, K. Sekiguchi, N. Odawara*

10:40-11:00
LED Inter-lighting in Year-Round Greenhouse Mini-Cucumber Production [204]

*X. Hao, J.M. Zheng, C. Little, S. Khosla*

**10:00-11:20**

**Light Emitting Diode Irradiation at Night Accelerates Anthocyanin Accumulation in Grape Skin [144]

*A. Azuma, A. Ito, T. Moriguchi, H. Yakushiji, S. Kobayashi*

11:00-11:20
Biomass Accumulation, Allocation and Leaf Morphology of *Impatiens Hawkeri* ‘Magnum Salmon’ Cuttings is Affected by Photosynthetic Daily Light Integral in Propagation [125]

*C.J. Currey, R.G. Lopez*

**11:00-12:00**

**Light interactions with pest and diseases**

11:00-11:20
Optical Manipulations of Insect Pests for Protecting Agricultural Crops [161]

*D. Ben-Yakir, Y. Antignus, Y. Offir, Y. Shahak*

11:20-11:40
Interruption of the Night Period by UV-B Suppresses Powdery Mildew of Roses and Cucumber [200]

*A. Suthaparan, A. Stensvand, K.A. Solhaug, S. Torre, L.M. Mortensen, D.M. Gadouy, H.R. Gislerød*

**11:40-12:00**

**Sponsor presentations**

**12:00-13:30**

**Lunch / Sponsor exhibition (*Forum main hall*)**
Oral program – Wednesday, 17th of October

Room 222/221

Session Chair: Ryo Matsuda

13:30-14:15  
**Keynote lecture 7:** Meta-Phenomics, Horticulture and the Value of Plant Trait Databases [138]  
*H. Poorter*

14:20-14:40  
**Light effects on crop growth and production II**  
Finding the Optimal Growth-Light Spectrum: Open versus Closed Crop Stands [241]  
*S. W. Hogewoning, G. Trouwborst, E. Meinen, W. van Ieperen*

14:40-15:00  
Effects of Light Intensity, Plant Density and Defoliation on Quality and Yield of Tomato Produced in Wintertime at Higher Latitudes [129]  
*M. J. Verheul*

15:00-15:20  
Rapid Regulation of Leaf Photosynthesis, Carbohydrate Status and Leaf Area Expansion to Maintain Growth in Irregular Light Environments [157]  
*K. Heinsvig Kjaer, C. O. Ottosen*

15:20-15:40  
An Enlightened View on Protected Cultivation of Shade-Tolerant Pot-Plants: Benefits of Higher Light Levels [202]  
*F. van Noort, J. Kromdijk, S. Driever, T. Dueck*

15:45-16:15  
**Closing session symposium** by Silke Hemming and Ep Heuvelink

Room 217

Session Chair: Jung Eek Son

14:20-14:40  
**Light measurement and modelling methods**  
Evaluation of LED Lighting Systems in Vitro Cultures [232]  
*T. Bornwaßer, H. J. Tantau*

14:40-15:00  
Transvision: A Light Transmission Measurement System for Greenhouse Covering Materials [231]  
*G. L. A. M. Swinkels*

15:00-15:20  
Feasibility Study on Combined Production of Algae and Tomatoes in a Dutch Greenhouse [226]  
*A. A. Slager, A. A. Sapounas, E. van Henten, S. Hemming*

15:20-15:40  
Image-Based Estimation of PPFD Distribution on Canopy Surface in Greenhouse [109]  
*Y. Ibaraki, T. Kishida, C. Shigemoto*
Poster Discussion Groups
Session A - Monday, 15th 14:40-15:50

Session chair: Sissel Torre

Poster Discussion Groups
Session A - Monday, 15th 14:40-15:50

Session chair: Sissel Torre

Poster Discussion Groups
Session A - Monday, 15th 14:40-15:50

Session chair: Sissel Torre

Light effects on crop growth and production a

[128] Optimizing a Year-round Cultivation System of Tomato under Artificial Light
M.J. Verheul, H.F.R. Maessen, S.O. Grimstad

[192] Effect of Supplementary Lighting on the Selected Physiological Parameters and Yielding of Tomato Plants (Solanum lycopersicum L.) in Autumn-Winter Cultivation
J. Gajc-Wolska, K. Kowalczyk, A. Metera, K. Mazur, D. Bujalski, L. Hemka

[196] Does the Lighting Time Influence Yield of Winter Grown Sweet Pepper and Tomato?
C. Stadler, A. Helgadóttir, M.Á. Ágústsson, M.A. Riihimäki

[291] Effects of Light Supplement by Different Artificial Light Sources to Chinese Cabbage Growth in Greenhouse
C. He, X. Yu

[221] Influence of UV Light Reduction on Growth and Development of Onions
P. Intichichack, Y. Nishimura, Y. Fukumoto

[296] Effect of Light Diffusion on Growth of Lettuce Plants in LED Plant Factory
W.H. Kang, J.W. Lee, D.H. Jung, J.E. Son

[127] Effects of Light Spectrum and Lighting Regime on Double Stalk Forcing of Phalaenopsis in the Controlled Environmental Chamber
M.Y. Chang, H.Y. Chung, W. Fang, C.C. Wu

Session manipulation by coverings, nets, screens a

[283] Does Diffuse Light Increase Photosynthesis Capacity of Tomato Plants?
K. Goen, D. Pinxteren, R. Moerkens

[158] Understanding how Diffuse Light Increases Yield in Tomato
T. Li, E. Heuvelink, T. Dueck, L.F.M. Marcelis

[174] Effect of Diffuse Glass on the Growth and Winter Production of Cucumber
J. Janse, T. Dueck, F. Kempkes

U. Schmidt, T. Rockschi, D. Dannehil, R. Salazar de Moreno, A. Rojano de Aquilar

V. Mohammadkhani, G.L.A.M. Swinkels, T.H. Gieling, J.P.M. van Ruijven

Session chair: Irene Vänninen

Light interactions with pest and diseases

[123] Fluorescent Illumination with High Red-to-far-red Ratio Reduces Attractiveness of Cucumber Seedlings to Sweetpotato Whitefly through Changes in Leaf Morphological Characteristics
T. Shibuya, J. Komuro, N. Hirai, Y. Sakamoto, R. Endo, Y. Kitaya

[182] Fluorescent Illumination with High Red-to-far-red Ratio and High Vapor Pressured Deficit Improves Powdery Mildew Resistance in Cucumber Seedlings

[190] Potato Plant Responses to Temperature Drop and Phytonematode Infestation Under Continuous Lighting
M.I. Sysoeva, E.M. Matveeva, V.V. Lavrova, E.G. Sherudilo

[284] BioPM Lamp Application as an Biopesticide for Whitefly (Trialeurodes vaporariorum) on Cucumber in High tunnel
X. Yu, C. He

[298] Regulation of Plant Resistance against Powdery Mildew in Tomato by the Application of Red Light
L.H. Stevens, J.D. Hofland-Zijlstra

[301] Microbial Colonization of Canopies in Greenhouse Grown Ornamental Plants
S. Gharaie, S. Khalil, K. Löfkvist, C.O. Ottosen, B.W. Alsanius

Session chair: Cary Mitchell

Lighting systems in plant factories and greenhouses including energy aspects

[293] Growing with LED Lighting of Different Spectral Quality Affects Morphogenesis and Production of Lettuce Plants
O. Avercheva, E. Bykova, E. Taranov, E. Bassarskaya, T. Zhigalova, V. Choob, V. Ptushenko

[234] Temperature, Light Intensity, and Photoperiod Affect Growth and Flowering in Eustoma grandiflorum
W. Oh

[261] Growth of Lettuce in a Closed-Type Plant Production System as Affected by Light Intensity and Photoperiod

[286] Cold Cathode Fluorescent Lamp (CCFL) Contained Far-red Light Range Enhanced Spinach Leaf Length
K. Yumoto, T. Kitaura, N. Kita, M. Miyanaga, T. Ikeda

[288] Effects of LEDs on Photosynthesis and Secondary Metabolites in Roses, Chrysanthemums, and Campanulas
T. Ouzounis, X. Fretté, E. Rosenqvist, C.O. Ottosen

[254] Establishment of Light Formula and Light Environmental Management Strategy for High-efficient Plant Cultivation with Artificial Light Sources
Q. Yang, W. Liu, L. Wei, R. Cheng

[267] Growth of Ixeris dentata (Thunb.) Nakai in a Closed-Type Plant Production System as Affected by Light Intensity and Photoperiod
J.H. Kang, H.M. Kim, B.R. Jeong, S.J. Hwang

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Session chair: Peter Lootens

Forum 2nd floor, bridge

Light influences on photosynthesis, morphogenesis, development a

[104] Effects of Alternating Light Intensity on CO₂ Assimilation of Ficus elastica and Dieffenbachia picta Plants, Grown for Indoor Landscaping
  M. E. Giorgioni

[115] Measurements of Short- and Long-term Photosynthesis and Growth under Various Qualities of Light Emitting Diode Light
  E. Goto, H. Matsumoto, S. Furuyama, K. Nanya, Y. Ishigami, S. Hikosaka

[172] Effects of Light Quality and CO₂ Concentration on Diurnal Photosynthetic Characteristics of Strawberry
  C.C. Wu, Y.H. Yen, M.Y. Chang, W. Fang

[179] Effects of Supplemental Lighting to a Lower Leaf Using LEDs with Different Wavelengths on Leaf Photosynthetic Characteristics in Sweet Pepper
  K. Murakami, R. Matsuda, K. Fujiwara

  R. Chiarawipa, Y. Wang, X.Z. Zhang, Z.H. Han, M. Rueangkanab

[243] Effect of Plant Photosynthesis Under Different Wavelengths of LED
  M. Lefsrud, M. T. Naznin, J. Gagne, M. Schwalb, B. Bissonette

[273] Photosynthetic gas exchange of Tomato (Solanum lycopersicum) in Fluctuating Light Intensity
  E. Kaiser, J. Kromdijk, E. Heuvelink, L.F.M. Marcelis
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Session chair: Royal Heins

Light effects on crop growth and production

[170] Early-Stage Growth and Carbohydrate Contents of Tomato under Continuous Lighting with or without a Diurnal Temperature Difference
N. Ozawa, R. Matsud, K. Fujiwara

[266] Use of High Output LED in Ornamentals
C.O. Ottosen

[239] Impact of Local Light on Number and Growth of Cells in Tomato Fruit

[277] Non-invasive Plant Growth Measurements for Detection of Blue-Light Dose Response of Stem Elongation in Chrysanthemum Morifolium
K. Heinsvig Kjaer

[227] In vitro Propagation and Rooting of Helleborus orientalis in Response to LED Lighting
E. Dhooghe, M.C. van Labeke

[302] The Effect of LED Assimilation Light and Increased Temperature in Strawberry Glasshouse Cultivation
T. Van Delm, R. Vanderbruggen, P. Melis, K. Stoffels, W. Baets

Session chair: Roberto Lopez

Light manipulation by coverings, nets, screens

E. Schettini, G. Vox

[212] Screening During the Vegetative Growth Phase Reduces Yield of Cucumber
H.P. Kläring, Y. Klopotek

[279] Early Exposure to UV Radiation during Propagation leads to a Yield Increase in Pepper (Capsicum annuum L.)
E. Elfadly, W. Sobeih, J. Wargent, N. Paul

[280] Efficiency of Plastic Types on Cucumber Production (Cucumis sativus L.),
S. Hassan, I. Ghoneim, A. Elsharkawy

[294] How Hanging Baskets Affect Light Quantity and Quality on Lower Crops in Poly-Covered Commercial Greenhouses
D. Llewellyn, Y. Zheng, M. Dixon

[248] Microclimate of a Pepper Crop under Screenhouse Conditions
N. Rigakis, N. Katsoulas, C. Kittas, E. Kitta, T. Bartzanas
Poster program – Tuesday, 16th of October

Session chair: Uwe Schmidt

**Light interactions with pest and diseases**

[177] Combination of Blue and Far-red Supplemental LEDs Enhanced Baby Leaf Lettuce Yield without Lowering Nutritional Phytochemical Content
Q. Li, C. Kubota

[178] Growth and Quality of Chinese Kale Grown under Different LEDs,
J. Xin, H. Liu, S. Song, R. Chen, G. Sun

[194] Effect of Supplementary Lightening on the Quality of Tomato Fruit (Solanum lycopersicum L.) in Autumn-Winter Cultivation,
K. Kowalczyk, J. Gajc-Wolska, A. Metera, K. Mazur, J. Radzianowska, M. Szatkowski

[223] Effects of Red and Blue Light Irradiation on Vindoline and Catharanthine Content in Catharanthus roseus
T. Fukuyama, M. Otuka, H. Watanabe, K. Ohashi-Kaneko, A. Takano, W. Amaki

[240] Effect of Light Regimen on Yield and Flavonoid Content of Warehouse Grown Aeroponic Eruca sativa
N.S. Mattson, E.D. Harwood

[255] Effects of Light Intensity on Nutritional Quality of Hydroponic Lettuce under Short-term Continuous Lighting Illuminated with LED
W. Zhou, W. Liu, Q. Yang

Session chair: Eiji Goto

**Light influences on photosynthesis, morphogenesis, development b**

[118] Effects of Blue and Red Light on Stem Elongation and Flowering of Tomato Seedlings
K. Nanya, Y. Ishigami, S. Hikosaka, E. Goto

[168] Effect of Photoperiod Prolongation with Red or Far red Light Irradiation at Low Intensity on Shoot Elongation Cessation and Flower Formation of One-year-old Japanese Pear
A. Ito, I. Azuma, T. Nakajima, T. Imai, T. Moriguchi

[191] Control of Continuous Irradiation Injury on Tomato Plants with a Temperature Drop
M.I. Sysoeva, T.G. Shibaeva, E.G. Sherudilo, E.N. Ikkonen

[185] Spectral Sensitivity of Flowering and FT-like Gene Expression in Response to a Night Break Treatment in the Chrysanthemum Cultivar ‘Reagan’

[229] Red and Far-Red Light Control Flowering in Long-Day Woodland Strawberry ‘Hawaii-4’
M. Rantanen, K. Mouhu, P. Palonen, P. Elomaa, T. Hytönen

[282] Impact of Light Intensity on Leaf Initiation in Young Cucumber and Tomato Plants: A Matter of Photosynthates Availability?
A. Savvides, N. Ntagkas, W. van Ieperen, J.A. Dieleman, L.F.M. Marcelis
Session chair: Marie-Christine van Labeke

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**Light influences on photosynthesis, morphogenesis, development c**

[207] Determining the Minimal Daily Light Sum for Forcing Azalea,
A. Christiaens, P. Lootens, I. Roldán-Ruíz, B. Gobin, M.C Van Labeke

[215] Photon Efficiency of Photosynthetic Biomass Accumulation by means of Microalgae in
Photobioreactors using the Example of *Chlorella vulgaris*
J. Bialon, T. Rath

[268] Improving Tomato and Pepper Transplants Quality Using Photoselective Filters
J. Javanmardi, S. Emami

[269] The Effect of Daily Integrated Irradiance on Composition of Lettuce
M. Gent

[272] Development of Leaf Parameters of Bell Pepper under Different Light Spectrum
I. Erdberga, I. Alsiņa

[236] Examining the Use of Energy Saving Bulbs in Providing Daylength Control in Ornamental
Horticultural Species
S. Jackson, S. Adams, B. Weaving, B. Thomas
Session C - Tuesday, 16th 14:40-15:50

Session chair: Carl Otto Ottosen

Light effects on crop growth and production c

[251] Carrying-over Effects of Light Quantity and Quality during Raising Seedlings on the Growth and Flowering in Petunia
   W. Amaki, Y. Tsuchiya, Y. Mine, H. Watanabe

[271] Effect of Light Source and DIF on Growth of Salvia plebeia R. BR. under Controlled Environment
   Y.G. Park, H.J. Oh, S.J. Hwang, B.R. Jeong

[274] Aspects on Light and Flowering of Poinsettia (Euphorbia pulcherrima Willd.)
   D. Ludolph

[289] Potential Use of Long Photoperiods Including Continuous Light for Production of Cucumber Transplants
   T.G. Shibaeva, M.I. Sysoeva

[100] Control of the Shoot Elongation in Bedding Plants using Extreme Short Day Treatments
   H.K. Schüssler, K.J. Bergstrand

[219] Growth Rate and Flowering Promoted by Night Interruption in Two Cymbidium Hybrids, ‘Red Fire’ and ‘Yokihi’
   Y.J. Kim, H.R. An, K.S. Kim

Session chair: Evelia Schettini

Light manipulation by coverings, nets, screens c

[132] Photosensitive Netting of Fruit Trees: Multiple Benefits Requiring Crop-specific Adjustments
   Y. Shahak

[153] The Effect of Spectrum Conversion Covering Film on Cucumber in Soilless Culture
   Y. Nishimura, E. Wada, Y. Fukumoto, H. Aruga, Y. Shimo

[245] Effect of Photosensitive Screens in the Development and Productivity of Red and Yellow Sweet Pepper
   J.Q. Santana, M.A. Balbino, T.R. Tavares, R.S. Bezerra, J.G. Farias, R.C. Ferreira

[252] Response of Photosynthetic Parameters of Sweet Pepper Leaves to Light Quality Manipulation by Photosensitive Shade Nets
   Y. Kong, I. Avraham, K. Ratner, Y. Shahak

[281] Improving Tomato and Pepper Transplants Quality Using Photosensitive Filters
   J. Javanmardi, S. Emami

[260] Test of a Greenhouse Covered by Polyethylene Film that Reflects Near-Infrared Radiation
   C. Kittas, N. Kastoulas, M. Katsoupa, Ch. Papaioannou
Session chair: Qichang Yang

Light regulating postharvest physiology & quality b
[108] Effects of Exogenous Hydrogen Peroxide on the Growth and Contents of Antioxiode Compounds in Leaf Lettuce Grown under an Artificial Light Source
N. Mori, H. Watanabe, M. Koshika, K. Omae, K. Ohashi-Kaneko, E. Ono, W. Amaki
[112] Effects of UV Irradiation on Growth and Concentrations of Four Medicinal Ingredients in Chinese Licorice (Glycyrrhiza uralensis)
[121] Effects of Light Quality of Three Different PPF Levels on Growth and Polyphenol Contents of Lettuce Plants (Lactuca sativa L.)
K. Shoji, K. Kitazaki, S. Hashida, F. Goto, T. Yoshihara, M. Johkan
[122] Effects of Light Quality on the Concentration of Human Adiponectine and Bovine a-Lactalbumin in Transgenic Everbearing Strawberry Fruit
S. Hikosaka, H. Yoshida, T. Chiba, E. Goto, N. Tabayashi, T. Matumura
[135] Changes of Aromatic Compound Contents in Perilla and Rocket Grown under Various Wavelengths of LED Light Conditions
E. Ogawa, I. Tonsho, H. Watanabe, K. Ohashi-Kaneko, E. Ono, W. Amaki, E. Goto
[276] UV-A or B Lamp Improves Phytochemical Concentration in Red Leaf Lettuce Plants Grown in a Closed-type Plant Production System
MJ. Lee, M.M Oh

Session chair: Arend Jan Both

Light measurement and evaluation methods
[107] In Situ Monitoring System for Chlorophyll Fluorescence Parameters of Tomato at Greenhouse in Northern China
Z. Li, J. Ji, Q. Zou, F. Li, H. Yu
[197] Long Time Analyses of Light Use Efficiency by Gas Exchange Measurement using Phytomonitoring Systems
U. Schmidt, T. Rocksch, D. Dannehl, R.S. de Moreno, A.R. de Aguilar
[224] Evaluation of Efficiency of Supplemental Lighting Based on Light Intensity Distribution on Canopy Surface Using Reflection Images
Y. Ibaraki, C. Shigemoto, T. Kishida
[295] Dynamic Measurement of Photosynthetic Rate with Growth Stage at Various Combinations of Light and CO₂ Levels by Using Multiple Chambers using LEDs,
T.Y. Kim, J.H. Shin, T.I. Ahn, J.E. Son
[297] 3-Dimensional Approach for the Estimation of Light Interception and Lettuce Growth with Light Intensity and Quality in Plant Factory
[300] Measuring Whole Plant Light Absorption using a Spectrogoniophotometer
P. Kalaitzoglou, H. Bartholomeus, E. Onac, W. van Ieperen, J. Harbinson, L.F.M. Marcelis
Session chair: Eva Rosenqvist

Forum 2nd floor, bridge

Light influences on photosynthesis, morphogenesis, development d

[140] Cucumber Seedlings Grown under High Red-to-far-red Illumination Shows Enhanced Resistance to Strong Light Stress
R. Endo, T. Shibuya, Y. Kitaya

[159] Light-Induced Colour Change in Two Winter-Grown Pepper Cultivars (Capsicum annuum L.)
C.M. Alcock, I. Bertling

[124] Uniformity in Seedlings Grown Densely under Different Light Sources
T. Shibuya, S. Takahashi, R. Endo, Y. Kitaya

[176] Monitoring of CO₂ Gas Exchange of Petunia Cuttings during Adventitious Root Formation (ARF) in respect to Different Light Intensities
Y. Klopotek, E. George, U. Druege, H.P. Klaering

[171] Effective Spectra for the Promotion of the Extension Growth of Tulips Grown with Night Lighting under a Natural Photoperiod
K. Sumitomo, A. Yamagata, T. Hisamatsu, T. Tsuji, M. Ishiwata, M. Yamada

[198] Light Response Curves of Selected Plants under Different Light Conditions
N. Domurath, F.G. Schroeder, S. Glatzel
Session D - Wednesday, 17th 09:15-10:15

* No presentations in Forum 3rd floor, right

Session chair: Constantinos Kittas

Forum 3rd floor, left

Light manipulation by coverings, nets, screens d

[210] Shading As an Effective Means for Crop Load Management and Fruit Quality Enhancement in Apple Trees
T. Aliev, A. Solomakhin, M. Blanke, A. Kunz, A. Klad

[211] The effect of Constraining the Intensity of Solar Radiation on the Photosynthesis, Growth, Yield and Product Quality of Tomato,
H.P. Kläring, A. Krumbein

[249] Transpiration and Photosynthesis of Sweet Pepper Growing under differing Screenhouse Nets
N. Katsoulas, A. Kandila, E. Kitta, A. Baille

[265] Effect of Shading by Date Palm Leaves on Growth and Yield of Potato under Different Irrigation Levels
A.M. Al-Moshileh, M.Z. El-Shinawy, M.I. Motawei

[187] Effect of Shade on Yield, Quality and Photosynthesis-related Parameters of Sweet Pepper Plants
J. López-Marín, A. Gálvez, A. González, C. Egea-Gilabert, J.A. Fernández

[193] Counteracting Low Light Levels in Protected Strawberry Cultivation using Reflective Mulches
B.W.W. Grout, M.J. Greig

Forum 2nd floor, bridge

Session chair: Chieri Kubota

Light influences on photosynthesis, morphogenesis, development e

[169] Effect of Different Light and Two Polysaccharides on the Proliferation of Protocorm-like Bodies of Cymbidium Cultured in Vitro
S. J. Nahar, K. Shimasaki, S. M. Haque

[237] Disentangling the Effect of Light Quantity and Light Quality on Bud Break in a Rose Crop
A.M. Wubs, E. Heuvelink, J. Vos, G. Back-Sorlin, L.F.M. Marcelis

[247] Effect of Light Quality and Cytokinin on Shoot Regeneration from Nodal Explant of Rhododendron brachycarpum
I. Sivanesan, B.R. Jeong

[262] Supplementary Light and Higher Fertigation EC in the Cultivation of Bromelia Improve Quality and Accelerate Growth
N. García Victoria, M. Warmenhoven

[278] The Role of Phytochrome B in Organogenesis Control in Young Cucumber Plants Under Continuous Lighting
M.I. Sysoeva, E.F. Markovskaya

[290] Analysis of ΦPSII and NPQ During Slow Phase of Chlorophyll Fluorescence Induction Phenomenon of Tomato Leaf
K. Takayam, Y. Miguchi, Y. Manabe, N. Takahashi, H. Nishina
Session chair: Martin Gent

Forum 2nd floor, right

Light regulating postharvest physiology & quality c

[213] Analysis of the Effect of Light-Emitting Diode (LED) Light with eight Different Peak Wavelengths on Growth, Metabolites and Minerals of *Brassica rapa* var. perviridis “Komatsuna”
K. Kitazaki, K. Shoji, F. Goto, S.N. Hashida, T. Yoshihara

[222] Temperature Modification of UV-B-induced Changes in Flavonoid Content and Morphology in Pea
A.G. Roro, K.A. Solhaug, J.E. Olsen, S. Torre

[228] Impact of Temporarily Reduced Irradiation on Anthocyanin Content of Lettuce
C. Becker, A. Krumbein, H.P. Kläring, L.W. Kroh

[256] Effects of Supplemental UV-A and UV-C Irradiation on Growth, Photosynthetic Pigments and Nutritional Quality of Pea Seedlings
W. Liu, Q. Yang

[275] Growth and Accumulation of Phytochemicals in Two Leaf Lettuce Cultivars Grown under Monochromatic Light-emitting Diodes
K.H. Son, M.M. Oh

[142] The Impact of Supplementary Short-term Red LED Lighting on the Antioxidant Properties of Microgreens
G. Samuolienė, A. Brazaitytė, R. Sirtautas, S. Sakalauskiūnė, J. Jankauskiene, P. Duchovskis, A. Novičkovas

Session chair: Jung Eek Son

Forum 2nd floor, left

Artificial light sources

[136] Solid-state Lamp for Lighting in Greenhouses
A. Novičkovas, L. Dabašinskas, P. Vitta, P. Duchovskis, G. Samuolienė, A. Brazaitytė, R. Sirtautas

[233] Investigation of the Junction Temperature Influence on the Photon Flux Yield of High-Power-LEDs
T. Bornwaßer, H.J. Tantau

[270] Two Different Types of LED-Light Source Systems Available for Light Effects Research in Horticultural Science
K. Fujiwara, K. Eijima, A. Yano

[285] Multispectral LED Array for Plant Research
M. Stasiak, D. Hawley, M. Dixon

[287] Design for High Production System for Baby Leaf using Hybrid Electrode Fluorescent Lamp (HEFL) in Plant Factory
K. Niira, A. Nakamura, A. Takeda, Y. Ishikawa, T. Ikeda

[119] Controllable Spectrum Plant Cultivation Light Source System using Five-Peak Wavelength LEDs
A. Yano, Y. Doi, K. Fujiwara
Excursion program – Thursday, 18th of October

Excursions

Thursday 18th of October

Tour Gelderland

7:30 h  Departure Wageningen
8.00 h  Arrival Bergerden
  Visit orchid grower Schouten & van Marwijk
10.00 h  Departure
10.30 h  Arrival Park Hoge Veluwe
11.00 h  Visit Kröller Müller Museum
13.00h  Lunch
14.30 h  Departure
15.00 h  Arrival Wageningen
  Visit Wageningen UR Greenhouse Horticulture labs
18.00 h  Arrival hotel

Tour Eindhoven

7.00 h  Departure Wageningen
8.45 h  Arrival Eindhoven
  Visit Philips
  Group 1:
  9.00 h Basics
  9.30 h Retail
  10.00 h Measurement chamber
  11.00 h summary
  Group 2:
  9.00 h Measurement chamber
  10.00 h Retail
  10.30 h Basics
  11.00 h summary
11.30 h  Departure
12.15 h  Arrival Arcen
  Visit Brewery Hertog Jan
  Lunch
14.30 h  Departure
15.00 h  Arrival Beessel
  Visit lettuce grower Delissen
16.00 h  Departure
18.00 h  Arrival Wageningen
## Tour Westland

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<td>Visit Wageningen UR Greenhouse</td>
<td>Visit rose grower Marjoland</td>
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<td>18.00 h</td>
<td>Arrival Wageningen</td>
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Abstracts - Oral Program
[167] Plant Lighting in Controlled Environments for Space and Earth Applications

C. A. Mitchell
Department of Horticulture and Landscape Architecture, Purdue University, West Lafayette, Indiana USA

Keywords: close-canopy lighting, controlled-environment agriculture, intracanopy lighting, light-emitting diode, photosynthesis, sole-source lighting, supplemental lighting

Abstract

Light is a requirement for plant growth and development that interacts powerfully with other environmental variables to define plant responses to the environment. Protected cultivation can eliminate off-nominal conditions that prevent plants from achieving their productivity potential. Light hardens plants off against growth-inhibiting effects of mechanical stresses in protected environments, and likely contributes to hardening in the field. Growth-dynamic and gas-exchange metrics reveal interactions of light level, CO₂ concentration, temperature, and nitrogen nutrition in stimulating crop productivity and nutritional composition while saving energy for lighting. Intracanopy lighting of planophile crops growing in controlled environments with low-power lamps overcomes aspects of dense plantings and mutual shading that occur with overhead lighting. For more than 20 years, plant researchers have experimented with solid-state light-emitting diodes (LEDs). LEDs have numerous technical advantages for plant lighting, including cool emitters that allow close placement to plant surfaces without scorching them. Thus, reduced power can be used to achieve adequate photon flux. When used as sole sources for photosynthetic, photomorphogenic, and/or photoperiod lighting, narrow-spectrum LEDs must be proportioned carefully to obtain desired plant responses. Potential exists for significant electrical energy savings using LEDs, but undesirable effects of wavelength deficiencies on plants also are being revealed by ongoing LED research. Intracanopy and close-canopy “smart lighting” with LEDs hold additional promise for plant-lighting effectiveness and efficacy. A natural extension of sole-source LED lighting approaches for space applications to supplemental LED lighting approaches has implications for improved profitability of the greenhouse industry.
[263] Plant Production in a Closed Plant Factory with Artificial Lighting

Eiji Goto
Laboratory of Environmental Control Engineering, Graduate School of Horticulture, Chiba University, Matsudo 648, Matsudo, Chiba 271-8510, Japan

Keywords: light-emitting diodes, photomorphogenesis, photosynthesis, phytochemicals, spectral distribution

Abstract

Plant factories where leafy vegetables are cultivated until harvest in closed systems with artificial lighting were proposed, developed, and implemented in Japan during the 1980s. During the 1990s, the products from these factories received high evaluations by the food service industry, to which they primarily catered. During the 2000s, commercial production of nursery plants of fruits and vegetables was initiated in plant factories. Since the late 2000s, plant factory technology has been introduced worldwide, particularly to Asian countries. Plant factories also provide good cultivation systems for the production of medicinal plants and genetically modified crops for pharmaceutical use. In late 2000s, light-emitting diodes (LEDs) were introduced to plant factories as a more efficient light source. LEDs are expected to reduce the electricity costs of lighting and cooling because they have a higher efficiency of converting electric power to light power and exert lower cooling loads than conventional light sources. To achieve plant production in plant factories by using LEDs, more achievement of plant research is required taking engineering and plant physiological approaches, in areas such as the creation of optimal LED lighting systems, promotion of photosynthesis, control of gene expression, photomorphogenesis, and synthesis of secondary metabolites. This study reviews recent research status and achievements regarding plant production in plant factories with artificial lighting and introduces plant research topics related to LEDs utilization.
[163] Continuous Light as a Way to Increase Greenhouse Tomato Production: Expected Challenges

Aaron I. Velez-Ramirez  
Horticultural Supply Chains Group and Laboratory of Plant Physiology, Wageningen University, Wageningen, The Netherlands

Dick Vreugdenhil  
Laboratory of Plant Physiology, Wageningen University, Wageningen, The Netherlands

Ep Heuvelink and Wim van Ieperen  
Horticultural Supply Chains Group, Wageningen University, Wageningen, The Netherlands

Frank F. Millenaar  
Vegetable Seeds Division, Monsanto, Bergschenhoek, The Netherlands

Keywords: Continuous light, Solanum lycopersicum, chlorosis, greenhouse, supplementary light

Abstract

Tomato plants need six hours of darkness per day for optimal growth; therefore, photosynthesis does not take place for 25% of the day. If tomatoes could be grown under continuous light, a substantial increase in production is expected. In practice, however, continuous light-grown tomato plants develop a potentially lethal mottled chlorosis. Such continuous-light-induced injury is only poorly understood so far. Recently, we proposed a number of hypotheses that aim to explain the continuous-light-induced injury, and rediscovered that wild-tomato species were reported as continuous-light-tolerant. Here, we (i) present a simulation study which shows that if an ideal continuous-light-tolerant tomato genotype is used and no crop adaptations to continuous light are assumed, greenhouse tomato production could be 26% higher when using supplementary lighting for 24 h day$^{-1}$ in comparison with using supplementary lighting only for 18 h day$^{-1}$ during day time, and (ii) discuss expected changes in greenhouse energy budgets and alterations in crop physiological responses that might arise from cultivating tomatoes under continuous light.
[165] Improving Sweet Pepper Productivity by LED Interlighting

K. Jokinen, L.E. Särkkä and J. Näkkilä
MTT Agrifood Research Finland, Horticulture, Toivonlinnantie 518, FI-21500 Piikkiö, Finland

Keywords: greenhouse, light transmittance, yield quality, profitability

Abstract
Light-emitting diodes (LEDs) have recently emerged as a potentially energy-efficient technology in horticultural lighting, and their low heat generation favors their use between the stems of sweet pepper (*Capsicum annuum* L.) trained to two-stem plants. We studied the effects of LEDs (57 W m$^{-2}$), installed between the stems without top lighting, on fruit yield and quality of greenhouse-grown sweet pepper cv. Ferrari. Plants were grown at 7.16 stems m$^{-2}$ in peat growing medium and fertigated with nutrient solution (2.5 dS m$^{-1}$). Red fruits were harvested weekly over 16 weeks. Continuous light measurements determined by the photosynthetic photon flux density (PPFD) indicated limited natural light availability inside the canopy at the level of fruit development, where no more than 5-10% of the radiation received at the top of canopy penetrated. LED interlighting considerably improved the light conditions there. The weekly marketable yields of LED-illuminated plants were equal to or greater than those from plants not receiving artificial light. LED interlighting increased the total marketable yield by 16% (LED 14.6 kg m$^{-2}$ and Non-LED 12.6 kg m$^{-2}$) mainly due to the increased fruit number. Fruits of LED-illuminated plants were deeper red in color, suggesting faster fruit maturation. The cost-benefit analysis showed that the yield advantage covered the electricity costs at present values, but the overall profitability of interlighting was sensitive to the yield advantage, product pricing and installation costs.
UV Radiation as an Exploitable and Diverse Tool in the Regulation of Crop Quality and Yield

E.M. Elfadly
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J.J. Wargent
Institute of Natural Resources
Massey University
Palmerston North, New Zealand

W. Sobeih
Arid Agritec Ltd
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Lancaster University, Bailrigg
Lancaster, UK

J.P. Moore and N.D. Paul
Lancaster Environment Centre
Lancaster University, Bailrigg
Lancaster, UK

Keywords: ultraviolet radiation, photosynthesis, polytunnel, plant biomass, net assimilation rate

Abstract

Responses of red leaved lettuce (Lactuca sativa) to ‘cross-over’ style treatments of different UV radiation (280-400 nm) environments were studied under both field (polytunnel) and controlled environment (supplementary UV lighting) conditions. Under field conditions, initial propagation in the presence of UV radiation and follow on growth, or ‘cropping’ under low or no UV environments increased leaf weight ratio (LWR) and net assimilation rate (NAR), and decreased leaf area ratio (LAR) of lettuce plants. In addition, plants transferred from a UV inclusive environment to a UV depleted environment exhibited significantly increased leaf dry weight and decreased root dry weight following transfer, whereas plants propagated and cropped under a no UV environment throughout also exhibited increased leaf dry weight, but displayed significantly higher root dry weight than plants exposed to a UV-inclusive environment. In controlled environment (CE) conditions, increased net photosynthesis was observed in those plants exposed to UV-B radiation during the propagation stage. Exploitation of such UV-mediated changes in plant growth and physiology during different phases of crop production could improve the long-term performance of transplant crops such as lettuce.
[147] Influence of Diffuse Glass on the Growth and Production of Tomato

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Keywords: haze factor, light transmission, development rate, fruit production, energy consumption

Abstract
There is a great deal of interest for diffuse glass in Dutch horticulture ever since higher light transmission values and the diffusing characteristics of diffuse glass have increased production for some crops. Thus an experiment was designed to examine the effects of a variation in haze factors and light transmissions for diffuse glass or a diffuse coating on the growth and production of tomato. The influence of diffuse glass with a haze factor of 45%, 62% and 71% and light transmission equal to or greater than that of standard glass, as well as standard glass with a commercial coating with a haze factor of 50% and 6% less light transmission than that of standard glass was compared to that of standard glass. The crops were planted mid December 2010 and grown to the middle of November 2011. The influence of diffuse light on light interception, crop morphology, photosynthesis and growth was measured and analysed. Light penetrated deeper into the crop resulting in a higher photosynthetic capacity in the lower canopy, but only in winter. Tomato grown under diffuse glass was more generative, transferring more into fruit production than vegetative growth, in comparison to standard glass or coated glass. The production under the three diffuse glass coverings showed a 7-9% increase in June relative to that under standard glass, and retained this increased production to the end of the year, ending with 8-11% more production. The most important reason for the increased production was an increase in individual fruit weight by 5-8 g. Plants grown under diffuse glass or coating were less susceptible to Botrytis spp. during the last months of the crop, possibly due to a higher dry matter content. The coating was applied in the beginning of May and the treatment continued through August when the global radiation diminished and more light was necessary in the crop and the coating was removed. The overall production under the coating was 5% higher than that under standard glass. An estimation of the benefits and consequences of diffuse light characteristics on the growth, development and production of tomato under Dutch conditions are discussed, along with recommendations for the optimal characteristics for diffuse glass.
[139] Plant Morphological and Developmental Responses to Light Quality in a Horticultural Context

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Keywords: assimilation light, LEDs, light quality, photosynthesis, photomorphogenesis

Abstract

Many horticultural crops (food and ornamental) are produced year-round in greenhouses at high latitudes, where the limited availability of natural sunlight restricts plant production during large parts of the year. To enable year-round plant production supplemental light is necessary to enhance photosynthesis, the primary process that drives growth and production. It is therefore not surprising that during the last two decades most of the research effort related to light in greenhouse horticulture has been directed towards optimizing the supplemental light use efficiency for photosynthesis, with emphasis on light intensity, duration and since recently also on light quality. For a long time, high pressure sodium (HPS) lamps were the preferred lamps for supplemental lighting. Nowadays, Light Emitting Diodes (LEDs) are gaining importance, mostly because of their potentially higher energy efficiency. Another important, less-well known attribute of LEDs is the much better possibility to control light quality. Besides the effect on photosynthesis, light quality also influences plant morphological and developmental processes, mostly mediated by a set of blue, red and far-red photoreceptors (i.e. cryptochromes, phototropins and phytochromes). Several of these processes, such as for instance internode and petiole elongation growth and leaf expansion have a direct impact on productivity via plant photosynthesis as mediated by light interception. Light quality can also induce leaf deformations and epinasty, which can negatively influence biomass production via reduced light interception. In ornamental crops, such as chrysanthemum, leaf deformations can have severe negative impact on the final ornamental value. Other important effects of light quality involve the development of stomatal density and the control of stomatal aperture, which both attribute to stomatal conductance and therefore potentially influence productivity, while also the leaf hydraulic resistance is influenced by light quality. This paper will overview some plant morphological and developmental processes that are influenced by light quality and are important for plant production in protected environments.
[103] Growth and Photosynthesis of Ornamental Plants Cultivated under Different Light Sources

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Keywords: Euphorbia pulcherrima, high pressure sodium lamps, light emitting diode, photosynthesis measurements, supplementary lighting

Abstract
New light sources for horticultural applications, intended to replace HPS lamps or fluorescent tubes, are currently being introduced in the market. Special attention is being devoted to LED technology, which permits optimisation of the spectral distribution of a light source. Consequently, LED lamps are generally assumed to be more efficient for driving photosynthesis than HPS lamps, for which much of the wavelength is outside the photosynthetic optimum range. In order to investigate the efficiency of LED technology in greenhouse applications, different types of LED lamps were compared with conventional HPS lamps in a series of experiments with Euphorbia pulcherrima. Cultivation took place in greenhouse conditions with natural daylight and 100 µmol m$^{-2}$ s$^{-1}$ supplementary lighting, supplied by white LED, red/blue LED or conventional HPS lamps (control). Plant development and photosynthesis rate were monitored over 4 months. Shoot elongation was highest for plants grown under HPS lamps, as was fresh weight. Measurements of photosynthesis under the different light sources revealed a trend for higher photosynthesis when white LEDs were used. However, when photosynthesis was measured at different light intensities using red/blue LEDs, plants grown under HPS lamps had the highest photosynthesis. The air temperature in the canopy was lower when the light was supplied with LEDs than with HPS lamps, thus delaying development. We concluded that the quality of light supplied was a significant factor for plant development in greenhouse conditions with supplementary light. There was a lack of correlation between measured photosynthesis and biomass production.
[146] Photosynthetic Light Responses in Relation to Leaf Temperature in Sun and Shade Leaves of Grapevines

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Keywords: Seasonal photosynthesis, temperature-dependency, Vitis vinifera ‘Semillon’, sun leaves, shade leaves, leaf morphology.

Abstract

How light attenuation influences the photosynthetic properties of sun and shade leaves within grapevine canopies was investigated by measuring photosynthesis along the shoots over the growing season, light responses of selected leaves at different temperatures and the specific leaf areas. Differences in photosynthetic rate became apparent in late spring when the canopies start to close; photosynthetic rates of shaded leaves peaked at 6 μmol (CO$_2$) m$^{-2}$ s$^{-1}$ while sun leaf rates peaked at 11 μmol (CO$_2$) m$^{-2}$ s$^{-1}$, and the differences accentuated as the season progressed. By mid-season (December), light-saturated photosynthetic rates at 12 μmol (CO$_2$) m$^{-2}$ s$^{-1}$ were significantly higher in sun compared with shade leaves at 5.5 μmol (CO$_2$) m$^{-2}$ s$^{-1}$. Basal and mid-node position leaves gradually become shaded while leaves at the apical shoot end still maintained high photosynthetic rates. Changes in leaf morphology also occurred, with the specific leaf area of the basal leaves shifting from sun to shade type leaves. Photosynthetic light responses showed typical sun-shade contrasts with higher $P_{\text{max}}$, lower photon yields and higher light-saturation in sun leaves. However, these responses were highly temperature – dependent and $P_{\text{max}}$ was highest at 25°C and declined at 20 and 35°C and above. By contrast, light intensities required to saturate photosynthesis increased from about 600 μmol (photons) m$^{-2}$ s$^{-1}$ at 20°C to over 1100 μmol (photons) m$^{-2}$ s$^{-1}$ at 35 - 40°C. We conclude that although shade has a marked impact on photosynthesis and leaf morphology, the temperatures that the vines experience over the growing season also have a marked impact on the photosynthetic responses to light.
The Effect of Irradiating Adaxial or Abaxial Side on Photosynthesis of Rose Leaves

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Key words: *Rosa hybrida* L., intra canopy lighting, absorption, transmission, reflection

Abstract

In many cropping systems most of the light irradiates the adaxial side of leaves. However, in cropping systems with intra canopy lighting a reasonable fraction of light may irradiate even the abaxial side of the leaves. The aim of this study was to investigate the effect of irradiating the abaxial leaf side compared to irradiating the adaxial side, in rose plants grown in glasshouse with the bending technique. The instantaneous effects on the optical properties and the light response of photosynthesis were analysed in intact leaves. Results demonstrated that the rate of net photosynthesis was higher when leaves were lighted from the adaxial side compared to the abaxial side. This was the consequence of both a higher light absorption and higher quantum yield (photosynthesis per unit absorbed light) in adaxial-lighted leaves.
[214] Effects of Continuous Lighting with or without a Diurnal Temperature Difference on Photosynthetic Characteristics of Tomato Leaves

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Keywords: DIF, gas exchange, photoperiod, physiological disorder, Solanum lycopersicum, supplemental lighting

Abstract
Too long photoperiods such as continuous lighting (CL) lead to chlorosis-like physiological disorder (CL-induced injury) in leaves of tomato. On the other hand, CL-induced injury was not observed where there is a diurnal temperature difference (DIF) of 8-10°C or more. The objective of this study was to investigate the interactive effects of photoperiod and DIF on photosynthetic characteristics of tomato leaves. Four-week-old plants were treated with a photoperiod of 12 (P12) or 24 h (P24) and a DIF of 10 (25/15°C, D10) or 0°C (20/20°C, D0) for 12/12 h day/night cycle. After two-week treatment, the light-limited ($A_{200}$) and light-saturated ($A_{1,600}$) rates of photosynthesis at photosynthetic photo flux densities of 200 and 1,600 μmol m$^{-2}$ s$^{-1}$ and chlorophyll (Chl), ribulose-1,5-bisphosphate carboxylase/oxygenase (Rubisco) and N contents of leaves were examined. Severe and moderate CL-induced injury was observed on leaves in P24D0 and P24D10, respectively, but not at all in P12D10. In P12D0, the whole leaves became pale green. $A_{200}$ was significantly lower in P24 treatments than in P12 treatments. There were no significant differences in $A_{200}$ based on DIF. In contrast, $A_{1,600}$ was significantly lower in D0 than in D10 irrespective of photoperiod. Thus, no interactive effect of photoperiod and DIF was found in the gas-exchange rates, suggesting that they affect different processes in leaf carbon metabolism independently. The Chl and Rubisco contents in P12D0 were significantly lower than those in the other treatments, associated with a lower leaf N content. Although the lower $A_{1,600}$ in P12D0 was probably related to the lower Rubisco content, the other differences in gas-exchange rates among treatments cannot be accounted for by the differences in the amounts of photosynthetic components examined. More detailed physiological and biochemical characterization is necessary to understand the complex effects of photoperiod and DIF on leaf photosynthesis.

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Keywords: diffused light, shading screen, plant temperature, haze factor

Abstract

Plants, cut flowers and vegetable crops, cultivated in greenhouses need to be shaded from time to time against too intense sun radiation. Shading screens are realizing this need. Depending on the location, in relation to the equator, and the type of crop, the shading level varies from 15% till 90%. Anticipating on the recent interest and proven positive effects of diffuse light Svensson has introduced shade screens that not only provide the required shade but also change direct sunlight into diffuse light. These shade screens are available in shade percentages of between 25 and 70% with a haze factor between 45 and 100%. Apart from the general positive effect of diffuse light in terms of a higher growth rate and a better quality, research by Svensson has shown that this new type of shading screen offers some extra positive side effects: 1. Diffuse shade screens allow for a 10% lower shade percentage, thus 10% extra light, resulting into a further increase in growth and yield. 2. Changing from aluminum to white strips results in a lower greenhouse temperature on sunny days (up to 2.5 °C), which further promotes growth speed and quality. The light diffusing shading screen has been introduced three years ago and found its way to the market all over the world.
Photomorphogenic Effects on Tomato Crop from Blue Light Manipulation through Photoselective Greenhouse Films

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Keywords: photoselective, blue light, greenhouse film, tomato

Abstract

The second most discussed effect of solar radiation after photosynthesis is photomorphogenesis and its specific effects on plant development. Differently from the red and far red regions of the electromagnetic spectrum, the plant responses to changes of radiation in the blue portion (400 to 500 nm) of the spectrum, although widely reported in the literature, are difficult to interpret at the level of plant physiology. One way for modifying the solar radiation impinging on plants is to play with the spectral characteristics of the transparent cover material of greenhouses. Plastic materials are particularly versatile in this regard, as they can be easily additivated with photoselective compounds that change the light spectrum that goes through the cover. This paper reports the results of a study where three different thin polyethylene films were used as greenhouse covers for a typical tomato cropping in the Mediterranean region (38° latitude). One film was a commercial standard film and was used as a reference, a second film contained a yellow pigment with absorption maximum at 450 nm and a third film contained a fluorescent film with emission maximum at 455 nm. A full environmental, spectral and agronomical dataset was collected during the study that lasted from January to June and corresponded to the entire cropping cycle of the plants. In terms of fruit yield, it was found that under the reference and yellow films the same number of fruits was collected, while the fluorescent film gave on average 33% more fruits. In terms of production weight, as compared to the reference film, the yellow and the fluorescent films provided a measured value respectively of +5 and +19%, the former being statistically not significant, while the latter confirmed the higher productivity observed as fruit number.
[292] Growing Value with LEDs in Horticulture

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Keywords: LED technology, light, plant growth, development, quality, light recipe, greenhouse, multilayer.

Abstract
The current environment as well as the world economic situation requests a high level of technical innovation to cover future problems as lack of fossil energy, water availability, scarcity of agricultural land to be able to feed the rising human population as well as keeping our nature and environment in a good shape. Lighting technology, specifically LED technology is one of the technologies that can help in producing crops and flowers in a more effective and sustainable way around the world. Successful and sustainable light solutions depend on a combination of specialized knowledge about plant growth, combined with high-quality LED systems technology. Philips has a long history in developing lighting solutions for horticultural applications. Since 6 years developing light recipes (mainly enabled by LED technology) for many different crop growth applications in greenhouses as well as in multilayer of city farms has been a key activity. Together with university research and practical field tests with growers, specific light recipes are build and combined with the latest LED technology. This poster presents outcomes of Philips light recipe development program in various plant production segments in the greenhouse and multilayer situations around the world: e.g. growth and production results from rose, tomato, potted plants, bulbs, and/or leafy vegetables. It shows how applying specific (LED)-light recipes at the right moment and stage of the plant growth can bring much efficiency and increase in quality and/or speed of production in various different cultivation systems.
[299] Diffuse Glass and Modern Glass Developments for Horticultural Applications

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Keywords: diffuse glass, light transmission, low emission, double glass, light spectrum

Abstract
Glass and greenhouse have a long story together. First was sheet Glass commonly used until Float Glass came into picture. With better mechanical resistance and better optical properties, the rising of the Float Glass was a first step to a higher awareness of the importance of a good Glass quality covering. Float Glass process was invented in 1950’s and this product is nowadays widely spread in the central and northern greenhouse construction, plastic being more used in the southern countries. Researchers and growers have pointed out the important characteristics that a glass should provide like Light Transmission / Diffusion / Energy control. All this key elements are to be tuned with glass and for the last 5 years many improvements have been made in that direction:
- Higher Light transmission in different spectrum range (UV, PAR, NIR, IR) considering all incident angles,
- Different diffusion percentage.
- Low Emissivity Glass and double Glazing
The goal to achieve is to broaden the understanding of Light incidence effect and to be able to custom device a Glass with suited properties for each type of crop. The 3 above stated elements are the core of our research along with condensation influence.
[259] Light Transmission through Greenhouse Covers

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Keywords: photosynthetic active radiation, glass, plastic film, screen, photoselectivity

Abstract
The selection of the greenhouse covering material is essential for the success of the protected horticultural production, and among the properties of a material (optical, chemical, physical, etc…) the most important for the growers are the optical properties, as they define the amount and quality of solar radiation entering the greenhouse and thus the amount of photosynthetic active radiation (PAR) that will be intercepted by the crop, determining the production of dry biomass. However, there is no such a material that can be considered optimum, in terms of optical properties. Therefore, the grower has to choose a suitable covering material, with the optimum optical properties for its specific growing conditions. The most important covering materials used in horticulture in terms of covered surface in the world are flexible plastic films, glass and different types of screens. The industry is continuously incorporating new optical properties to these materials that may be of interest for the growers depending on their specific growing conditions. In the case of glass recent developments tested in The Netherlands include anti-reflection coatings, to increase the global radiation transmission at low sun radiation incident angles; new glasses have also been tested with different levels of light diffusion with none of minimum loss of global transmission, with very promising results in terms of light use efficiency by the crops, and thus, interesting yield increases. Other types of filters being tested are near infrared filters (absorption or reflection) both in glass and in plastic films, with results that suggest that reflection is preferable and that few materials are available that do not affect PAR transmission too. UV filters have provided very remarkable results in limiting the infestation by pests in plastic films. In the case of screens, a large variability of materials are available (in terms of porosity, colour of the threads, photoselective filters, etc.), and recently have been subject of different studies to understand better the combination of direct transmission of light through the pores and the interaction with the threads of the incoming radiation.
[173] Solar Transmittance of Greenhouse Covering Materials

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Keywords: PAR transmittance, light transmittance, AR glass, PMMA, PE-film, ETFE-film, drop condensation, dirt

Abstract

Light is an important growth factor in greenhouses. The choice of a covering material strongly influences the light transmittance of a greenhouse. For low energy greenhouses double and even triple covering materials are available. Also covering materials with higher light transmittances than conventional float glass are available. When these materials are used for double glazing the light transmittance might be equal or even higher than that of single glazing units. The aim of this project was to measure the transmittance of different covering materials for solar radiation and PAR under greenhouse conditions. For this purpose 20 different covering materials were installed on the southern roof of an east-west oriented greenhouse. Underneath these specimens, PAR and solar radiation were continuously measured and compared to the outside conditions from 2006 to 2011. Transmittance was determined for different incident angles of solar irradiation, direct and diffuse radiation, as well as under the influence of condensation, dust and dirt accumulation, and the aging of the materials. Drop wise condensation on the inner surfaces of the covering materials reduced PAR transmittance. Dust had an impact on the transmittance as well but its influence varied over time since dust particles accumulated during dry periods were partially removed by rain. An influence of aging on the materials’ light transmission could, however, not yet be detected.

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Keywords: shading, porosity, air temperature, climate heterogeneity

Abstract
In this paper the effect of solar radiation distribution in a typical screenhouse was numerically investigated, taking into account the thickness and aerodynamic properties of the screen and its spectral, optical and thermal properties. A two dimensional computational fluid dynamics (CFD) model was used to render the building's geometry, and the Discrete Ordinates (DO) model to simulate the radiation transmission through the screen, taking into account its spectral distribution in three wavelength bands. The results show the influence of the properties of screen materials on the distribution of solar radiation, air velocity and air temperature inside the screenhouse. Decreasing screen porosity resulted in an increase of air temperature and in a decrease of air velocity under the screenhouse. In higher screen porosities, the flow was dominated by buoyancy effects, showing the importance of internal temperature gradients. Screening materials with high absorbance reduce internal solar radiation and air temperature and lead to the development of secondary recirculation where the air is trapped.
The Effect of Gutters and Roof Vents on Light in a Multi-Span Greenhouse

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Keywords: PAR, ventilation, roof vents, screens, shading

Abstract
To effectively ventilate large, multi-span gutter connected greenhouses, in the Mediterranean region, it is usually required to use both side and roof vents. Since the roof vents and gutters are constructed of opaque structural elements and since the vents are generally covered with insect-proof screens, they may partially block the penetration of solar radiation into the house. The present work characterizes the disturbance induced by the vents and gutters to the level and distribution of light reaching the plants. Experiments were carried out in a typical multi-span greenhouse with roof vents on which insect-proof screens were installed. To measure the PAR (photosynthetically active radiation) above the plants a sensor was placed on a cart that moved along a horizontal beam positioned 2.6 m above ground level inside the greenhouse; a motorized system moved the trolley continuously across more than one greenhouse span back and forth throughout the day. Two additional sensors were used as reference: one was located inside the greenhouse, just below the plastic cover at the greenhouse ridge, to compensate for the effect of the cover type and accumulated dust on the cover, and the other was located outside the greenhouse to measure ambient PAR levels. The mean daily PAR level immediately below the greenhouse cover was 64% of the level outside the greenhouse. Above the crop the mean daily PAR level over one greenhouse span (including regions that were shaded by the gutters and vents) further decreased and was only 47% of the outside level. Results show that the structural elements of the roof vents significantly affect light distribution. At midday the light level in the region below the roof vents may drop by nearly 27% in comparison to the level measured at the centerline of the greenhouse span. Thus, although roof vents improve natural ventilation they may deteriorate light level and its distribution.

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Keywords: transmissivity, PAR, solar IR, table grapes, leaf functioning

Abstract

Vineyard can be covered with plastic materials in order to protect vines and grapes from adverse weather conditions and to influence the microclimate, aiming at modifying the growing conditions in comparison with those in open field. This technique may advance berry ripening in table grapes. The radiometric properties of the plastic covering films influence canopy microclimate, leaf functioning, yield components and berry quality of grapevines. Three polyethylene films were tested in Southern Italy in 2011: two commercial films, coded “YELLOW” and “NEUTRAL” according to their colour, and an experimental film coded “BASF”, as it was provided by BASF Italia Srl. The plastic films were tested on a seedless grapevine variety (Vitis vinifera cv. Sublima) grown with a deficit-irrigation. The radiometric tests were carried out in laboratory. In the field, environmental parameters, such as photosynthetic photon flux, air temperature and relative humidity, were recorded. Moreover, the main parameters of vine ecophysiological activity, such as leaf gas exchange and vine water status, were investigated. At harvest, the vine productivity and the grape quality were assessed. The BASF and the YELLOW films were characterised by the PAR total transmissivity coefficient equal to 86.3% and 86.0%, respectively; the same coefficient was lower for the NEUTRAL film (81.8%). The YELLOW film was characterised by the highest solar IR transmissivity coefficient (90.0%), while the BASF film by the lowest one (81.0%). By analyzing the yield components, berry and cluster weight were found higher under the BASF film than under the other two types of covering films.
[246] Yellow and Red Sweet Pepper Quality under Photoselective Screens and Field Crop Conditions

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Key words: Capsicum annuum var. annuum, protected crop, nutritional quality, physico-chemical

Abstract
Photoselective screens increase the diffused radiation, attenuating the extreme climatic conditions and allowing for greater efficiency in the production of vegetables in protected cultivation. However, there are little information about the effect of these screens on physical chemistry and nutritional quality of colored sweet peppers. This research evaluated the effect of blue and red photoselective screens on the quality of two cultivars of the hybrids sweet peppers in Brazilian Midwest climatic conditions. The Eppo (yellow) and Margarita (red) hybrids, from Syngenta Seeds, were cultivated in 40% shading screenhouses. Field plots were used as control. It were evaluated 15 fruits per plant from each hybrids harvested when they had commercial characteristics, by random selection of plants. It was evaluated the ratio between the total plant mass and length in natura fruits. In order to evaluate the effect of the treatments (screens and field condition) under the fruits quality in terms of nutritional parameters were measured: pH, total soluble solids (°Brix), titratable acidity, centesimal approximated composition and vitamin C by the classical methods of analysis. The mean values of the weight / length ratio varied from 15.20 (EPPO field conditions) to 19.81 (EPPO red screen). The cultivation of pepper in red screens promoted fruits with the highest weight per centimeter. The soluble solids content ranged from 6.37 (Margarita blue screen) to 8.45 (Eppo field conditions). The yellow sweet pepper had a greater concentration of soluble solids in comparison to red. There was no difference in moisture content and vitamin C between the hybrids and the crop conditions. The photoselective screens have promoted differences in some physico-chemical characteristics of fruits, but not in the nutritional quality.
[264] Light and Energy Saving in Modern Greenhouse Production

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Keywords: light, energy, carbon dioxide exchange rate (CER), light use efficiency (LUE)

Abstract
The greenhouse industry tries to make as much use as possible of the natural light available to crops. The amount of available light is reduced by covering material and greenhouse construction, presently a light reduction of around 30%. In order to save energy, double covering material is often used in addition to one or two energy curtains. These results in a reduction of 70-80% of the natural light compared to outside the greenhouse and an increase in the air humidity, but also a reduction in energy consumption in the same range. Artificial lighting, where up to 40% of the electricity is converted to photosynthetic active radiation (PAR) can be used in connection with different energy saving methods and still ensure good crop growth. Maximum energy saving, and using CO₂ combined with artificial light, brings us to the concept of semi-closed greenhouses. Better methods for re-using surplus energy must be developed for this concept.
[151] Energy-efficient, Uniform, Supplemental Plant Lighting for Research Greenhouses

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Keywords: research greenhouse, supplemental lighting, plant lighting uniformity, plant lighting efficacy, energy efficiency, luminaire, PPF, PAR

Abstract

Teaching and research greenhouses at universities and research stations typically require supplemental plant lighting. Lighting for research greenhouses is unlike lighting for commercial greenhouses. Aisles are often wider to permit group access, only parts of the greenhouse may contain plants, and light requirements may differ from place to place throughout the growing space. This paper describes how an innovative luminaire reflector design can provide rectangles of light, uniformly, where and when required. With the luminaires housing Philips Elite AGRO® 315 W ceramic metal halide lamps, mounted vertically, as an example, 280 μmol m⁻² s⁻¹ can be provided 1.07 m below the luminaire, with no light falling outside the boundary of the lighted area and providing a 0.91m x 1.83m lighted area with a uniformity coefficient of variation (CV) of 0.05 over the entire pattern. Luminaires can be mounted to provide larger or smaller lighted rectangles, or spaced to create adjoining or overlapping rectangles, creating lighting patterns with greater or less quantum flux, greater or less vertical uniformity, and different lighted areas, all with comparable CV values. Sections of benches can be controlled individually to provide different daily light integrals, or other control protocols may be used. The luminaire was designed using commercial computer software and this paper presents light values from those simulations to demonstrate the flexibility of the resulting luminaire. The paper discusses a multiplicity of ways to combine and overlap light patterns to produce a wide range of uniform quantum flux, while retaining the capability to light plants without wastefully spilling light onto the aisles, or lighting sections of benches temporarily empty of plants.
[120] Effects of Light Quality and Light Period on the Flowering of Everbearing Strawberry in a Closed Plant Production System

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Keywords: blue light, continuous lighting, flower differentiation, LED, recombinant protein production

Abstract

We studied the effects of light quality and light period on the flowering of everbearing strawberry plants (Fragaria × ananassa Duch. ‘HS138’) during the nursery period, to increase the fruit production efficiency of transgenic strawberry plants in a closed plant production system. The plants were grown under a 16-h light period versus continuous lighting illuminated by white fluorescent lamps, blue LEDs, or red LEDs. Flowering was significantly earlier in plants grown under (1) blue LEDs compared to red LEDs, irrespective of light period, and (2) continuous lighting compared to the 16-h light period, irrespective of light quality. The results show that blue light advances the flowering of everbearing strawberry plants compared to red light. While continuous lighting by blue LEDs advanced flowering and shortened the vegetative growth period, the fruit yield of plants grown under continuous lighting by blue LEDs was higher than that of plants grown under our standard cultivation conditions (i.e., 16-h light period by white fluorescent lamp). In conclusion, shortening the nursery period by adjusting light quality and light period increased fruit production efficiency compared to standard cultivation conditions.
Flexible Spectra LED Arrays for Sole Source Lighting and Growth Comparisons with Conventional High Pressure Discharge Lighting Using *Arabidopsis thaliana*

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**Keywords:** artificial lighting, controlled environment, light emitting diode, metal halide lamp, tungsten halogen lamp

**Abstract**

High-power (HP) light emitting diodes (LEDs) offer exciting opportunities for plant lighting research. LED technology now provides intensity levels and wavelengths potentially well suited to study plant growth and development under ‘realistic’, or specific artificially manipulated radiation environments. However, while the ability offered by LEDs to specify precisely the spectral composition provides greater flexibility than conventional broad-spectrum lighting, it also presents significant challenges in characterising what might constitute an ‘optimum’ light spectrum for plant growth. Plant growth and development under custom-designed HP LED arrays, capable of supporting up to 700 LEDs and as many as 10 spectral peaks, were studied within the controlled environment rooms at the New Zealand Controlled Environment Laboratory (NZCEL). White-based and red-blue (RB) based LED spectra, consisting of multitude peaks between 400 nm and 740 nm, were examined for their potential as sole-source lighting rigs for growing *Arabidopsis thaliana*. Development rates and biomass were measured from germination to seed set under 200 µmol m$^{-2}$ s$^{-1}$ and 400 µmol m$^{-2}$ s$^{-1}$ photosynthetically active radiation (PAR), provided by HP LED arrays or the standard high pressure discharge (HID) metal halide and tungsten halogen lighting rig used within NZCEL. Development rate was comparable under the two light sources, but greater biomass obtained under LED suggests an additional potential benefit of LEDs over conventional HID lighting.
[188] Developing LED Light Recipes for Multi-layering Systems: LED as an Alternative for HPS in forcing of Rhododendron simsii

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Keywords: LED assimilation light, forcing, flowering, multi-layering cultivation

Abstract
Recent developments show that Light Emitting Diodes (LED) can most likely not replace High Pressure Sodium (HPS) lights for full production cycles. However, the typical discrete spectral properties of LED’s makes them highly suitable for (1) steering plant or flower development at specific growth stages and (2) providing optimal light at close distances to the plant, e.g. in multi-layered systems. We explored this potential to steer flowering induction in the Ghent azalea (Rhododendron simsii). We developed an optimal light recipe for multi-layered forcing. Rhododendron simsii cultivation necessitates a forcing period in order to obtain intense flower colours and uniform flowering. Forcing requires three weeks 21°C, 70-80% RH and 91µmol/m²s light intensity. This means extreme high energy input in winter. HPS lights have a high degree of heat radiation preventing their use in multi-layered systems. Since LED’s seems suitable, to determine the optimal wavelength composition and intensities we compared four LED-units equipped with different amounts of Red, Far-Red and Blue light with conventional HPS lamps and a control. Except for the control, none of the lighting treatments received external sunlight to mimic multi-layered conditions. The experiment was repeated eight times. Measurements indicated increased flower size under additional lighting. All three wavelengths are necessary for optimal flower quality, although red light is of far greater importance then blue light. Light intensities of 91µmol/m²s with LED give comparable or even better results than HPS. With LED, the necessary lighting period can be reduced compared to HPS lights. Our results show potential for the use of LED in multi-layered systems for the forcing of azalea, with potential to reduce energy cost remarkably.
Light-emitting Diodes: On the Way to Combinatorial Lighting Technologies for Basic Research and Crop Production

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Keywords: photomorphogenesis, light-emitting diodes, combinatorial lighting technologies, *Brassica juncea*, *Lactuca sativa*, *Ocimum gratissimum*, *Coleus blumei*, *Tagetes patula*

Abstract

Recently developed high-brightness light-emitting diodes (LEDs) offer new opportunities in the future plant lighting technologies. Application of the new-generation of light sources provide remarkable conditions for the control of photomorphogenesis in plants, accelerating the breeding cycles, improving food quality, and energy saving. LEDs appear to be powerful instruments for light spectrum manipulation for crop growth regulation. Combinatorial lighting technologies will emerge on the basis of LED application: variable-spectrum lighting modules could be designed using various combinations of high-power monochromatic (narrow-band) LEDs. In our experiments, we studied application of LEDs with the narrow-bandwidth wavelength emissions in the photocontrol of basic physiological processes in several vegetable and ornamental crops. Plants were grown in controlled environment. PPF was provided by LED panels which were composed of blue and red light LEDs with the peak wavelengths at 460, 635, and 660 nm, respectively. Various spectral photon distribution in the long-wave region was provided using 635 and 660 nm LEDs separately or in combination. Changes in plant growth responses, phase transitions, pigment accumulation were observed in various light environments. Experimental data show that different LED systems with discrete wavelength ranges peaking at blue and red spectral regions can be used effectively both for basic research of plant photomorphogenesis and for the fine tuning of physiological processes in plants and optimization of the species/cultivar light regimes.
Using LEDs to Quantify the Effect of the Red to Far-Red Ratio of Night- Interruption Lighting on Flowering of Photoperiodic Crops

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Keywords: floriculture crops, greenhouse lighting, light-emitting diodes, long days, phytochrome

Abstract
Many commercial floriculture growers use incandescent (INC) lamps for photoperiodic lighting because they are inexpensive and emit an effective spectrum. However, since INC lamps are energy inefficient and are being phased out of production, we investigated the use of light-emitting diodes (LEDs) for regulating flowering of the long-day plants petunia (Petunia multiflora 'Easy Wave White') and snapdragon (Antirrhinum majus 'Liberty Classic Cherry'), and the short-day plant marigold (Tagetes erecta 'American Antigua Yellow'). In addition to a 9-h short-day (SD) control, 4-h night interruption (NI) treatments delivered during the 15-h night were provided by INC lamps or LEDs with seven different red (R, 600 to 700 nm) to far-red (FR, 700 to 800 nm) ratios (R:FR) ranging from only R to only FR. Under the LED treatments, the estimated phytochrome photoequilibria ($P_{FR}/P_{R+FR}$) in plants ranged from 0.16 (under FR light) to 0.89 (under R light). Seedling height and node number at transplant, date of first visible bud, date of first open flower, flower number, plant height, node number below the first flower, and lateral branch number were recorded. The INC NI (R:FR=0.59) and LEDs with an R:FR of 0.66 to 2.38 and 0.28 to 1.07 promoted flowering the most in petunia and snapdragon, respectively, and LEDs with an R:FR ≥0.66 inhibited flowering the most in marigold. There was little or no effect of NI treatments on inflorescence or flower bud number for marigold and petunia, but the treatments that accelerated flowering of snapdragon the most generally resulted in fewer flower buds. Plant height was greatest under moderate R:FR in marigold and petunia, while snapdragon exhibited the opposite trend. We conclude that the LED treatments with a moderate R:FR were effective both for promoting flowering in petunia and snapdragon and for inhibiting flowering in marigold.

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Keywords: PAR, DLI, greenhouse, light-emitting diode, Solanum lycopersicum, spectral quality.

Abstract
Supplemental lighting is proven to increase transplant growth and quality in vegetable nursery greenhouses. To evaluate plant responses to supplemental LED light quality, tomato seedlings (cv. Komeett) were grown in a greenhouse (Tucson, AZ, USA) until the second true leaf stage with 55.5 ± 1.4 μmol m⁻² s⁻¹ photosynthetic photon flux of supplemental LED lighting (18-hour photoperiod). Treatments consisted of different red : blue photon flux ratios (1) 100 % red : 0 % blue, (2) 96 % red : 4 % blue, (3) 84 % red : 16% blue and a control without supplemental lighting. These ratios were evaluated under low and high daily solar light integrals (DLI) (8.9 ± 0.9 and 19.4 ± 1.9 mol m⁻² d⁻¹, respectively) created by different shade screens deployed in the greenhouse. Growth and morphological parameters including dry shoot mass, leaf count, stem diameter, hypocotyl length, leaf area, and chlorophyll concentration indicated the benefit of supplemental light, especially under low DLI, but there were no significant differences among different red : blue ratios regardless of DLI. The seedlings also exhibited the same high photosynthetic capacity measured under 1000 μmol m⁻² s⁻¹ PPF, ambient temperature and CO₂ concentration regardless of the red : blue ratios. From this preliminary study it seems that for ‘Komeett’ tomato seedlings grown in greenhouse, use of 100 % red LED supplemental lighting was sufficient and no additional blue light was required regardless of DLI.
[130] A 3D Model of illumination, Light Distribution and Crop Photosynthesis to Simulate Lighting Strategies in Greenhouses

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Keywords: functional-structural plant model, HPS lamps, LED, ray tracer, crop structure

Abstract
A functional-structural model for a tomato crop, situated in a greenhouse, was developed to calculate the most efficient lamp (HPS, LED) positions and crop structure, with the objective to reduce energy consumption and improve light use efficiency. The model was built within the GroIMP platform and written using the dedicated modelling language XL. The entire production system is described as a 3D scene including a virtual greenhouse with the crop and light sources (natural light and lamps). The pathways of individual light rays were modelled multi-spectrally with an inversed path tracer. Plant organs (leaves, internodes, flowers, fruits) are the basic units of the multi-scaled, fully object-oriented model. Surface textures and colours were included for all 3D objects. For the current objective a static 3D mock-up of an existing crop was used. Measured 3D distribution pattern and spectrum of light emitted by the lamps were fed into the model. The modelled horizontal light distribution agreed well with measurements. Effects of different positions, reflector types, and spectra of lamps, and plant architectural and optical properties on light distribution and photosynthesis were evaluated. In total 10 illumination scenarios were simulated to quantify crop absorption and loss of light. In summary, a more efficient illumination strategy was predicted when the light was more focused on the crop by lamp reflectors, at inter-lighting (LEDs), and with a reflecting screen above the lamps. The inter-lighting strategy also resulted in a relative increase of light intercepted by fruit and stems relative to lighting from the top of the crop.
Two Distinct Phytochrome-mediated Regulation Systems Contribute to Night-break Response in Flowering of the Short-day Plant Chrysanthemum

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Keywords: chrysanthemum, flowering, light quality, night break, phytochrome

Abstract
Chrysanthemum (Chrysanthemum morifolium Ramat.) is a short-day plant that initiates flowering when nights are longer than critical night length, and flowering is inhibited by an illumination at the middle of the long night (night break; NB). NB with red light effectively inhibits flowering, which is repromoted by subsequent exposure to far-red (FR) light (Cathey and Borthwick, 1957). This suggests the involvement of phyB-type receptors. To elucidate the role of light signalling on photoperiodic flowering in chrysanthemum, flowering response under various photoperiodic treatments was tested using different light qualities. When white light was used during the main photoperiod, NB with red light had the strongest effect on inhibition of flowering, whereas NB with blue (NB-B) or far-red (NB-FR) light had little inhibitory effect. However, with a main photoperiod of blue light (B_NB), NB-B and NB-FR strongly suppressed flowering, which suggests the involvement of a blue/FR light-absorbing photoreceptor such as phyA. Moreover, the inhibitory effect of NB-B was partially reversed by subsequent exposure to a FR light pulse. The inhibitory effects of NB-B and NB-FR were cancelled when red light supplemented blue light during the main photoperiod (BR_NB). Although B_NB and BR_NB similarly affected the expression of circadian clock-related genes, only B_NB suppressed expression of the chrysanthemum orthologue of FLOWERING LOCUS T (CmFTL3). Therefore, at least two distinct phytochromes may be involved in NB-induced inhibition of flowering, and light quality during the main photoperiod affects sensitivity to light irradiation at the middle of the flower-inductive dark period.
[137] Control of Plant Morphology by UV-B and UV-B-Temperature Interactions

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**Keywords:** morphology, temperature, shoot elongation, UV-B

**Abstract**

Chemical plant growth retardants (PGRs) are used to control height of greenhouse grown plants. Increasing environmental awareness has strongly promoted interest in alternative methods. Since UV-B is known to reduce shoot elongation, the use of supplemental UV-B radiation or UV-B and UV-A-transmitting cladding material such as F-clean appears highly interesting. Substantially reduced shoot elongation was observed in a variety of bedding and pot plants produced in the spring in Norway at 59ºN under F-clean compared to polyethylene. Furthermore, although natural UV levels are low in the autumn at 59ºN, a 30% reduction in the use of PGRs as a consequence of reduced shoot elongation were then observed in poinsettia (Euphorbia pulcherrima) under F-clean. Poinsettia exposed to short diurnal periods of UV-B radiation in the night, also showed reduced internode lengths and increased branching. Effect of UV-B and its interaction with temperature on morphology was investigated using pea (Pisum sativum) as a model system. The UV-B stimulated reduction in shoot elongation was substantially enhanced when given in combination with a temperature drop treatment. Also, plants were then less susceptible to UV-B-induced damage, indicating an effect of temperature reduction on UV-protective mechanisms.
Short Main Shoot Length and Inhibition of Floral Bud Development under Red Light Can Be Recovered by Application of Gibberellin and Cytokinin

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Keywords: floral induction, gene expression, LED, light quality, shoot elongation

Abstract

Light quality is one of the important factors controlling the morphogenesis of plants. In some species, blue light promotes shoot elongation and flowering, whereas red light inhibits these responses. In this study, we investigated the effects of light quality and application of some phytohormones on growth and floral induction in petunia ‘Petunia hybrida cv. Baccarat blue’. Petunia plants with five true leaves were exposed to white fluorescent lamps, or red or blue LED light in growth cabinets. Plant height was reduced under red light compared to blue light treatment. In addition, floral bud formation was drastically inhibited under red light. Application of GA3 enhanced main shoot elongation and floral bud formation under red light, but did not promote further floral bud development and flowering. However, BA application increased expression of the PhFT (FT like) and PhFBP20 (SOC1 like) genes, and promoted initiation of floral buds and flowering under red light without much elongation of the main shoot. GA1 and GA4 contents in petunia decreased under red light compared to blue light treatment. Thus, the dwarfed plant shape under red light is linked to low content of active GA. Indeed, the expression of a PhGA20-oxidase gene under red light was low, resulting in low levels of active GA. However, in the case of petunia, GA might not have much influence on floral induction and flower bud development. On the other hand, cytokinin contents and dose response to BA application were not so much influenced by the light qualities. Thus, cytokinin seems to have an ability to promote floral bud formation through the up regulation of SOC1-like floral induction genes under red light. However, the effect of BA on floral induction may be independent from the physiological regulation systems controlled by light quality.
Red and Blue Light effects during growth on Hydraulic- and Stomatal Conductance in Leaves of Young Cucumber Plants

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**Keywords**: *Cucumis sativus*, Leaf Hydraulic Conductance, Light Quality, Stomatal Conductance

**Abstract**

In greenhouses at high latitudes artificial lighting (AL) is applied in winter as supplementary light source to increase photosynthesis and plant growth. Additionally, AL is already solitary used in closed systems for commercial plant production. The spectral composition of AL (light quality) usually deviates from solar light, causing long-term morphological and developmental changes as well as short-term functional responses in plants. Light quality directly influences leaf photosynthesis via changes in stomatal aperture and photosynthetic quantum efficiency. Stomatal conductance ($g_s$), however, also depends on leaf characteristics such as the size, number, and distribution of stomata over the upper and lower surfaces of a leaf, which develop on the long-term. Besides, stomatal aperture is also influenced by leaf water status, while vice versa, leaf water status depends on transpiration and $g_s$. Leaf water status is also affected by its internal conductance for (liquid) water transport through the leaf ($K_{leaf}$). It has often been suggested that $g_s$ and $K_{leaf}$ should be properly dimensioned for appropriate control of $g_s$ in relation to water stress. We investigated long-term effects of light quality on $K_{leaf}$ and $g_s$ in leaves of young cucumber plants, which were grown under red (R), blue (B) or combined red and blue (RB) LED (light emitting diode) light. Light quality-induced differences in $g_s$ were largely due to differences in stomatal density, which were mainly due to differences in epidermal cell size. $K_{leaf}$ was influenced by light quality and positively correlated with changes in $g_s$ across the applied light qualities. Our results show that in horticultural production systems where AL is used, light quality effects on both plant photosynthesis and plant water relations are important for the efficient production of high quality plants.
Abstract

The growth of plants may be divided into two stages: (1) the supply of carbohydrate from photosynthesis, and (2) the demand of carbohydrate for bio-synthesis, leading to structural growth. Normally supply exceeds demand in cool temperatures, while the opposite is true at warm temperatures. To match supply and demand, photosynthesis is inhibited in the cool temperature range and synthesis (growth) is inhibited in the warm temperature range. The signal for the supply-demand imbalance is presumably obtained from the state of the carbohydrate pool (temporary storage), which fluctuates between a maximum level around sunset and a minimum level around dawn. A simple model, that incorporates this presumed mechanism, is presented and used to estimate the response of structural growth and of carbohydrate content to light and temperature in the cool and warm temperature ranges. The model predicts maximum growth rate at an intermediate temperature, which is positively correlated with light level. It also predicts an increase of non-structural carbohydrate at cool temperatures. Both predictions are in qualitative agreement with observations. The model may be considered as an attempt at a mechanistic explanation of the observed phenomena, but experimental and modelling deficiencies currently restrict its predictions to the general features of the process only.
[216] Prospecting the Use of Artificial Lighting for Integrated Pest Management

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Keywords: greenhouse crops, artificial lighting, light intensity, wavelength distribution, photo-period, plant protection, photobiology, visual ecology, photoreceptors, insects, mites, fungal diseases, secondary metabolites

Abstract

Developments in artificial lighting technologies and greenhouse cladding materials increase the possibilities of manipulating pests and beneficial species. Here, we review the direct and indirect plant-mediated effects of light characteristics on pests and beneficial organisms, focusing on arthropods and their natural enemies. Some examples on the possibilities of managing plant diseases, alone and in combination with pests, with light are also envisioned. Light intensity, photoperiod and wavelength distribution affect plant functions and physical and chemical quality which, in turn, can be reflected in the performance of herbivores. The attenuation of UV-light in HPSL spectrum and in the natural winter daylight of northern latitudes may make plants more vulnerable to pests, whereas the high ratio of red to far-red of HPSLs may act to compensate for the effects of attenuated UV-levels. High red to far red ratio has been shown to result in increased production of plant phenolics and physical defences which, in turn, can negatively influence the performance of some herbivore guilds on plants. Specific spectra produced by LEDs can influence plant quality and hence herbivore performance, but direct effects on arthropods can be even more pronounced, such as the inability of locating host plants by visually orienting pests in red and blue light. Other direct effects of artificial light on organisms include the detrimental effect of UV-C and UV-B on arthropods and fungi, diapause prevention by species-specific wavelengths or photoperiods, attraction to yellow-green wavelengths and polarized light, reduced visibility of prey in specific spectra which, in turn, reduces vector transmitted diseases, interactive effects of light quality and photoperiod on fecundity, species-specific effects of continuous light on the population growth of arthropods and plant-infesting fungi as well as the red light-induced resistance in plants to plant pathogenic fungi. Based on the reviewed literature, the practical implications for IPM as well as knowledge gaps are presented.
Effect of Overnight Supplemental Lighting with Different Spectral LEDs on the Growth of Some Leafy Vegetables

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Keywords: Chinese mustard, garland chrysanthemum, lettuce, light quality, Welsh onion

Abstract

The use of light emitting diodes (LEDs) for supplemental lighting in greenhouses is a major interest. Overnight lighting with LEDs is expected to increase the crop yield and quality with less cost. Growth chamber experiments were carried out to investigate the effect of overnight supplemental lighting by LEDs with four different spectral qualities (blue, green, red, and far-red light) on the growth of three cultivars each of lettuce, garland chrysanthemum, Chinese mustard, and Welsh onion. Plants transplanted in 7.5 cm plastic pots were placed in the growth chambers at the 4-6 true-leaf stage and were grown under different spectral light treatments for three to five weeks. The originally installed cool white fluorescent lamps were used during the day (10 h) period. The photosynthetic photon flux (PPF, 400-700 nm) at the top of plants was adjusted to 100 µmol m⁻² s⁻¹. During the night (14 h) period, overnight lighting by LEDs was provided at a PPF level of 50 µmol m⁻² s⁻¹. The day and night air temperatures were maintained at 25 and 20ºC, respectively. The relative humidity was maintained at 70% throughout the two periods. The results showed that the growth of most plant species was affected by the light quality of the overnight lighting. Particularly, the shoot fresh weights of lettuce under blue and red light were 22 and 38% greater, respectively than in the control without overnight lighting. Blue and red light showed a similar effect on the shoot fresh weight of garland chrysanthemum. Blue light promoted the elongation of stem and leaves of both crops.
[204] LED Inter-lighting in Year-Round Greenhouse Mini-Cucumber Production

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\textbf{Keywords:} \textit{Cucumis Sativus}, light spectrum, microclimate, supplemental light, yield and quality

\textbf{Abstract}
Inter-lighting, applying part of supplemental light within crop canopy, can improve light distribution within canopy and thus increase crop yield and light use efficiency. Inter-lighting with HPS (high pressure sodium) lamps has been successfully tested in Scandinavia. However, the high bulb temperature with HPS has prevented its use in the popular twin-row greenhouse vegetable cultivation system (with small row width). Light emitting diodes (LEDs) have low bulb temperature, making it a potentially suitable light system for inter-lighting. The ‘waste’ heat generated by the inter-light LED may also be beneficial to the crop as our previous study with grow pipes has shown that adding some heat inside crop canopy improves microclimate and cucumber productivity. Light quality can affect the content of antioxidants and produce quality, and a specific spectral composition may trigger a special crop response. Therefore, we investigated the response of greenhouse mini-cucumber to LED inter-lighting with different spectra. Mini-cucumber plants were grown in 2 greenhouses during the winter. Top-lighting (145 \textmu mol PAR m\textsuperscript{-2} s\textsuperscript{-1}) was provided with HPS lamps. Control (no LED inter-lighting) and 3 LED inter-lighting treatments (red, blue and white LEDs, 14.5 \textmu mol PAR m\textsuperscript{-2} s\textsuperscript{-1}, 10% of the top-lighting) were applied inside both greenhouses. All LED inter-lighting treatments improved fruit visual quality. They also increased fruit yield beyond the increase in PAR (more than 10%) in early production period. However, the yield increase with LED inter-lighting gradually diminished toward the late production period. The smaller crop canopy and lower canopy coverage over the LED inter-lighting system in the late growing season might have reduced inter-light interception, decreasing its beneficial effects. Further winter experiments are being conducted to improve mini-cucumber response to LED inter-lighting in late growth period.
[144] Light Emitting Diode Irradiation at Night Accelerates Anthocyanin Accumulation in Grape Skin

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Keywords: anthocyanins, grape, light-emitting diode, temperature

Abstract
We investigated whether irradiating grape bunches with light-emitting diodes (LEDs) at night would enhance anthocyanin accumulation in grape skin. The total anthocyanin contents were significantly higher in irradiation treatments with blue or red LED than in the control, and the effect was significantly stronger with blue LED. Quantitative real-time PCR analysis showed that cumulative daily expression levels of MYB transcription factor genes and anthocyanin biosynthesis pathway genes were higher in the LED irradiation treatments than in the control. These findings suggest that LED irradiation at night enhances the expression of anthocyanin biosynthesis–related genes, and accelerates anthocyanin accumulation. On the other hand, diurnal expression analysis showed that the expressions were low during daytime for both MYB and anthocyanin biosynthesis-related genes when air temperature was high, while the expression levels were high during night for MYB and in the morning for anthocyanin biosynthesis pathway genes when air temperature was low. Therefore, their expressions could also be affected by the ambient temperature. All these results suggest that the increase of anthocyanin contents by LED treatments at night occurred under an environmental condition (low temperature) which favors the expression of anthocyanin biosynthesis–related genes.
Biomass Accumulation and Allocation and Leaf Morphology of *Impatiens hawkeri* ‘Magnum Salmon’ Cuttings is affected by Photosynthetic Daily Light Integral in Propagation

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**Keywords:** floriculture, New Guinea impatiens, photosynthetic photon flux, vegetative propagation, young plants

**Abstract**

Recent research has shown that increasing the photosynthetic daily light integral (DLI) during propagation of cuttings increases root growth and overall quality of rooted cuttings. Our objectives were to determine how biomass accumulation and allocation and leaf morphology of *Impatiens hawkeri* (New Guinea impatiens) cuttings were influenced by the photosynthetic DLI during root development in propagation. Cuttings of New Guinea impatiens ‘Magnum Salmon’ were inserted into propagation substrate in cell trays and placed under mist in environmental conditions for callus development (approximately 5 mol·m\(^{-2}\)·d\(^{-1}\)) for 7 days. After 7 days, cuttings were placed under DLIs of 2.5, 8.5, or 15.6 mol·m\(^{-2}\)·d\(^{-1}\) for 14 days. Total, leaf, stem, and root dry mass increased for cuttings within each DLI over time, and dry mass generally increased with DLI. Dry mass partitioning was greatest into leaves for cuttings under 2.5 mol·m\(^{-2}\)·d\(^{-1}\) and roots for cuttings under 8.5 and 15.6 mol·m\(^{-2}\)·d\(^{-1}\). Total leaf area increased throughout the experiment for all cuttings, while final total leaf area was highest under 15.6 mol·m\(^{-2}\)·d\(^{-1}\). The leaf area ratio and specific leaf area increased for cuttings under 2.5 mol·m\(^{-2}\)·d\(^{-1}\), but not under higher-light treatments. These results suggest cutting morphology and physiology is plastic in response to DLI during root development.
[138] Meta-Phenomics, Horticulture and the Value of Plant Trait Databases

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Keywords: allocation, chlorophyll, database, dry matter content, environment, light, phene, specific leaf area

Abstract

For a proper understanding of the long-term growth responses of plants to their environment it is indispensable to know the dose-response curves of a wide range of phenotypic traits, for the relevant environmental factors. A database is described that compiles the necessary information on a wide range of growth-related traits, unlocking the information that has accumulated in the literature over the past 50 years. Results for the 12 most important environmental factors are collected. With help of this database it is shown how general dose-response curves can be derived for a range of traits in response to differences in the quantity of light. The information obtained in this way can be used to model the growth of plants and - ultimately - to select for genotypes that are optimally adjusted to a certain combination of environmental factors.

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Keywords: artificial sunlight, cucumber, far-red, light emitting diodes (LEDs), photomorphogenesis, supplemental lighting, tomato

Abstract
Photosynthesis per unit leaf area is widely used as a measure for crop productivity. However, especially in an open crop (e.g. young plants) morphological responses to light quality that affect light interception are also important. After all, it is the photosynthetic rate per crop area rather than the photosynthetic rate per leaf area that determines productivity. Earlier work showed a substantial biomass increase for young cucumber plants grown under 100% artificial sunlight compared with 100% high pressure sodium light (HPS). Here we show the effect of artificial sunlight as a supplemental light-source by simulating a greenhouse situation in a climate chamber. Tomato plants were grown under 17h artificial sunlight (50% of total PAR) supplemented with 50% HPS, LEDs (red/blue), or artificial sunlight. The 100% artificial sunlight-grown plants produced 32-45% more dry weight, due to morphology allowing a more efficient light interception. Artificial sunlight lamps are important for research, but probably not energy-efficient enough for commercial crop production. Therefore the second aim was to simplify the solar spectrum while retaining enhanced crop productivity. Red/blue/far-red LEDs, at a ratio inducing the same phytochrome photostationary state (PSS) as natural sunlight, and sulfur-plasmalamps, emitting a continuous spectrum in the PAR-region, were tested as supplemental light-sources in a greenhouse experiment. Additionally, red/blue LEDs, HPS (reference) and artificial sunlight lamps (qualitative reference) were tested. Red/blue/far-red resulted in a visual appearance similar to the artificial sunlight-plants, while red/blue LEDs produced the most compact morphology. Red/blue/far-red enhanced dry weight for cucumber (+21%) and tomato (+15%) compared with HPS. Dry weight and compactness were intermediate for sulfur-plasma. The differences were attributable to effects of leaf orientation and positioning on light interception, and not to photosynthesis per unit leaf area. The PSS appears to be a key-factor to control crop morphology, allowing either ‘sunlight’ crop characteristics to enhance productivity, or oppositely to produce more compact plants. Combined utilization of assimilation and signaling properties of light offers novel opportunities for protected crop production.
[129] Effects of Plant Density, Leaf Removal and Light Intensity on Tomato Quality and Yield

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Keywords: *Lycopersicon esculentum*, artificial light, sink-source, soluble solid content, truss-leaf ratio, variety, winter production.

Abstract

Tomato quality is becoming more and more important for the consumer’s willingness to pay and therefore for the economy for producers and wholesalers. The objective of this paper was to investigate whether a combination of increased plant density and leaf removal could improve tomato yield and quality. In addition, the effect of light intensity on fruit soluble solid content was studied while outside radiation was low. Two tomato (*Lycopersicon esculentum* Mill.) varieties, one round tomato, ‘Dometica’, and one cherry tomato, ‘Susanne’, were planted 13th October 2008 in the research glasshouse at Bioforsk Vest Særheim and harvested until 16th February 2009. Plants were grown at a plant density of i) 4.0 plants per m$^2$, without deleafing or with removal of one of three leaves, ii) 6.0 plants per m$^2$, with removal of one of three or three of six leaves, or iii) 8.0 plants per m$^2$ with removal of three of six or two of three leaves. Plants were subjected to light (HPS SON-T 400W) with an intensity of 180 or 260 µmol m$^{-2}$s$^{-1}$ PAR during 18 hours a day. Results showed that highest yields were obtained using 6.0 plants per m$^2$ with removal of one of three leaves. Also higher light intensity increased yield, due to an increase in the number of fruits, while fruit weight was unaffected. Soluble solid content of the fruits was not affected by light intensity, plant density and leaf removal. In conclusion, manipulation of plant density in combination with leaf removal can be used to increase yield. An increase in light intensity increases yield but not fruit quality in terms of fruit size and fruit soluble solid content. Allocation of soluble solids to tomato fruits per m$^2$ ground area is not affected by variety, light intensity or truss-leaf ratio.
[157] Rapid Regulation of Leaf Photosynthesis to Maintain Growth in Irregular Light Environments

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Abstract

Protected plant productions in northern latitudes rely heavily on supplemental light use to extend the number of light hours during the day. To conserve electricity and lower costs, a low-energy input system uses supplemental lights preferable during less expensive off-peak hours and turn lighting off during peak load periods in the afternoon and in the morning. This system, though more cost-effective than conventional lighting methods, creates irregular lighting patterns of natural sunlight interrupted with supplemental lighting. Despite being disturbed in their circadian activity, plants grown in such irregular light environments exhibit growth rates linearly related to the daily light integral (DLI). This contradicts with the assumption that plants perform better with a circadian clock matching the environmental clock and suggest that plants are able to buffer their circadian activity in order to maintain carbohydrate status and growth in unpredictable light environments. Our recent results show rapid regulation of photosynthesis and leaf carbohydrate status to maintain growth and light interception in dynamic light environments when campanula, rose and chrysanthemum were grown in a cost-efficient light control system. Plant dry matter production was in all cases linear related to DLI, despite changes in daily light duration and light intensity of supplemental light suggesting that DLI is the main limiting factor for the prediction of production time in optimal temperature conditions.
[202] An Enlightened View on Protected Cultivation of Shade-Tolerant Pot-Plants: Benefits of Higher Light Levels

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Keywords: next generation cultivation, light intensity, daily light integral, diffuse light, natural irradiance

Abstract

Commercial protected cultivation of shade-tolerant pot-plants in the Netherlands has expanded enormously in the last decade. Typically, very low daily light integrals are applied (3-5 mol PAR m$^{-2}$ day$^{-1}$), which are achieved by use of heavy screening and application of a layer of chalk (CaCO$_3$) on the outside of the greenhouse to increase reflection of incoming irradiance. Although these low daily light integrals are meant to avoid damage by high light intensities and/or high temperatures, it is clear that they carry a production penalty, since potential crop growth is directly related to the amount of light that can be captured and efficiently used. Additionally, it remains unclear whether current daily light integrals are too conservative, which would create room for optimisation. Recently, a number of experiments have been carried out to examine the possibilities and limitations for cultivation of several shade-tolerant pot-plants at higher daily light integrals. For most species, plants could be grown faster when more light was allowed. Also, a significant reduction in energy use for heating could be achieved if more natural irradiance was allowed to enter the greenhouse. However, use of more light required higher levels of relative humidity to avoid light damage. In this paper, we present a synthesis of experiments, as well as an outlook to further improvements.
Light from Different Wavelengths Affects Expression of Genes Encoding Phospholipases A₂ and D in Peel from Mandarins at Different Maturation Stage during Postharvest Storage

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Keywords: Citrus, fruit quality, lipid signalling, plant immunity, postharvest pathogens

Abstract

Previous studies showed that blue light reduced fungal colonization by *Penicillium digitatum* in mature tangerines and activated *CssPLA₂α* gene expression, whereas inhibition of PLA₂ enzymatic activity allowed infection to progress. Red light, an inhibitor of PLD, promoted infection as well. These data strongly suggested i) involvement of lipid-derived signals on citrus fruit immunity against postharvest pathogens and ii) activation of lipid signalling by light. In this work we explored the potential of LED-light treatments to manipulate lipid signal production in tangerines. We selected two different maturation stages: mature-green and full mature fruit. Fruit were maintained for 3 days in chambers equipped with LEDs emitting from 600-780nm (red/far red), 580-670 nm (red), 470-620 nm (green) and 410-540 nm (blue) wavelengths, and 40 μmol.m⁻².s⁻¹ of intensity before inoculation with a suspension of *Penicillium digitatum* spores and then stored for 6 days in the same conditions to follow infection development. The expression of *CssPLA₂α*, *CssPLA₂β*, *CsPLD α* and *CsPLDγ*, was studied by quantitative real time PCR. Our results show that blue and green light reduced fungal growth in the fruit surface more effectively in mature-green than in full mature fruit whereas red light treatment promoted decay irrespective of the maturation stage. Gene expression was differentially affected by light, showing a complex regulation.
Light Emitting Diodes with a High Proportion of Blue Light Affects External and Internal Quality Parameters of Pot Roses differently than the traditional High Pressure Sodium Lamp

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Keywords: light quality, morphology, post-harvest, physiology, roses, senescence, water loss

Abstract
Alterations in light quality affect plant quality but the effects vary significantly between species. In this study, we analyzed internal and external quality parameters of pot roses (Rosa x hybrida ‘Toril’) grown under different light qualities provided by light emitting diodes (LED, 80% red and 20% blue) and the traditional high pressure sodium (HPS) lamps. The experiments were conducted in closed growth chambers and in greenhouse during winter with supplemental lighting (100 µmol m$^{-2}$ s$^{-1}$). LED-grown plants showed higher chlorophyll and anthocyanin content and more thorns than HPS-grown plants. The stem and pedicle length were significantly shorter in LED-grown plants compared to HPS although the total production period was not affected. There was no significant difference in the storability of dark stored plants at high temperature (24°C) between the two light qualities. However, at 4°C a better storability was found in LED-grown plants and the flowers were more vital and a lower pH and osmolarity was found in petals 4 weeks after storage indicating delayed senescence compared to HPS-grown plants. Further, desiccation tests were performed on detached leaves to study the drought stress tolerance. When growing the pot roses under high relative air humidity (90%), LED-grown leaves had significantly higher water content (WC) after 3 h of desiccation compared to leaves from HPS.
[161] Optical Manipulations of Insect Pests for Protecting Agricultural Crops

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Keywords: whiteflies, aphids, thrips, optical additives, reflective mulch, colored shading net, UV blocking insect screen.

Abstract

Sucking insect pests, such as aphids, whiteflies and thrips, cause great economic losses for growers of agricultural crops worldwide. These pests inflict direct feeding damages and they often transmit pathogenic viruses to crop plants. These pests use reflected sunlight as optical cues for host finding. The optical properties, size, shape, and contrast of the color cue greatly affect the response of these pests. Therefore, manipulation of optical cues can reduce the success of their host findings. These pests are known to have receptors for UV light (peak sensitivity at 360 nm) and for green-yellow light (peak sensitivity at 520-540 nm). Green-yellow color induces landing and favors settling (arresting) of these pests. High level of reflected sunlight (glare) deters landing of these insects. We propose to use optical cues to divert pests away from crop plants. This can be achieved by repelling, attracting and camouflaging optical cues. The manipulating optical additives can be incorporated to mulches (below plants), to cladding materials (plastic sheets, nets and screens above plants) or to other objects in the vicinity of the plants. Cladding materials should contain selective additives that let most of the photosynthetically active radiation (PAR) pass through and reflect the wavelengths that sucking pest perceive. Results of our studies indicate that optical manipulation can reduce the infestation levels of sucking pests and the incidences of viral diseases they transmit by 2-10 folds. Delay of the aphids infected with non-persistent viruses that must be transmitted within minutes to 1-2 hours by arresting colors is expected to reduce the efficacy of viral transmission. This technology can be made compatible with the requirements for plant production and biological control. Optical manipulations can become a part of integrated pest management programs for both open field and protected crops.
[200] Interruption of the night period by UV-B suppresses powdery mildew of rose and cucumber

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Key words: Cucumis sativus, powdery mildew, Rosa × hybrida, UV-B radiation

Abstract
Experiments were conducted to determine the optimum dose of UV-B (280-315 nm) required for suppression of powdery mildews of rose (Rosa × hybrida) and cucumber (Cucumis sativus). Daily exposure to UV-B during dark at 1.2 W m\textsuperscript{-2} for 2 to 5 min substantially suppressed powdery mildew in pot roses cv. Toril without measurable damage to the plants. Compared with the non-UV-B treated control, mildew severity nine days after inoculation was reduced by a factor of 2.6 or 51 times after daily exposures of 2 or 5 min, respectively. In cucumber cv. Confida, the optimum exposure time to suppress powdery mildew was 5 to 10 min. Brief night time exposure to UV-B may provide a non-chemical option to suppress powdery mildews in greenhouse crops, where such pathogens have been historically problematic, and fungicide resistance problems are a continuing challenge.
[232] Evaluation of LED lighting systems in *in vitro* cultures

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**Keywords:** LED lighting system, *in vitro*, average PPFD, energy efficiency

**Abstract**

Many LED lighting systems for plant exposure are available on the market. The information to compare those systems varies between the numerous producers. There are still many descriptions of the systems that depend on photometric units like the luminous flux or light yield. But it turned out that radiometric units like the Photosynthetic Active Photon Flux Density (PPFD) are generally accepted to evaluate the electromagnetic radiation of an illuminant for plant exposure on a surface. Together with measurements of the required electrical power relative to one square meter the energy efficiency was calculated and described in $\mu$mol s$^{-1}$ W$^{-1}$. But the PPFD differs on the illuminated surface. Therefore the energy efficiency is affected by the position of the sensor. A solution of this problem is to work out the average PPFD (PPFD$_{\Theta}$) before calculating the energy efficiency. To compare the LED lighting system with conventional lamps including fluorescent tubes the PPFD on a shelf board (1500 mm x 500 mm) was measured on 161 measured points. With these data the PPFD distribution on the surface could be displayed and the PPFD$_{\Theta}$ was calculated. The PPFD distribution strongly depends on the shelf board distance or the distance between the lamp and the PPFD sensor. In a LED lighting system it furthermore depends on the LED density and the location of the LEDs. Using the deviation squares from the PPFD$_{\Theta}$ the PPFD distribution of the different lighting systems at various settings (LED density, shelf board distance) could be compared. This work shows a way to evaluate lighting systems. It points out the differences between the methods of evaluating lamps. Currently there is no consistent method to measure the output of lamps for the exposure of a shelf’s surface and to make the lamps comparable with each other.

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Keywords: Hemispherical, Light transmission, Integrating sphere

Abstract

For determining the optical performance of greenhouse covering materials other than standard float glass the current Dutch NEN 2675 norm is no longer appropriate. The emergence of a new generation of materials (diffuse, layered) resulted in a new measuring protocol developed by TNO and Wageningen UR. In line with this protocol Wageningen UR has developed an accurate measuring device (Transvision) for measuring the light transmittance for direct and hemispherical incident light. The device is based on spectral analysis of a perpendicular beam passing the material under a variable angle of incidence into an integrating sphere. With the angular transmission data, the hemispherical transmission can be calculated which is the most important benchmark for the performance as a covering material at Northern latitudes. The device is specially developed for measuring thick, multi-layer and large materials which cannot be cut for testing, like tempered or structured glass panes. For clear float glass the device meets the specifications of the NEN 2675 and the results are comparable with those of professional spectrometer systems.
[226] Feasibility Study on Combined Production of Algae and Tomatoes in a Dutch Greenhouse

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Keywords: algae production, modelling, light, temperature, productivity, economic analysis

Abstract

The Dutch horticultural sector shows interest in production of microalgae. When microalgae and a tomato crop are produced in the same greenhouse, both shared advantage of and competition for resources will occur. In this study a model was developed to predict algae biomass production in tubular photobioreactors (PBR) and to assess the economic feasibility of combined production of tomatoes and algae. The effects of the location of the PBR in the greenhouse, the diameter of the PBR tubes, the algae biomass concentration, the light intensity and the PBR temperature were considered. The economic feasibility of combined production was calculated, taking into account both investment and running costs. Three possible locations for the PBRs were considered. The most sensitive growth factor influencing economics of the systems was light. Economic feasibility of algae production underneath the tomato crop was poor; a minimum unit biomass production cost of 70 € kg\textsuperscript{-1} dry matter (DM) was calculated. Increasing the light intensity by decrease of the tomato LAI by extra leaf picking increases economic feasibility of algae production underneath the crop. Economic feasibility of algae production in a separated compartment was computed to be good with a minimum unit biomass production cost of 11 € kg\textsuperscript{-1} DM. The developed model can function as a basis for further research on combined production of a crop and microalgae in Dutch greenhouses.
[109] Image-Based Estimation of PPFD Distribution on the Canopy Surface in a Greenhouse

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Keywords: Digital camera, Light control, Light intensity distribution, Reflection image, Tomato canopy

Abstract
In this study, a simple and useful method is provided to evaluate the light environment in a greenhouse. Light intensity distribution on the canopy surface was estimated as a photosynthetic photon flux density (PPFD) histogram using reflection images. Reflection images of the tomato canopy surface were acquired from three different directions using a digital camera through a blue–green band-pass filter. PPFD was measured at one point on the canopy by a quantum sensor simultaneously with imaging and was used for determining a regression model for calculating PPFD on leaves from image pixel values. The PPFD histograms estimated from the reflection images were compared with the histograms of actual PPFD determined by measuring all leaves in the target canopy surface using a quantum sensor. The histograms showed similar patterns, with the mean estimated values being close to the measured values. The pattern of the PPFD histograms estimated from the reflection images changed over time during the day. The changes in the mean values calculated from the estimated PPFD histograms corresponded to those in PPFD measured on the horizontal plane. These results suggest that reflection image-based estimation of PPFD distribution on a plant canopy surface can be used for simple evaluation of the light environment in a greenhouse.
Abstracts - Poster Program
[128] Optimizing a Year-round Cultivation System of Tomato under Artificial Light

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Keywords: Lycopersicon esculentum, cropping schedule, growth temperature, plant age, plant density, yield potential

Abstract
The use of supplementary light is necessary to assure year-round production in northern countries. In Norway the use of artificial light is favored by a long winter season, a mild climate along the coastline and the availability of hydroelectric energy. Earlier experiments and practical experiences have shown that the use of artificial light increased cucumber production from 40 to 180 kg m\(^{-2}\). The goal of this research was to optimize the yield potential of tomato production under supplementary light. In 2003-2004, production potential using artificial light (with a photon flux density of 220 µmol m\(^{-2}\)s\(^{-1}\), provided by 400 W SON-T lamps during 18 hours a day) was investigated using a cropping schedule of three plantings a year with a culture length of 17 weeks each. Planting dates were 10\(^{th}\) September 2003, 14\(^{th}\) January 2004 and 19\(^{th}\) May 2004. Tomato plants (Lycopersicon esculentum Mill. 'Espero'), with visible flowers on the 1\(^{st}\), 2\(^{nd}\) or 3\(^{rd}\) truss, were planted at a density of 3.0, 3.5 or 4.0 plants per m\(^{2}\) in two greenhouse compartments at temperature set points of 21/18/22°C or 24/21/25°C (day/night/ventilation temperature). Results showed that higher plant density, the use of older plants at planting and higher growth temperature increased tomato yields. All growing factors should be adjusted with respect to planting date and light intensity in order to give optimum result. A maximum year-round production of 101 kg m\(^{-2}\) of 1\(^{st}\) class tomatoes during 33 harvesting weeks was registered. Based on these results, a yield potential of tomato production using artificial light of 125-140 kg m\(^{-2}\) is realistic. We used our experimental results to develop commercial tomato production in Norway, achieving yields over 100 kg m\(^{-2}\) a year.
[192] Effect of Supplementary Lighting on the Selected Physiological Parameters and Yielding of Tomato Plants (*Solanum lycopersicum* L.) in Autumn-Winter Cultivation

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**Keywords:** light intensity, plants tomato, photosynthesis, transpiration, chlorophyll content

**Abstract**

Light is one of the basic factors needed by plant for its development. Apart from daylight, which penetrates the greenhouse, also an supplementary artificial lightening is applied. Despite a number of research on plant supplementary lightening with lamps of various light effectiveness there is still little information on the effect of light quality on the growth and development of plants and how particular light spectra may cause various changes in a plant. Joining red and blue light together in a proper ratio may significantly modify the content of such parameters as chlorophyll, net photosynthesis or the content of total nitrogen. The research aimed at the assessment of the effect of supplementary lightening with the lamps LED and HPS on the chosen physiological parameters of tomato plants. Our research revealed that an intensity of photosynthesis higher by 30% was characteristic for plants which were extra lightened with the HPS lamps as compared to the LED lamps. No significant differences were observed in the transpiration intensity of plants which were supplementary lightened with the LED and HPS lamps. A higher by 25% stomata conductance was characteristic for tomato plants supplementary lightened with the HPS lamps as compared to the plants supplementary lightened with the LED lamps. No significant differences were observed in the leaf chlorophyll content with the supplementary lightening with the LED and HPS lamps. The obtained commercial crop of tomato fruits was at the comparable level for both light sources.
Does the Lighting Time Influence Yield of Winter Grown Sweet Pepper and Tomato?

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Keywords: Capsicum annuum, Lycopersicon esculentum, high-pressure vapour sodium lamps, supplemental lighting

Abstract

The extremely low natural light level is the major limiting factor for winter glasshouse production in Iceland. Therefore, supplementary lighting is essential to maintain year-round production. The energy costs could be decreased by lighting during the cheaper night tariff as well as during whole weekends. The objective of the study was to test whether decreasing energy costs by lighting at cheaper times will result in satisfactory yields. Sweet pepper (Capsicum annuum L. ‘Ferrari’, 9 stems/m² and ‘Viper’, 6 stems/m²) and tomatoes (Lycopersicon esculentum Mill. ‘Encore’, 2.5 plants/m²) were grown in two growth cabinets under high-pressure vapour sodium lamps for a maximum of 18 hours light. During the period of high electrical costs for time dependent tariffs one cabinet got supplemental light during the night and during the whole weekend, whereas during the other months it was uniformly provided from 04-22 h as in the other cabinet. Temperature was kept at 24-25 °C / 17-20 °C (day / night) for sweet pepper and at 22-23 / 18-19 °C (day / night) for tomatoes. When sweet pepper received light during nights and weekends marketable yield was 5-10 % lower compared to the normal lighting time. However, when normal lighting time had been restored, the yield continuously approached the yield of the traditional lighting time. In contrast, accumulated marketable yield of tomatoes that received light during nights and weekends did not approach the yield obtained at normal lighting time with final yields amounting to about 15 % less yield. From an economic viewpoint it is recommended to provide light at normal times.
[291] Effects of Light Supplement by Different Artificial Light Sources to Chinese Cabbage Growth in Greenhouse

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Keywords: Light supplement, artificial light source, Chinese cabbage, seedlings growth, greenhouse

Abstract

Illumination intensity is a very important factor for vegetable growths. In winter, the day length is short and the sunshine is weak in greenhouse, so it is necessary to use supplement light for health seedlings. In this experiment, 2 chinese cabbage varieties were used, Huangwuxin and Qianbai 2, and 4 kinds of artificial light sources were used, plant growth lamp, high pressure sodium lamp, spherical dysprosium lamp and sulfur lamp. The Chinese cabbage seeds were saw on tray plate on Nov.25th, and transplanted into 50 holes tray on Dec. 5th. The seedlings tray were treated under 4 artificial light with similar illumination intensity (10000Lux) for about 10 h each day. 2 weeks past, the effects of light supplement could be achieved. The results showed that the best artificial lamps for plant shoot growth were sodium lamp and sulfur lamp, which increased the shoot fresh weight higher than CK and others treatments at first 7d treatments. After 2 weeks treatment, the best shoot dry weight increase is still the high pressure sodium lamp, then the sulfur lamp. Owing to the low power, plant growth lamp has few effects to plant growth comparing with CK. In conclusion, light supplement increased the growth rate of Chinese cabbage seedlings. High pressure sodium lamp is the best artificial light source for light supplement, then is sulfur lamp, dysprosium lamp and plant growth lamp has few effects on Chinese cabbage seedlings growth compare to control.
[221] Influence of UV Light Reduction on Growth and Development of Onions

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Keywords: UV light, red and green onion, growth, development

Abstract

Plants convert light into energy needed for growth and development. Sun light with ultraviolet (UV) light has positive and potentially harmful effects on plant growth and development, as well as its yield. We conducted this study to evaluate the influence of UV light reduction on growth and development of two onion cultivars (*Allium cepa* L. cv. Hidamari and cv. Sonic (hereafter called red onion and green onion)). Two onion cultivars grown on a plastic nursery tray (L 47.3xW 32.5xH 10.0cm) with one to one proportion of bark compost and mountain soil were cultivated in a plastic house (3x22 m) and covered with three kinds of plastic film (100 µm in thickness) where plants were exposed to 91% UV, 49% UV and 7% UV transmission (hereafter called high, medium and lowest UV, respectively). As expected, UV light reduction rates had influence on growth and yield, as well as bulb quality of two onions. After 5.5 and 6.5 months of cultivation for red and green onions, respectively, the growth and development as well as yield of two onions reduced at medium UV by 11%, but increased at lowest UV by 27% compared to high UV. SPAD value of the biggest leaf was the highest on plants grown under lowest UV, but was only significantly different on red onion and resulted in greater plant height, bulb’s fresh weight and size. The result was also applied to green onion. Although, the growth and development in term of fresh mass were greater along with UV light reduction, but dry mass reflecting dry weight of bulb and biggest leaf was the same. Bulb color of red onion exposed to the lowest UV became darker but became lighter for green onion. Overall, the lowest UV light resulted in superior plant growth and development in two onion cultivars.
[296] Effect of Light Diffusion on Growth of Lettuce Plants in LED Plant Factory

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Keywords: diffuse light, light diffusion filter, light-emitting diode, plant factory

Abstract
Recently the number of plant factories using light-emitting diode (LED) as artificial light source has been increased. However, LED emits highly directional light as its emission surface is very small. It is well known that plants under diffuse lights grow more and faster than those under direct light because diffuse light can penetrate plant canopy deeper than direct light. Thus, LED lighting may have low canopy penetration capability, and this may result in lower growth of plants with lower light-use efficiency in the plant factory. The objective of this study was to determine whether diffusing the lights from LED luminaire would improve the growth of lettuce plant. Lettuce plants (Lactuca sativa L. cv. ‘green-skirt’) were transplanted at 14 d after seeding and grown hydroponically for 25 d after transplanting. Fresh weight, dry weight and light intensity were compared among 3 cases: without diffusion filter (control), with diffusion filter attached to LED luminaire surface to minimize light diffusion (Tr. 1), and with diffusion filter installed in distance from LED luminaire surface to maximize light diffusion (Tr. 2). Fresh and dry weights were significantly higher in Tr. 2 than control, while the difference between control and Tr. 1 was not significant. This result indicates that light diffusion enhanced the plant growth. This enhancement may depend on the density of LED chips on the lighting apparatus. However, there was loss of light while diffusing the light due to the design of the diffusing apparatus. From the results, the efficient use of light diffusion filter should be considered in plant factory.
[127] Effects of Light Spectrum and Lighting Regime on Double Stalk Forcing of *Phalaenopsis* in the Controlled Environmental Chamber

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**Keywords:** artificial light, light emitting diode, light quality, flower forcing, orchid

**Abstract**

*Phalaenopsis* is the most important floral crops in Taiwan. However, subject to the local weather, the flower stalk can be induced only in winter. Thanks to the advancement of controlled environment agriculture, the farmers can produce orchid flowers year-round by installing the air conditioner in greenhouse to provide cool environment for flower forcing. However, uneven distributions of temperature and light in greenhouse cause the asynchrony of flowering. Also, large proportion of energy is wasted in cooling the overhead spaces where no plants exist in the greenhouse. These disadvantages increase the management difficulty and operation cost. This study attempted to conduct the flower forcing task in a controlled environmental chamber equipped with multilayer cultivation beds and artificial lights. Two experiments were conducted to investigate the effects of different lighting spectrum and lighting regime on the emergence of flower stalk. The small-sized orchids *Phalaenopsis* “PengBo Little Angel MS47” were cultivated in the condition of photoperiod 12 hr and day/night 27/18 °C for 45 days. In the light spectrum experiment, six treatments of different light spectra at 200 μmol m$^{-2}$ s$^{-1}$ were selected as the light sources. The results showed that the treatment of 5000K cold white LED was the first treatment reaching 100% of the spiking rate at day 34. Furthermore, it also reached 100% of the double stalks rate at day 42, better than others. This spectrum seems helpful to promote the 2$^{nd}$ stalk emergence. In the lighting regime experiment, four different lighting regimes were conducted: 16H, 16L, 12H and 12L (the number denotes hours of the light period; H and L denote light intensity 160 and 120 μmol m$^{-2}$ s$^{-1}$). The daily light integral (DLI) of 4 treatments are 9.216, 6.912, 6.912, 5.184 mol m$^{-2}$, respectively. The results showed that the rate of double stalks emergence was affected by total light integral (TLI). The rate of double spikes for 16H treatment was 100% at day 42, and was only 20% for 12L treatment. Under same TLI, The rate for 16L was 60%, better than the one for 12H (40%). This means longer light period at each day would enhance the development of the 2$^{nd}$ stalk of the selected orchid.
[283] Does Diffuse Light Increase Photosynthesis Capacity of Tomato Plants?

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Keywords: Diffuse light, tomato, glasshouse, photosynthesis

Abstract  
Recent years the use of diffuse glass in greenhouse horticulture has gained a lot of interest. Earlier studies have shown a strong positive effect of these glass types on the growth and development of crops like tomato and cucumber. This is caused by a more diffuse vertical light transmission within these crops compared to standard glass. Between February and November 2011 we conducted a trial at Research Centre Hoogstraten, Belgium. Growth and development of tomato plants under standard and diffuse glass were compared in two greenhouses (500 m²). An overall production (kg/m²) profit of 5% was recorded under diffuse glass, mainly due to an increase in fruit weight. To achieve such an increase a plant requires a higher photosynthesis activity. However, no differences were found in plant morphology (length, leaves, stem width). When stem density was raised (33.3cm instead of 37.5cm) 8% more fruits where harvested. Again no differences in morphology were found. Preliminary light measurements showed no clear differences in light transmission (μmol/m²s) between diffuse and standard glass at the top of the plant. On the other hand we did record a higher vertical light transmission within the crops under diffuse glass. This could result in a higher photosynthesis capacity of the lower leaves and perhaps of the whole canopy. In 2012 (and ongoing), this experiment was repeated and extended with an additional greenhouse with a diffuse coating, applied beginning of May on standard glass. Plant morphology, light measurements (μmol/m²s) and leave temperatures (°C) will be recorded. Additionally the photosynthesis capacity of the leaves on different stages will be compared between greenhouses. First results are promising and show a higher photosynthesis capacity of the leaves under diffuse glass. These results could explain the production increase. Nevertheless, this production increase still needs confirmation in the present trial.
[158] Understanding how Diffuse Light Increases Yield in Tomato

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Keywords: Light distribution, temperature, photoinhibition, cumulative production

Abstract

Light is not uniformly distributed in greenhouses, but this can be improved if the light is diffuse. To determine the effect of diffuse light on crop growth and development, an experiment with tomato crop was conducted from December 2010 to November 2011 under commercial crop management. Three kinds of glass were used as greenhouse covering: standard glass (no diffuse light, 0% haze) and two types of diffuse glass which transformed an increasing fraction of the direct irradiation into diffuse irradiation (45% and 71% haze). As presented by Dueck et al. yield increased by 7.8% under 45% haze and by 9.4% under 71% haze, compared to the reference. During the experiment we performed measurements in order to understand these effects. Diffuse light penetrated deeper and more homogeneously into the canopy, which led to higher photosynthesis rates in the middle and bottom canopy layers. Furthermore, less photoinhibition was measured under diffuse light treatment when the outdoor irradiation was high. Under sunny conditions the temperature of upper leaves in the canopy was 3 to 5 °C lower in the greenhouses with diffuse glass compared to the control, while greenhouse air temperatures were comparable. The leaf anatomy, canopy structure, total nitrogen and chlorophyll contents of top, middle and bottom canopy layers were also studied in order to further explain the increased production under diffuse light. The results showed that diffuse glass on greenhouses is one way to improve the light use efficiency of greenhouse crops.
[174] Effect of diffuse glass on the growth and winter production of cucumber

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Keywords: haze factor, light transmission, energy consumption, development rate, fruit production, fruit quality

Abstract

Research in The Netherlands has shown that it was possible to increase the yield of cucumbers in greenhouses covered with diffuse glass by 6 to 9%, despite the fact that light transmission was sometimes even reduced by diffuse glass. However, these experiments were performed in spring and summer, and never started before the middle of February. The proportion of direct to diffuse light during the winter months is relatively low in the north of Europe. For cucumber growers it is important to know if a yield increase due to the use of diffuse glass will also occur in an early cucumber crop, with a planting in December. Thus an experiment was designed to examine the effects of diffuse glass on cucumber compared to those of standard glass in the winter season. The diffuse glass had a haze factor of 71% and was covered with an anti-reflexion coating in order to realize the same light transmission as standard glass. The cucumbers, cv. Venice were planted in December 2011 and were grown in an umbrella system to the end of April 2012. The growing conditions in each treatment were optimized. The effect of diffuse light on e.g. light interception, light spectrum, photosynthesis, crop morphology, growth, energy consumption, yield and quality were measured and analysed. Results on the growth and development of cucumber are discussed in relation to the light quality and quantity in these treatments.
[184] Effect of Light Reduction by Double Screen Systems and Roof Installed Cooling Equipment in Closed Greenhouses on Leaf Photosynthesis and Stomatal Conductance

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Keywords: screens, cooling, photosynthesis, stomatal conductance, light transmission, CO₂, closed greenhouse

Abstract
To save energy in greenhouses ore harvest energy from closed systems a lot of equipment is available for better isolation and heat extraction inside the greenhouse. Some of this equipment like multi-layer screen systems are heat exchangers for cooling and dehumification has to be attached above the canopy in the roof zone of the greenhouse. However because of this a significant reduction of the incoming light has to be accepted. On the other hand in closed greenhouses a higher relative humidity and higher CO₂ concentration can be achieved. With this the plants can be protected against stress and a higher net photosynthesis was anticipated. The thesis of compensation of light reduction by increased photosynthesis with higher CO₂ level in closed greenhouses was evaluated. In an experimental greenhouse facility with two greenhouses a comparison experiment was executed. By the installation of a double screen system and a finned pipe cooling system under the roof of a 307 m² Venlo type greenhouse, the light transmittance was decreased by 13 % against a reference greenhouse (9% by double screen system, 4 % by the finned pipe cooling system). Two new prototypes of phytomonitoring systems for long time measurements in different canopy height in each greenhouse were used. Net photosynthesis, stomatal conductance, cumulative CO₂ uptake and gas exchange efficiency (GEE) were estimated for both greenhouses simultaneously. In the result of the experiment two different situations were found. On days with higher global radiation the CO₂ content in the closed greenhouse was higher against reference greenhouse because of the closed operation by technical cooling. On days with low radiation less ventilation was necessary resulting in an equal average of CO₂ content. Only on these days the net photosynthesis was higher in the reference greenhouse because of more light interception in the canopy. In the average of the measuring period from May to July 2011 in the closed greenhouse the cumulative CO₂ uptake of the plant leafs were 32.4 % higher against reference greenhouse. With 27.8 % higher CO₂ content the average GEE in the closed greenhouse was 30.3 % higher against reference greenhouse. Stomatal conductance in the reference greenhouse was lower than stomatal conductance in the closed greenhouse and net photosynthesis in the reference greenhouse significant decrease with lower stomatal conductance.
[199] Investigation of the effect of a micro-structured surface on the optical performance of greenhouse covering materials

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Keywords: microstructure, hemispherical transmittance, light measurements, optical properties

Abstract

Micro structured surfaces are of great interest due to their special properties. Higher light transmittance, higher isolation value and self-cleaning lotus effect are three qualities that are of great importance for development of greenhouse covering materials. In a collaborative research project we developed new structures for greenhouse covering materials. Structures which increase light transmission are micro V, micro Pyramids and Moth-eye. In a previous study (Swinkels, 2010), the hemispherical transmittance of micro-structured surfaces was investigated using the ray-tracing simulation model. The model based calculations for a double sided v-groove structure predict a gain of ca. 6.6% in hemispherical transmittance. This paper reports on the measurement of transmittance of micro structured surfaces for perpendicular and hemispherical radiation for the cladding materials PET/PMMA, PDMS, PC and laminated glass. The transmittance of hemispherical light is measured by an integrating sphere and a moveable light source. Measuring procedures and the methods and calculation models are explained. The theoretical effects of the micro structure on the optical performance will be worked out in the paper. Measurement results are compared with the results from the ray-tracing simulation model. Future perspectives of such greenhouse covering materials will be elaborated on in the paper.

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Keywords: Radiation uniformity, radiation transmission, direct radiation, diffuse radiation.

Abstract

In the Mediterranean area, the east-west orientation of the greenhouses improves natural light transmission during the low radiation season, as compared with the north-south orientation, but generates light transmission differences between the different zones of the greenhouse. The scarce available information on this topic has been documented at the greenhouses eaves level, where shades from some of the greenhouse structural elements do not interfere light transmission. A study on the transmission and spatial uniformity of light, at the crop level, of two east-west oriented greenhouses was run in Almeria (Spain). The greenhouses were a Venlo type glasshouse, covered with a conventional 4 mm glass, and a gothic type arch-roofed plastic multispan (multitunnel), covered with a 0.2 mm thick plastic film. The light transmission data, quantified using linear solarimeters along the transversal section of the spans at the crop level, show transmission differences along the span section in both greenhouses. Small differences in light transmission between greenhouses were measured. Information on the estimated components, direct and diffuse, of light inside both greenhouses will be presented.
Fluorescent Illumination with High Red-to-far-red Ratio Reduces Attractiveness of Cucumber Seedlings to Sweet potato Whitefly through Changes in Leaf Morphological Characteristics

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Keywords: fluorescent lamp, metal-halide lamp, preference test, transplant production

Abstract
Pest management after transplantation is essential in horticultural production. In this study, we evaluated attractiveness of cucumber (*Cucumis sativus*) seedlings grown under fluorescent lamps with high red-to-far-red ratio (R:FR) light (FH) or metal-halide lamps (ML), that provided a spectrum similar to that of natural light, to sweetpotato whitefly, *Bemisia tabaci* (Gennadius) biotype B, adults (called whiteflies, hereafter) by preference tests. The seedlings were grown under FH (R:FR = 10) or ML (R:FR = 1.2) until first true leaves had fully expanded at a photosynthetic photon flux density of 350 µmol m⁻² s⁻¹ with a photoperiod of 12 h d⁻¹. Pairs of seedlings, one grown under FH and the other under ML, were installed in four cages, and then approximately 100 whiteflies were released in each cage under ML. We counted whiteflies on leaves of each cucumber seedling 24 h after release. Time required for whiteflies to land on the leaf surface of FH or ML seedlings was measured by non-choice tests in which the whiteflies was released in cages including FH or ML seedling individually. There were significantly fewer whiteflies on FH cucumber seedlings (31%) than on ML seedlings (69%) 24 h after release. FH seedlings’ leaves had higher relative chlorophyll content and greater leaf-dry-mass per area, which indicates greater leaf thickness, than ML seedlings. The time required to land on leaf surfaces tended to be longer in FH seedlings than in ML seedlings. The lower attractiveness of FH seedlings to whiteflies was probably caused by leaf morphological characteristics of FH seedlings such as deeper color and greater thickness resulting from high R:FR illumination.
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[182] Fluorescent Illumination with High Red-to-far-red Ratio and High Vapor Pressured Deficit Improves Powdery Mildew Resistance in Cucumber Seedlings

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Keywords: fluorescent lamp, morphological characteristics, pest management, R:FR, Sphaerotheca cucurbitae, transplant production

Abstract
We investigated the effects of light quality and vapor pressured deficit (VPD) on powdery mildew resistance in cucumber (Cucumis sativus) seedlings by inoculation tests in order to produce high quality transplants by using artificial light. The seedlings were grown under fluorescent lamps with high red-to-far-red ratio (R:FR) light (R:FR = 10.5; FH), which have been commonly used in the transplant production systems, or with low R:FR light (R:FR = 1.1; FL) before the inoculation test. The spectrum of FL was almost the same as that of FH, except in FR region. The growth conditions were maintained at an air temperature of 28 °C, a VPD of 24.6 kPa, and a photosynthetic photon flux of 300 µmol m⁻² s⁻¹ at the canopy surface with a photoperiod of 12 h d⁻¹. When the cotyledons were fully expanded, powdery mildew fungus (Sphaerotheca cucurbitae; PM) were inoculated onto the adaxial leaf surface of seedlings by spraying PM spore suspension. The inoculated seedlings were then grown under the same condition. The inoculation test was also carried out for seedlings grown under high VPD (= 44.3 kPa) or low VPD (= 4.9 kPa) condition. The PM colonies on FH seedlings was fewer than that on FL seedlings 7 d after the inoculation. The fewer colony of PM indicates that PM resistance in seedlings was improved by the illumination from FH. The PM resistance was also improved by growing under the high VPD. The leaf dry mass per area, which indicates leaf thickness, of seedlings under FH and the high VPD was greater than that under FL and the low VPD, respectively. From these results, we conclude that the PM resistance would be improved by high R:FR fluorescent illumination and high VPD treatment through the morphological changes in leaves.
[190] Potato Plant Responses to Temperature Drop and Phytonematode Invasion Under Continuous Lighting

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Keywords: Solanum tuberosum L., Globodera rostochiensis Woll., nematode, infestation, resistance, 24 h photoperiod

Abstract
Plant defenses and resistance against pathogens can be affected by changing environmental conditions. Light is the major external factor influencing plant growth and development and it is also required for establishment of a complete set of resistance responses in plant-pathogen interactions. Potato cyst-forming nematode (PCN) Globodera rostochiensis Woll. is a widespread endoparasite of root system which causes significant reduction in potato yield in terms of quality and quantity. Under Nordic conditions potato crop is often subjected to a combination of low temperature and PCN invasion. The aim of the study was to investigate potato plant responses to a short-term temperature drop combined with PCN infestation under continuous lighting. Potato plants (‘Nevsky’) were grown under 24-h photoperiod. At the stage of 3 leaves plants were treated with a daily short temperature drop from 23°C to 5°C for 2 h during 6 days. Control plants were grown under constant temperature of 23°C. Then plants were infested by potato cyst-forming nematode (10 cysts per plant) and maintained under 23°C with continuous light for 1 month. Drop-treated plants were more compact and had healthy (without light injury symptoms) leaves and higher plant developmental rate. Infestation by PCN also decreased plant height, but not affected plant development. Nematode infestation had no effect on the activity (Fv/Fm) of PSII reactive centers of plants. Temperature drop treatment halved potato plant infestation by PCN. Possible mechanisms of plant cross-adaptation to biotic and abiotic stresses are to be discussed.
[284] BioPM Lamp Application as an Biopesticide for Whitefly (*Trialeurodes vaporariorum*) on Cucumber in High tunnel

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**Keywords:** BioPM lamp, biopesticide, whitefly pest, cucumber, high tunnel

**Abstract**  
Whitefly (*Trialeurodes vaporariorum*) is a kind of severe pest on vegetables in protected horticulture. Insect proof net and chemical are usually used for whitefly prevention, but the effects is not good. Bio PM lamp is a new instrument designed by KGM corporation in Korea, which can flash sparkle at night for 10 min per hour, and 3 times during 3 hours. The flashlight would impair the nerve system of insect so that the pest will be killed and the pest population density may decrease. The experiment were hold in plastic high tunnel, which is 38m long and 5.4m width, the Bio PM lamp were hung opposite on 2 sides. After 10 days treatments, the results showed that population decline rate of whitefly was 13.2-39.4% from 3d to 10d. The control efficiency of the Bio PM lamp achieved 74.6%. So the application of Bio PM lamp as an artificial physical treatment to prevent whitefly population density is a useful tool to control pest in greenhouse, the cost is low and the control efficiency is high. In the end, we suggest that the Bio PM lamp can be used as a safety pest prevention technique on organic vegetable production in greenhouse.
[298] Regulation of Plant Resistance against Powdery Mildew in Tomato by the Application of Red Light

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Keywords: red light, powdery mildew, induced plant resistance, tomato

Abstract

Light is the energy source for biochemical production and acts as a regulator for plant growth, morphology and development. Increasing evidence shows that light also affects plant resistance against pathogens. Higher percentages of fungal infections are found in shaded field sites when compared to non-shaded field sites, indicating that the ratio between red and far red light plays a role. Interestingly, phytochrome photoreception has been reported to modulate the plant defense response that is known as systemic acquired resistance (SAR). SAR is generally expressed upon infection with obligate biotrophic fungal plant pathogens, like powdery mildews. The interaction between phytochrome and SAR responsiveness suggests that control of mildew in horticultural crops may be improved by the strategic application of red light. Here we present the effects of pulses of red light irradiation on the expression of SAR and on the development of powdery mildew in artificially inoculated young tomato plants. The parameters investigated are the quantity, timing and duration of red light irradiation. A chemical inducer of SAR is used as positive control. SAR expression is determined before and after mildew inoculation by the enzyme activity of the pathogenesis related proteins PR-2 and PR-3, which catalyse the degradation of fungal cell wall polymers.
[301] Microbial Colonization of Canopies in Greenhouse Grown Ornamental Plants

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Keywords: Begonia, culture dependent method, extraction method, Impatiens hawkeri, Kalanchoe blossfeldiana, LED

Abstract
To reduce the use of energy in greenhouse production, alternative methods for heating and artificial lightning have been suggested. In this context, light emitting diodes (LED) have been proposed as alternatives to high pressure sodium lamps which traditionally are used for assimilation lighting in greenhouse production. LED light differs to conventional lighting by high pressure sodium lamps with regard to spectral distribution, light distribution as well as heat emission. Due to the interrelationship between air temperature and humidity, also the water availability on the leaf surface is affected. The altered energy consumption of LED consequently result in differences in the microclimate within the greenhouse and around the crop with a decrease in air temperature and increase in relative humidity and consequently lead to changes in the microbial community structure on the crop and in the cropping system. The objective of the present study was to develop a standard method for description of microbial phyllosphere communities associated to greenhouse grown ornamental plants. Extraction methods were screened using a two-factorial approach with extraction solutions as factor 1 and detachment treatments as factor 2. In this step the phyllosphere microbiota was described using a culture dependent approach, involving diluted malt extract agar (0.5 MA) for enumeration of fungal colonies as well as diluted tryptic soy agar (0.1 TSA), standard nutrient agar I (SN I) and standard nutrient agar II (SN II). Impatiens hawkeri, Kalanchoe blossfeldiana as well as Begonia were used as model plants. We found that extraction using Tris buffer and stomacher treatment (5 min, normal speed) without ultrasonic exposure was the most efficient detachment method. TSA and MA reflected the prevalence of culturable bacteria and fungi best. The results were verified on young and mature Begonia leaves exposed to SON-T, two LED-treatments (red; 80% red, 18% blue). The project was funded by the EU-Interreg project “GreenGrowing” and is facilitated within the framework of the postgraduate school, µHORT, funded by the Swedish research council Formas.
[293] Growing with LED Lighting of Different Spectral Quality Affects Morphogenesis and Production of Lettuce Plants

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Keywords: growth, Lactuca sativa, light emitting diodes, morphogenesis, photosynthesis, production

Abstract

Light emitting diode (LED)-based light sources are a promising light source both for studies concerning the role of light spectrum in plant growth and development, and for horticulture, due to their high efficiency and safety. However, there is still a need to find an optimal spectrum for a LED-based light source that would allow plants to develop high production. We studied growth and photosynthetic apparatus in lettuce (Lactuca sativa L.) plants grown with LED-based light sources with different spectra: red (660 nm) and blue (450 nm) LEDs (RB); red and blue LEDs with added green (535 nm) LEDs (RGB); red and blue LEDs with added amber (590 nm) LEDs (RAB). In the morning and evening hours, a small amount of light from far-red (750 nm) LEDs were added to the spectrum of the light source. Plants grown with fluorescent lamps were used as a control. Light intensity used was 200 μmol/(m² s) photosynthetically active photons. Plants were studied at the age of 27-30 days, which is the age of harvest. All plants grown with LEDs had higher weight and leaf area than control plants. Among them, plants grown with RB spectrum showed the highest shoot fresh and dry weight. Adding green or blue light to the spectrum reduced shoot dry weight. The ratio of leaf length to width was higher in RGB plants, and internodes longer, than in control plants, which indicates that green light may stimulate cell elongation in lettuce. Plants grown with LEDs had lower photosynthetic pigment content per leaf area and lower photochemical chlorophyll fluorescence quenching than control plants. We can conclude that LED lighting slightly affects the photosynthetic apparatus in lettuce plants, alters their morphogenesis, in particular, stimulates cell elongation. The RB spectrum seems to be the best for growing lettuce with LED lighting.
Temperature, Light Intensity, and Photoperiod Affect Growth and Flowering in *Eustoma grandiflorum*

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**Keywords:** daily light integral, energy saving, lisianthus, long day plant, photosynthetic photon flux

**Abstract**
For year round production of good quality crops, we need to understand the growth and flowering response to various environmental condition such as light and temperature. Lisianthus (*Eustoma grandiflorum*), a qualitative long day plant, is relatively sensitive to light conditions. The objective of this study was to examine the growth and flowering responses of lisianthus to temperature, photoperiod, and light intensity during post-seedling stage. ‘El Paso Deep Blue’ lisianthus plants with four true leaf pairs were grown in growth chambers maintained at 16/12 (LT), 22/18 (MT), and 28/24°C (HT) (day/night) and provided three photosynthetic photon fluxes [PPF; 100 (LL), 200 (ML), 400 (HL) μmol·m⁻²·s⁻¹] for 8 (short day, SD, 08:00-16:00) and 16 h (long day, LD, 08:00-24:00) by fluorescent lamps and incandescent lamps. After treatments for three weeks and growing for one week in a greenhouse of 20°C, data on growth and development were collected. Higher temperature, higher PPF, and longer photoperiod promoted plant growth and flowering. Effects of light condition on the number of leaves and flower buds, total branch length, and shoot dry weight were greater with increasing the average daily temperature. An increase of 100-200 μmol·m⁻²·s⁻¹ could constitute an increase of 6°C to promote flowering under the same photoperiod. Therefore, growers can have a chance to choose one regimen of heating or supplemental lighting depending on cost without a delay of harvesting time and a loss of crop quality.
[261] Growth of Lettuce in a Closed-Type Plant Production System as Affected by Light Intensity and Photoperiod

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Keywords: anthocyanin content, chlorophyll fluorescence, Lactuca sativa L., LED

Abstract

This study was conducted to examine the effect of light intensity and photoperiod on the growth of leaf lettuce (Lactuca sativa L. ‘Hongyeom Jeockchukmyeon’) in a closed-type plant production system. Seeds, sown in 240-cell plug trays (60 cm x 41 cm x 5 cm), were germinated for 3 days and seedlings were grown for 24 days in a chamber-type plant factory lit 24 hours with fluorescent lamps (FL, Philips Co. Ltd., the Netherlands). Seedlings, transplanted at a density of 20 cm x 20 cm in a completely randomized design, were grown under LEDs (R:B:W=8:1:1, FC Poibe Co. Ltd., Korea), at one of the 4 light intensities (200, 230, 260 or 290 µmol·m⁻²·s⁻¹ PPF), and each with one of 3 photoperiods [18/6 (1 cycle), 9/3 (2 cycles) or 6/2 (3 cycles) (Light/Dark)]. Plants were cultured for 35 days under the condition of 21 ± 1°C, 70 ± 10% RH. Plants were fed with a recycling nutrient solution (initial pH 6.0 ± 0.5 and EC 1.5 dS·m⁻¹) contained in a deep floating tank. The plant height and fresh weight (top) were the greatest in the 290 µmol·m⁻²·s⁻¹ with photoperiods of 9/3 (2 cycles). Fresh weight (bottom), dry weight (top), and the longest length of root were the greatest in the 290 µmol·m⁻²·s⁻¹ with photoperiods of 18/6 (1 cycle). Leaf width, number of leaves, dry weight (bottom), and leaf area were the greatest in the 290 µmol·m⁻²·s⁻¹ when the plant was grown under a photoperiod of 6/2 (3 cycles). Anthocyanin content was also found the highest in the 290 µmol·m⁻²·s⁻¹ with photoperiod of 6/2 (3 cycles). The chlorophyll fluorescence was significantly higher in the 260 µmol·m⁻²·s⁻¹ PPF with a photoperiod of 6/2 (3 cycles) than in the 290 µmol·m⁻²·s⁻¹ PPF with a photoperiod of 9/3 (2 cycles). The high light intensity with a long photoperiod gave a significant increase in the development of the plant. The results suggest that the plant grew the best under a light intensity of 290 µmol·m⁻²·s⁻¹ PPF with a photoperiod of 18/6 (1 cycle) or 9/3 (2 cycles).
Cold Cathode Fluorescent Lamp (CCFL) Contained Far-red Light Range Enhanced Spinach Leaf Length

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Keyword: hydroponics, petiole, plant factory

Abstract
We investigate the effect of far-red light to growth of spinach (Spinacia oleracea L.) in plant factory condition. We designed two light condition regime, white CCFLs (control), white CCFLs and CCFLs which produced only far-red light range (FR). Both of light condition was set with 200 µmol m⁻² s⁻¹. The growth of spinach for both treatments was estimated by measurement of leaf length, fresh weight and dry weight at 40 days after germination. Growth conditions were kept at 20 ± 2°C, RH 60 ± 5% and 12h-photoperiods in plant factory. In result, the leaf growth, especially petiole growth at FR regime was increased 60% of it at control. The dry weight also tended to increase under FR regime. This indicates that the morphological changes to spinach leaves were induced by far-red light. These light combinations might be applied for another leafy vegetable species production under plant factory condition.
[288] Effects of LEDs on Photosynthesis and Secondary Metabolites in Roses, Chrysanthemums, and Campanulas

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Keywords: LED, photosynthesis, secondary metabolites, roses, chrysanthemums, campanulas, ornamental plants

Abstract

Integration of light emitting diodes (LEDs) in current growing systems receives full attention as they provide the opportunity to control light spectrum. In most cases, such research has focused on vegetables, whereas LED effects have not been extensively studied on ornamental plants. The experiment took place from November 2011 to January 2012 using potted \textit{Rosa hybrida} ‘Scarlet’, \textit{Chrysanthemum morifolium} ‘Coral Charm’, and \textit{Campanula portenschlagiana} ‘BluOne’. Plants were grown under a purpose-built LED array from Philips yielding approximately 200 \textmu mol m\textsuperscript{-2} s\textsuperscript{-1} for 16 hours per day. The temperature in the greenhouse compartments was set to 24\textdegree C and 18\textdegree C during the day and night, respectively. The four light treatments were (1) 40\% Blue 60\% Red, (2) 20\% Blue 80\% Red, (3) 100\% Red, and (4) 100\% White. The plants were grown to flowering (except chrysanthemums) and plant growth was recorded at the end of the experiment. During the experiment the net photosynthesis ($P_n$) of the plants was measured both directly under the LED lamps and under typical greenhouse high-pressure sodium lamps, making light response curves for both cases. Non-invasive measurements of secondary metabolites were performed \textit{in situ} by Dualex (an optical absorbance meter) and leaf samples were later analyzed by HPLC. The leaf area was greater with increasing amount of blue light, while pure red light increased total fresh and dry weight. In roses, high blue light produced more colored buds. In general, the differences between treatments were limited; however, the most extensive abnormalities were observed in the pure red light treatments. HPLC analyses showed that increasing blue light ratio results in an increase of phenolic acids and flavonoid compounds. There was a close correlation between the two quantification methods of secondary metabolites. The results will be further discussed in terms of physiology, morphology, and secondary metabolism.
[254] Establishment of Light Formula and Light Environmental Management Strategy for High-Efficient Plant Cultivation with Artificial Light Sources

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Keywords: light formula (LF); necessary light spectrum; light-emitting diodes (LEDs); plant factory; light environment management strategy (LEMS)

Abstract

Light is a vital environmental factor that affects plant growth and development by acting on plants not only as the sole energy source of photosynthesis, but also as one kind of environmental signal. Light requirements of plants are subjected to species, cultivar, growth and developmental stages, environmental conditions and manipulation target of yield & quality. Therefore, detailed studies on light formula (LF) based on physiological requirement are urgently needed for getting high yield and good quality of plants. With the development of semiconductor solid light sources, light-emitting diodes (LEDs), research on monochromatic light to plant physiology became possible. Therefore, the light quality requirements for all kinds of plants can be precisely and extensively studied to obtain the optimal light spectrum component for high productivity and good quality. The LF was defined as optimized monochromatic light component illuminated by LEDs for getting higher biomass and better nutritional quality of plants. Based on published literatures, red and blue light spectrum are macro-necessary LF component, and purple, green, yellow, cyan and orange light spectrum are micro-beneficial LF component, while far-red and ultraviolet light spectrum are functional LF component. Generally, a kind of LF is composed of one or two kinds of necessary light spectra, several micro-beneficial and functional light spectra for special plant during certain period and certain environmental conditions. The LF is a crucial scientific issue that should be established for plants with artificial light. More importantly, the LF is an important part of light environment management strategy (LEMS). The LEMS refers to a comprehensive management method of light environment, including light intensity, LF and photoperiod for one special plant, which should be established for plants with artificial light sources. It is assumed that the LF and LEMS will be preferentially applied in plant factory with entire artificial light source.
**[267] Growth of *Ixeris dentata* (Thunb.) Nakai in a Closed-Type Plant Production System as Affected by Light Intensity and Photoperiod**

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**Keywords:** chamber-type plant factory, LED, photosynthetic rate, tip-burn

**Abstract**  
This study was conducted to examine the effect of light intensity and photoperiod on the growth of *Ixeris dentata* (Thunb.) Nakai in a closed-type plant production system. Seeds, sown in 240-cell plug trays (60 cm x 41 cm x 5 cm) on January 17, 2012, were germinated for 3 days and grown for 13 days in a chamber-type plant factory lit 24 hours with LEDs (R:B:W=8:1:1, FC Poibe Co. Ltd., Korea). Seedlings, transplanted at a density of 20 cm x 20 cm in a completely randomized design, were grown under LEDs (R:B:W=8:1:1, FC Poibe Co. Ltd., Korea), at one of the 4 light intensities (200, 230, 260 or 290 µmol·m⁻²·s⁻¹), and each with one of 3 photoperiods [12/12 (1 cycle), 6/6 (2 cycles) or 4/4 (3 cycles) (Light/Dark)]. Plants were cultured for 22 days under the condition of 25 ± 2°C, 70 ± 10% RH. Plants were fed with a recycling nutrient solution nutrient solution (initial pH 7.0 and EC 2.0 dS·m⁻¹) contained in a deep floating tank. Leaf length, leaf width, fresh weights of top and root, dry weight of root, and chlorophyll fluorescence were obtained in the 230 µmol·m⁻²·s⁻¹ with photoperiods of 6/6 (2 cycles). Leaf area was significantly higher 260 µmol·m⁻²·s⁻¹ with photoperiods of 12/12 (1 cycle) than 290 µmol·m⁻²·s⁻¹ with photoperiods of 12/12 (1 cycle). Length of the longest root and number of leaves were the greatest 290 µmol·m⁻²·s⁻¹ than in other treatments. Higher incidence of tip-burn was observed 290 µmol·m⁻²·s⁻¹ with photoperiods of 12/12 (1 cycle) or 4/4 (3 cycles). Photosynthetic rate, stomatal conductance rate, transpiration, and CO₂ absorption rate was significantly higher 230 µmol·m⁻²·s⁻¹ than 200, 260, 290 µmol·m⁻²·s⁻¹ when the plant was grown under a photoperiod 12/12 (1 cycle). Tip-burn was observed high light intensity in 260 and 290 µmol·m⁻²·s⁻¹. Therefore, economic feasibility and productivity side for *Ixeris dentata* (Thunb.) Nakai cultivation in the closed-type plant production system optimum light intensity can be appropriate in 230 µmol·m⁻²·s⁻¹. The results obtained suggest that plant grew the best kept by light intensity at 230 µmol·m⁻²·s⁻¹, & photoperiod of 6/6 (2 cycles).
Effects of Alternating Light Intensity on CO$_2$ Assimilation of *Ficus elastica* and *Dieffenbachia picta* Plants, Grown for Indoor Landscaping

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**Keywords:** artificial lighting, interior foliage plants, light compensation point, light efficiency

**Abstract**  
Indoor landscaping increasingly uses plants on new hydroponic systems, including green walls, for greening private and public spaces, not always well or sufficiently lighted. Lamps are often essential to ensure a suitable light intensity for plant growth and for the production of a dense and brightly coloured canopy, even if many commonly used species originate in the lower layers of tropical and subtropical forests and have a high ability to tolerate poor light levels. The photosynthetic response to light flecks is a well known characteristic of many plants native of the lower layers of forest and especially those living on the floor of dark and moist tropical forests. The effects on CO$_2$ assimilation of a constant or alternating light intensity were tested in *Dieffenbachia picta* ‘Camille’ and *Ficus elastica* ‘Decora’ plants, grown under 8/16 hours of day/night in a phytotron. The compared intensities were 20, 40 or 80 µmol m$^{-2}$ s$^{-1}$ for constant light and 20/40 or 40/80 µmol m$^{-2}$ s$^{-1}$ for alternating light, at 8 minute intervals. The CO$_2$ assimilation was measured throughout the 8 hours of lighting, by an infrared gas analyzer LI-6400XT, on completely expanded leaves. The light intensity regimes influenced the trend of CO$_2$ assimilation curves and the total daily assimilated CO$_2$ in both species. In *Ficus* the photosynthetic activity under constant 20 and 40 µmol m$^{-2}$ s$^{-1}$ was very low (0.7-0.9 µmol CO$_2$ m$^{-2}$ s$^{-1}$ on average during the 8 hour light period) and increased to 1.4 µmol CO$_2$ m$^{-2}$ s$^{-1}$ under 80 µmol m$^{-2}$ s$^{-1}$, with two well marked peaks after 0.5 and 5 hours from the start of lighting. The 40/80 alternated intensity resulted in a total daily assimilation of 54 mmol CO$_2$ m$^{-2}$, 33.2% higher than under 80 constant lighting. In *Dieffenbachia* the CO$_2$ assimilation was around 0.2-0.6 µmol CO$_2$ m$^{-2}$ s$^{-1}$, averaged for the 3 constant intensities, whereas at 20/40 alternating lighting the rate increased to 1.2 µmol CO$_2$ m$^{-2}$ s$^{-1}$, equivalent to +67% on total daily assimilation.
[115] Measurements of Short- and Long-term Photosynthesis and Growth under Various Qualities of Light Emitting Diode Light

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Keywords: assimilation chamber, growth parameter, photosynthetic rate, single-peak LEDs, white LEDs

Abstract

Recently, various peak wavelengths of light emitting diodes (LEDs) have been introduced as a light source in plant production systems such as plant factories. In single-peak LEDs such as blue, green, and red LEDs, a small difference (20–40 nm) in peak wavelength sometimes causes a large difference in photosynthetic rate and growth. In white LEDs, spectral differences in the green and red regions of white light affect photosynthetic rate and growth. Therefore, a combination of different color LEDs makes it more difficult to determine the appropriate light quality for plant growth. In this study, we developed a new apparatus to measure the photosynthetic rate and growth accompanying the morphological changes that occur under various light quality conditions. Our apparatus consists of an open-type assimilation chamber, a premixing container to control air temperature and humidity, and a light source unit. Blue (405, 430, 450, and 470 nm), green (510 and 530 nm), and red (595, 640, 660, and 680 nm) LEDs, and a combination thereof, and white LEDs of different spectra can be mounted to the light source unit. To study the effect of ultraviolet (UV) light on photosynthesis and morphogenesis, UV lamps with peak wavelengths at 290, 320, and 350 nm can be added to the LED light. Photosynthetic photon flux can be controlled from 100 to 1,000 μmol m$^{-2}$ s$^{-1}$ at the canopy level. Plants can be grown in the chamber for 1 to 2 weeks, and the rates of photosynthesis and transpiration can be continuously monitored. This apparatus enables us to investigate the effect of light quality on short- and long-term growth by combining the measurements of the photosynthetic rate and the growth parameters under various light conditions. In this study, we report the results of experiments performed using lettuce, red perilla, and tomato seedlings.
Effects of Light Quality and CO₂ Concentration on Diurnal Photosynthetic Characteristics of Strawberry

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Keywords: artificial light, controlled environment agriculture, photosynthesis, spectrum, elevated CO₂

Abstract

As photosynthetic efficiency changes with wavelength and CO₂ level, several artificial light sources for strawberry production were tested. Strawberry (Fragaria ×ananassa Duch. cv. Toyonoka) plants were planted in a growth chamber (25/20°C, 16 h photoperiod, 400 µmol m⁻² s⁻¹), including Warm White (WW, 3 000K, R:G:B=43:40:17), Cool White (CW, 6 500K, R:G:B=23:40:37), and TLRA (Tubular Lamp with Red Additive, R:G:B=59:29:12) for seven weeks. The diurnal photosynthetic characteristics of net photosynthetic rate, stomatal conductance, and transpiration rate were measured by portable photosynthetic system (LI-6400). The results showed that diurnal photosynthetic characteristics of strawberry were different among treatments. Net photosynthetic rate was the highest under CW lamps and treatment under TLRA lamps was the lowest. The peak value of net photosynthetic rate appeared after 5, 7 and 3 hours of exposure to WW, CW and TLRA lamps, respectively. The diurnal variation of net photosynthetic rate was a single-peak curve under WW and CW lamps and a double-peak curve under TLRA lamps. There was a significant midday depression when plants exposed to TLRA lamps for 9 hours. Our results showed that spectral quality during light period affected the diurnal pattern of photosynthetic characteristics. We also compared the photosynthetic characteristics at elevated 1200 µL⁻¹ CO₂ concentration used of different light quality lamps. The effect of light quality on photosynthesis characteristics changed with CO₂ concentration. The highest photosynthetic rate and plant growth were again under CW lamp irradiation. No significant midday depression was found when plants were exposed to TLRA lamps at elevated CO₂. Elevated CO₂ treatment resulted in increased plant photosynthesis under all tested light treatments and altered the effect of spectral quality on the diurnal photosynthetic characteristics of strawberry.
[179] Effects of Supplemental Lighting to a Lower Leaf Using LEDs with Different Wavelengths on Leaf Photosynthetic Characteristics in Sweet Pepper

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Keywords: intracanopy lighting, leaf senescence, LEDs, wavelengths, Capsicum annuum

Abstract
Supplemental lighting within a canopy, called intracanopy lighting (IL), is a recently proposed technique for high-wire grown vegetable production in greenhouse. Light-emitting diodes (LEDs) are an appropriate light source for IL because the source is required to be compact. In addition to enhancing instantaneous canopy photosynthesis, IL also reduces a decrease in photosynthetic capacity of irradiated lower leaves during senescence. Although the relationship between light wavelengths and instantaneous photosynthesis has been well described, the relationship between the wavelengths and the decrease in photosynthetic capacity during leaf senescence has not been researched. To investigate the effect of LED wavelengths on the decrease in photosynthetic capacity, we carried out growth chamber experiments with sweet pepper (‘Special’) seedlings. Top lighting was provided by white fluorescent tubes at a photosynthetic photon flux density (PPFD) of 300 µmol m\(^{-2}\) s\(^{-1}\). Five treatments consisted of four IL treatments with different types of LEDs and control without IL. The IL was provided by white, blue, green or red LEDs to a mature leaf of each plant at a PPFD of 150 µmol m\(^{-2}\) s\(^{-1}\). After five-week treatment, photosynthetic characteristics of the leaves were examined. Net photosynthetic rates measured under mixed light from red and blue LEDs at 300 or 1,500 µmol m\(^{-2}\) s\(^{-1}\) PPFD tended higher in the four IL treatments than in control. The amounts of leaf N, chlorophyll and ribose-1,5-bisphosphate carboxylase/oxygenase in IL treatments also tended greater than those in control. Among the IL treatments, significant differences were observed neither in the photosynthetic rates nor in the amounts of leaf N and the photosynthetic components. These results indicate that IL reduces the decrease in photosynthetic capacity of lower leaves in sweet pepper irrespective of its wavelengths. Thus, LEDs with wavelengths which maximize the instantaneous photosynthesis should simply be appropriate for IL.

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Keywords: carbon assimilation, photosynthetic capacity, photosynthesis model, light intensity, seasonal change

Abstract  
The aim of this study is to estimate a leaf’s photosynthetic acclimation to light conditions in 5 different ages of a 10-year-old grape leaf (Vitis vinifera L. x Vitis labrusca L. ‘Kyoho’) during the growing season (early May to late September). The photosynthetic capacity model was considered and described as based on a non-rectangular hyperbola. The light response of photosynthesis was also analyzed by using linear and non-linear regression. Photosynthetic acclimation to light showed the highest curve at 8 weeks after the leaf unfolded. The values of gross carbon assimilation ($A_{\text{max}}$) and the net photosynthetic rates ($P_n$) were different from each other around 30-40% throughout the season of leaves. Meanwhile, the light saturation point ($I_s$) during each stage of growth of the leaf had reached the peak $\approx 700$-$1,000 \, \mu \text{mol m}^{-2} \text{s}^{-1}$. In addition, the estimated values were highly correlated with the observed values of the leaf photosynthesis responses to light variations at 8 weeks after unfolding ($r^2 = 0.82^{**}$). Thus, a measurement of the photosynthetic acclimation provided here might be useful for estimating the photosynthetic light responses among the seasonal and diurnal variations.
[243] Effect of Plant Photosynthesis Under Different Wavelengths of LED

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Keywords: Irradiance, LED, Lettuce, PAR, Petunia, Photosynthesis, Tomato

Abstract

Plants require light for photosynthesis and to control many hormonal and morphological changes. The photosynthetically active radiation (PAR) curve represents the percent of light absorbed and utilized by the different pigments in the plant as a function of wavelengths between 400 and 700 nm. This curve has been developed based on the photosynthetic efficiency (action spectrum) and plant pigment light absorbance curves, with maximum photosynthesis occurring in the red and blue spectrum of light and less in the green region. With the development of light emitting diodes (LEDs) over the complete range of PAR (400 – 700 nm), research is now possible to determine the impact of wavelength over a range of light intensities on plant growth. The photosynthesis rate of seedlings from three species of plants were tested using different wavelengths of LED arrays, tomato (Solanum lycopersicum), lettuce (Lactuca sativa), and petunia (Petunia × hybrida), using a LI-COR whole plant gas exchange system. A total of 14 different wavelengths of LED arrays across the PAR spectrum and three irradiance levels were used for the test. From our results we found that the peak photosynthesis rates occurred between 630 and 680 nm wavelengths in the red spectrum and between 430 and 450nm wavelength LED arrays for the blue spectrum. There were some slight exceptions from these results that were both irradiance level and species specific. This research will allow for improved selection of LEDs in the PAR spectrum for plant production.
[273] Photosynthetic gas exchange of Tomato (*Solanum lycopersicum*) in Fluctuating Light Intensity

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**Keywords:** LED, modelling, dynamic lighting, RuBP regeneration, Rubisco, stomata

**Abstract**

In order to achieve high yields and year-round production, tomato (*Solanum lycopersicum*) production in greenhouses requires an extensive light integral. In northern countries, such as the Netherlands, year-round tomato production is impossible without inputs of artificial lighting. To save energy and money, it is of interest to investigate strategies that rely on dynamically modulating the intensity of artificial lighting. This can be achieved by using LEDs which, unlike the currently used high-pressure sodium (HPS) lamps, can be switched on and off frequently without considerable loss of efficiency and potential lifetime. In order to assess the quantitative effect that light fluctuations have on tomato leaf photosynthesis, photosynthesis under non-steady state conditions must be characterised. In this poster, we present combined gas exchange and chlorophyll fluorescence measurements of tomato (cv. Cappricia) leaf photosynthesis during gain and loss of photosynthetic induction. Different kinetic phases can be distinguished that could reflect limitations by RuBP regeneration capacity, Rubisco activation state and stomatal opening and closing. These processes are activated in light and deactivated in the dark; their activation takes less time than their deactivation. We intend to combine these measurements with enzyme activity assays at a range of combinations of CO$_2$ concentration, temperature and vapour pressure deficit to assess dynamic behaviour of photosynthetic gas exchange under conditions relevant to current greenhouse cultivation. The results will be fed into a crop growth model to explore novel lighting strategies.
[170] Early-Stage Growth and Carbohydrate Contents of Tomato under Continuous Lighting with or without a Diurnal Temperature Difference

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Keywords: chlorosis-like disorder, DIF, growth analysis, Solanum lycopersicum, supplemental lighting

Abstract
In tomato, too long photoperiods including continuous lighting result in chlorosis-like disorder on leaves. This disorder is suggested to be related to excess carbohydrate accumulation in leaves. On the other hand, the disorder is reduced or eliminated by a diurnal temperature difference (DIF) of 8-10°C. The relationship between the inhibition of the disorder by DIF and the extent of carbohydrate accumulation has not been investigated. The aim of this study was to examine growth and carbohydrate contents of tomato under continuous lighting with or without DIF. Tomato seedlings (‘Momotaro Fight’) were grown under neutral white fluorescent lamps in growth chambers from three to seven weeks after seeding. Four treatments consisted of the combination of two light/dark periods of 12/12 h (P12) and 24/0 h (P24) and two 12/12-h temperatures of 20/20°C (D0) and 25/15°C (D10). Photosynthetic photon flux density (PPFD) during the light period was 400 µmol m⁻² s⁻¹ for P12 treatments and 200 µmol m⁻² s⁻¹ for P24 treatments. The daily integrals of PPFD and temperature were thus identical in all treatments. In P24D0 treatment, severe chlorosis-like disorder was observed after the four-week treatment. In P24D10 treatment, moderate disorder was observed. In P12 treatments, the disorder was not observed. Shoot dry weight was the largest in P24D10 treatment, followed in order by P12D10, P24D0 and P12D0 treatments. This indicates that continuous lighting resulted in higher shoot dry weight in each DIF treatment while zero DIF resulted in lower shoot dry weight irrespective of the light/dark period. Our results also showed that shoot dry weight was not correlated with the severity of disorder under the conditions of the present experiment. Growth analysis revealed that shoot dry weight was correlated with net assimilation rate rather than leaf area ratio. The results on diurnal carbohydrate turnover in leaves will be discussed.
[266] Use of High Output LED in Ornamentals

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Keywords: LED, ornamentals

Abstract

Until recent there have been more or less two choices for light emitting diodes – to use low output units close to plants either for confined environments or for interlighting between crops typically vegetables, while or high output lamps that can substitute current HPS lamps has been in the pipeline from several smaller companies. An experiment was performed in winter 2012 from Jan to March using high output LED lamps and SONT lamps in two experimental greenhouses at the University of Aarhus. The aim was to evaluate the use of LED and conventional lamps in a standard setup using four varieties potted roses and two varieties of campanula growing in the same light level (120 µmol m-2s-1) and identical temperature set points (18°C night, 21°C day and 24°C for ventilation) and 800 ppm of CO2 We did not use chemical growth regulation as one focal point was the effects of plant growth and morphology. To secure that the leaf temperatures was maintained at the same level the top heating system was allowed to increase if needed. The energy use in kWh for lamps and for heating (below/above) was recorded on a daily basis. The results showed relative small differences between the treatments, but significant differences in roses was seen in stem weight and number of flowers and buds reflecting that the SONT grown plant were 2-4 days earlier irrespective of cultivars. There were no differences in leaf area but we found more yellow leaves in the plants. The campanula showed no differences in fresh/dry weights but one cultivar was approximate one week earlier. Since the set points for supplemental lights was identical in the two compartments the light period was identical and the LED lamps used 40% of the energy supplied to the SONT lamps in the period. The energy used for heating was identical for the bottom heating but increased by on average 100% resulting in an average heat energy increase (in kWh) of 40-50% depending on the outside weather which was unusual cool in 2012. Since the costs of electricity per kWh is higher that heat kWh the experiment proves that high output LED has reached a stage that results in substantial energy saving potential especially on crops that does not require high leaf temperatures.
[239] Impact of local light on number and growth of cells in tomato fruit

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Key words: sink strength, cell number, cell size, pericarp, fruit growth

Abstract
In most studies on fruit growth in response to light, treatments are imposed at plant level. Such treatments lead to only limited insight into generative growth response since the interaction with vegetative response cannot be ignored. In order to study the effect of light on tomato fruit growth, a cuvette system with 100 μmolm⁻²s⁻¹ light was constructed. The light was from white Light Emitting Diodes (LEDs). The system was used to illuminate individual tomato trusses. Three local light treatments were applied (no light, light for 12 hours and light for 24 hours) to one truss per plant of tomato cultivar Komeett. The hypothesis tested was whether fruits grown in the presence of light exhibit higher sink strength compared to those grown in the dark. Fruit diameter and fresh weight, pericarp cell number and cell size were measured half way and at the end of fruit development. Preliminary results indicate no significant difference in fruit fresh weight and diameter at both harvest stages. Half way during fruit development, pericarp cell number was 23% higher in light-grown fruits while cell size was 11% lower compared to fruits grown in the dark. These results contradict findings reported from an earlier in vitro experiment where light was found to increase fruit sink strength through activation of enzymes within the starch synthesis pathway. Our results suggest a compensatory mechanism for final fruit diameter and weight at the cell level since cell size increase appeared to make up for deficiencies in cell division activity.
Non-invasive plant growth measurements for detection of blue-light dose response of stem elongation in *Chrysanthemum morifolium*

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**Keywords:** blue light, morphogenesis, LED, stem elongation

**Abstract**  
Quantitative and qualitative imaging of plant growth and development in response to environmental factors under greenhouse conditions visualises plant performance on-site and may increase our knowledge of how rapid plants change their growth pattern in relation to environmental stimuli. In the present study a non-invasive plant growth sensor (PlantEye, Phenospex B.V, Heerlen, NL) was tested in analysing changes in diurnal stem elongation patterns and plant height in response to the spectral quality of the light environment. Plants were grown in four different LED supplemental lighting treatments with 0%, 12.5%, 18.5% and 22.5% blue light under greenhouse conditions in winter (18 h day/4 h night). The non-invasive measurements were carried out automatically every four hour with three repetitions, and supported by manual measurements of plant height every third day. A strong linear relation between the non-invasive measurements and manual measurements of plant height was achieved, and a blue-light dose-response showing a decrease in plant height in relation to an increase in blue light was demonstrated. However, the non-invasive plant growth sensor was not able to distinguish between diurnal fluctuations in the rate of stem elongation, and leaf movements, and therefore a further analysis of diurnal variations in leaf angular positions and stem elongation was conducted under greenhouse conditions. Plants were pruned just below the main meristem, and the leaf movements were measured every hour during the following three days showing a clear pattern of upward moving leaves during the afternoon and night, and downward moving leaves during the early hours of the day. These movements were subtracted from the values measured on non-pruned plants grown under the same environmental conditions showing changes in the diurnal stem elongation pattern in relation to day length and environmental conditions. The results are novel in describing a method for measuring diurnal stem elongation in high-resolution on a plant canopy and under greenhouse conditions.
[227] In vitro propagation and rooting of *Helleborus orientalis* in response to LED lighting

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**Keywords:** Helleborus, LED, propagation, Ranunculacea, rooting

**Abstract**

*Helleborus* is an early spring flowering perennial with increasing horticultural importance. To explore these advantages an efficient *in vitro* propagation system for *Helleborus* is crucial. In the past, the main goals of *in vitro* lighting were to sustain photosynthesis and to regulate the photoperiod. Nowadays, the development of LED technology opens the door to a plethora of applications. Therefore, we investigated the effect of light quality (more specific red, blue, red + blue and white LED and white TL light) on the propagation and rooting of *Helleborus orientalis*. We found that the light spectrum had no effect on the propagation rate as such, but that it influenced the plant morphology (plant height, number of leaves per plant, leaf length, % dry matter). Also rooting was influenced. Red and white LED lights as well as control TL lamps resulted in a significantly longer root compared to the blue and red + blue LED lighting. However, the red LED lighting resulted in the highest number of roots.
The Effect of LED Assimilation Light and Increased Temperature In Strawberry Glasshouse Cultivation

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Keywords: *Fragaria x ananassa* cv. Clery, LED, assimilation light, temperature, earliness

Abstract
Assimilation light in horticulture has been subject of many research. A lot of experience is built up with high pressure sodium lamps, but since the introduction of LED lamps, the possibilities increased enormous. In this research, LED lamps are used in an early strawberry glasshouse cultivation to examine the possibilities regarding advancing the strawberry season without losing production. In one glasshouse LED lamps are installed (Philips GreenPower LED Production DR/B 150) with deep red and blue wavelengths. So only growing light is included in the LED lamps. This light differs from common night-interruption light which contains also far-red light (Van Delm et al, 2012). The LED assimilation modules are installed to produce 70µmol/s/m². Two glasshouses, one with and one without LED assimilation lamps, were planted at 14 December 2011 (14 plants/m²) with trayplants of cultivar Clery. The plants were lighted between 15 December and 15 March during a part of the night and during dark moments of the day. Because the plants receive more light, it is possible to increase temperature. The average day- and night temperature in the lighted glasshouse were respectively 2.34°C and 1.50°C higher than the unlighted glasshouse. Total heating costs and energy costs of the LED lamps are registered, so the return is calculated. The first fruits were picked 26 days earlier in the lighted glasshouse. Mid-harvest date differed 17 days. There were no statistical differences in total yield and under the LED lights there were more large fruits, although this difference is small (0.4 kg/m²). This research shows it is possible to force the plants to advance the strawberry season with almost four weeks with retaining fruit quality, fruit size and total yield.
[149] Effects of Agrochemicals on the Radiometric Properties of different anti-UV Stabilized EVA Plastic Films

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Keywords: greenhouse film, iron, chlorine, sulphur, solar radiation, transmissivity

Abstract
Most of the agrochemical substances used in protected cultivation, especially those based on sulphur and chlorine, generate by-products that lead to a degradation of the covering materials together with a variation of their mechanical and physical properties. The degradation due to agrochemicals depends on their active principles, method and frequency of application, and ventilation. A research was carried out by means of laboratory and field tests to evaluate how agrochemicals contamination and solar radiation influence the radiometric properties of ethylene-vinyl acetate copolymer (EVA) films used for crop protection. The films were manufactured adding different light stabilizer systems and were exposed to natural outdoor weathering at the experimental farm of the University of Bari (Italy; 41° 05' N) in the period from 2006 to 2008. Each film was tested as covering of two low tunnels: one of the two tunnels was sprayed from inside with the agrochemicals containing iron, chlorine and sulphur while the other one was not sprayed and used as control. Laboratory tests were carried out on the new films and on samples taken at the end of the trials. The experimental tests showed that both the natural weathering together with the agrochemicals did not modify significantly the radiometric properties of the films in the solar and in the PAR wavelength range; within 6 months of experimental field tests the variations of these radiometric characteristics were at most equal of 10%. Significant variations, up to 70% of the initial value, were recorded for the stabilised films in the LWIR wavelength range.
[212] Screening During the Vegetative Growth Phase Reduces Yield of Cucumber

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Keywords: Cucumis sativus L., dry matter, greenhouse, leaf starch content, leaf sugar content, light use efficiency, photosynthesis

Abstract
In order to reduce heat energy in greenhouse crop production, (transparent) screens may also be used during the day, in particular in the early growth phase when rapid leaf area development necessitates high temperatures. However, energy reduction must be put in relation to light reduction-induced yield loss. In this study, the effect of shading cucumber plants by up to 55 % during their vegetative growth phase on photosynthesis, growth and yield in the following generative phase was quantified. Shading the plants during the first five weeks under Central European winter conditions reduced leaf area by 0.4 % per 1 % reduction in photosynthetic active radiation (PAR). Moreover, leaf photosynthesis and, consequently, leaf dry matter content, leaf starch content and leaf sugar content of shaded plants were significantly diminished. Over the next two weeks, the leaf photosynthesis of the previously shaded plants fully recovered under full light and a leaf area index (LAI) of 3.5 m² m⁻² was achieved, which is considered optimal for crop photosynthesis. Yield, however, was diminished from the very first harvest week by 0.39 kg m⁻² per 1 µmol m⁻² reduction in the mean daily PAR during leaf area development. Over the next two weeks, yield losses increased to 0.66 kg mol⁻¹ and hit 0.76 kg mol⁻¹ after six weeks of harvest. The effect of PAR on plant growth was proportional when relating the PAR integral over the entire experimental period to total yield and total dry matter production, respectively. Using these relationships, growers can optimise potential energy savings against potential yield losses.
[279] Early Exposure to UV Radiation during Propagation leads to a Yield Increase in Pepper (*Capsicum annuum* L.)

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**Keywords:** ultraviolet radiation, polytunnel, photoseselective cladding films, propagation

**Abstract**

There is significant scope to exploit fundamental light responses in crop plants by manipulating the light environment reaching the crop; particularly where crops are grown in protected environments such as glasshouses and polytunnel. The recent advances in polymer chemistry and manufacturing methods have produced a range of novel films that selectively filter specific radiation wavelengths, in which can provide the opportunity to exploit plant light responses for crop production. The work reported here has characterized the response of commercial pepper cultivar, Nilson F1 when grown under different plastic films with contrasting UV transmission i.e. UV transparent film (THB-UVT), standard horticultural film (THB-ST) and Mesh. We have shown that, at the end of the propagation phase, we achieved a stronger seedling under THB-UVT film which was characterized by growth reductions in terms of total leaf area, plant height, shoot & root fresh weight and thicker leaves compared with those propagated under Mesh or THB-ST film. “Cross-over” treatment from UV transparent film to the standard film resulted in an increase in the fruit number and weight at the end of cropping phase, whilst yield of plants propagated under Mesh was the lowest. These findings show that UV exposure during the early stages of growth have a direct effect on the subsequent stages of fruit yield.
[280] Efficiency of Plastic Types on Cucumber Production (*Cucumis sativus* L.)

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**Keywords:** ultraviolet radiation, cucumber, plastic covers, luminanceTHB

**Abstract**

Greenhouse films have traditionally used an absorber of short wavelength UV as part of the stabiliser package. Replacing or augmenting this with alternative absorbers can broaden the band of UV absorption up to wavelengths of 370 to 380nm, and this is the principle used in some greenhouse film for insect and/or fungal control. Plant responses to light spectral quality can be exploited to deliver a range of agronomically desirable endpoints in protected crops. The work reported here has characterized the response of commercial cucumber cultivars, Hesham F1 and Brengy F1 when grown under different plastic films of Luminance THB AF UV-Opaque, Clear AFUV-Opaque, Luminance THB UV-Opaque and Polyvinyl chloride (P.V.C). Our results indicated that, Luminance THB AF UV-Opaque film significantly increased plant height, number of leaves per plant and the average plant leaf area of both cucumber cultivars when compared to the other plastic cover. The highest early yield was obtained by using Clear AF UV-Opaque film, however, the highest total yield; number of fruits per plant and per square meter was achieved by cladding greenhouse by Luminance THB AF UV-Opaque one. Meanwhile, the lowest mean values of fruit yield and its components were attained by using P.V.C.
[294] How Hanging Baskets Affect Light Quantity and Quality on Lower Crops in Poly-Covered Commercial Greenhouses

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Keywords: hanging baskets, shading, PAR, red:farred, shade avoidance, daily light integral

Abstract
Commercial greenhouse growers in Ontario habitually grow hanging baskets over top of spring bedding plant crops in order to maximize the use of greenhouse space. In a market typified by high labor costs and low return on investment, this practice has helped growers to remain competitive and profitable. However, it was noted significant reductions in the quality of the underlying crop in certain situations, which can offset the additional profits made from the hanging basket crop. While it is generally believed that hanging baskets significantly alter the quantity and quality of sunlight incident on the underlying crop, there is very little supporting empirical data in the literature. The objective of this study was to investigate the effect of hanging basket on the quantity and quality of light incident on the underlying crop in various commercial greenhouses in Southwest Ontario, Canada. Basket and undercrop level photosynthetically active radiation (PAR) measurements were continuously taken over the spring cropping season (approx. 12 weeks) in 2012 in three different commercial polyhouses. The resulting PAR data was integrated over each day to generate daily light integrals (DLI). Spectral measurements were also taken at each of the locations several times over the course of the season. DLI's at basket level ranged from about 2 to 30 mol m\(^{-2}\) day\(^{-1}\), depending on the weather, while the daily PAR incident on the undercrop was reduced by about 15 to 60% over the course of the season. The mean red:farred was 1.14 and 1.02 at hanging basket and undercrop levels respectively.
Abstract

In the present study, the influence of three different shading nets with different colour, shading intensity and porosity on the screenhouse and crop microclimate was experimentally investigated. The experiments were carried out from May to October of 2011 in the experimental farm of the University of Thessaly in Velestino, Central Greece. Seedlings of pepper plants were transplanted during May in three screenhouses and in open field. The three screenhouses were covered with the following nets: (a) an anti-thrip insect proof white net with shading intensity of about 13%, (b) an anti-thrip insect proof white net with shading intensity of about 34% and (c) a green shading net with shading intensity of about 36%. Shading nets (a) and (b) had same porosity but different shading intensity while shading nets (b) and (c) had similar shading intensity but different porosity. The following parameters were recorded regularly inside and outside the screenhouses: global solar radiation, air temperature and humidity and crop temperature and transpiration rate. In addition, wind speed and direction were also measured outside the screenhouses. The results showed that the reduction of solar radiation above the crop was proportional to the shading intensity of the net. It was found that the air temperature values measured under the screenhouses were similar to those measured in the open field. However, the canopy to air temperature difference was higher in the open field than under screenhouse conditions, with the lowest values observed under the screenhouse covered by the anti-thrip insect proof white net with shading intensity of 35%. In addition, the canopy-to-air vapour pressure deficit was significantly lower in the crop grown under shading that in the open field.
[177] Combination of Blue and Far-red Supplemental LEDs Enhanced Baby Leaf Lettuce Yield without Lowering Nutritional Phytochemical Content

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Keywords. Controlled environment, Lactuca sativa, light emitting diodes, light quality, plant factory

Abstract

Light emitting diodes (LED) offer an advantage in designing custom-made light quality required for specific plant response. Our previous study showed that use of blue (B, 400-500 nm) supplemental light increased health-promoting phytochemicals such as anthocyanins and carotenoids in lettuce (Lactuca sativa), while that of far-red (FR, 700-800 nm) light decreased the phytochemicals but increased the leaf expansion and growth (yield), when used as supplement to white fluorescent lamps as the main light source (Li and Kubota, 2009). This study was conducted to examine the effect of the combination of B and FR light on yield and phytochemical accumulation of lettuce. ‘Red Cross’ baby leaf lettuce plants were grown in a growth chamber for 22 days under photosynthetic photon flux (PPF, 400-700 nm, the sum of main and supplemental light), photoperiod, and air temperature (day/night) of 300 µmol m⁻² s⁻¹, 16 h, and 25°C/20°C. White fluorescent lamps were used for the main light source. Supplemental B and FR light were provided for 12 days at 130 and 160 µmol m⁻² s⁻¹ PPF respectively in an alternating manner in which plants received supplemental light for one day with B followed by one day with FR. After 12 days, plant fresh and dry mass were 40.7 and 29.8 % greater respectively with the supplemental light treatment compared with the white light control without supplemental lights. Chlorophyll, anthocyanins, xanthophylls, and β-carotene were 0.49 (mg/kg FW), 3.0, 0.44 and 0.20 (mg/g DW), comparable to those of the white light control. Our results showed that when combined with B light, supplemental FR could be used for enhancing yield of baby leaf lettuce grown under white fluorescent lamps without lowering important health-promoting phytochemicals. This study demonstrated successfully the concept that monochromatic LEDs can be combined complementarily to induce specific plant responses.
[178] Growth and Quality of Chinese Kale Grown under Different LEDs

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Keywords:  light quality; Brassica alboglabra; growth; quality

Abstract
Effects of light quality on growth and quality of Chinese kale (Brassica alboglabra Bailey) were studied by different Light Emitting Diode (LEDs) (red:blue=8:1 8R1B, red:blue=6:3 6R3B and red:green:blue=6:2:1 6R2G1B, 12 h, 50μmol·m⁻²·s⁻¹) in hydroponic. The growth of Chinese kale was affected by different LEDs treatment. There was no significant difference in plant height, diameter of flower stalk (the edible part) and leaf number among 3 LED treatments. The fresh weight of shoot, root and plant in 8R1B and 6R2G1B treatments were significantly higher than those in 6R3B treatments. The dry weight of shoot and flower stalk in 8R1B treatment were significantly higher than those in 6R2G1B and 6R3B treatments. The quality of flower stalk in Chinese kale was affected by LEDs treatment. The concentrations of vitamin C and soluble protein in flower stalk of 6R3B treatment were significantly higher than those in 8R1B and 6R2G1B. The soluble sugar concentration in flower stalk of 6R3B treatment were significantly higher than other 2 treatments, while reducing sugar concentrations was no remarkable difference. There was no significant difference in concentration of soluble phenol, flavonoids and amino acid among 3 LEDs treatment. The nitrate concentration in flower stalk of 6R3B treatment were significantly lower than other 2 treatments, and the activities of nitrate reductase were significantly higher than other 2 treatments.
[194] Effect of Supplementary Lighting on the Quality of Tomato Fruit 
* (Solanum lycopersicum L.) in Autumn-Winter Cultivation

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**Keywords:** chemical compounds, sensory analysis, LED, HPS lamps

**Abstract**
One of the most important factors affecting many physiological processes including the intensity of photosynthesis and thus a proper growth, development and quality of plants is light. Chemical investigations carried out for various vegetable species (lettuce, tomato cucumber) revealed that the use of LED lamps positively affected their growth and phytochemical traits. The present work aims at comparing the effect of supplementary lighting type on the chemical composition and sensory quality of tomato fruits cultivated in the autumn-winter season. Two greenhouse tomato cultivars (Komeett F₁ and Starbuck F₁) were used in this experiment. Fruit quality was evaluated by the content of total sugars, dry matter, nitrate (NO₃), phosphorus and potassium. Sensory analysis was carried out using the profile method (QDA). The use of a supplementary light source increased the content of total sugars in Komeett F₁ cultivar fruits by 39.4% for HPS and 17.9% when used LED light. The dry matter content in fruits was at similar level. A lower content of nitrates in tomato fruits was observed in the combinations where plants were lighted with HPS as well as LED lamps. However, there was not a significant effect of supplementary lighting on phosphorus content in tomato fruits. Cultivating tomato with supplementary light significantly affected the fruit sensory quality. Plants supplementary lighted with HPS and LED lamps were characterized by fruit with higher flesh juiciness, sweeter taste and higher overall quality.
[223] Effects of Red and Blue Light Irradiation on Vindoline and Catharanthine Content in Catharanthus roseus

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Keywords: catharanthine, Catharanthus roseus, light quality, monoterpenoid indole alkaloids, pharmaceutical compounds, vindoline

Abstract

Vindoline (VDL) and catharanthine (CAT) are important constituents in Madagascar periwinkle (Catharanthus roseus) for producing the dimeric monoterpenoid indole alkaloids, which are utilized in human cancer treatments. In this study, the effects of irradiating Madagascar periwinkle cultivars with red light alone (R), blue light alone (B) or mixture of red and blue light (RB) on VDL and CAT content in leaves were investigated. As repetitive mating has seldom been performed in this plant, Taitan, Kermesia and Dealbata were cultivated under the white fluorescent lamps with an intensity of 100 ± 20 μmol m⁻² s⁻¹ for a 16-h photoperiod at 23 ± 2°C for 35 d. The total VDL and CAT content was higher in Taitan and Dealbata than in Kermesia. As Taitan showed higher seed germination percentage than Dealbata, Taitan was selected for further examination. Taitan was cultivated under R (660 nm), B (470 nm) or RB (R/B light PPFD ratio of 2/1) with an intensity of 150 ± 20 μmol m⁻² s⁻¹ and a 16-h photoperiod for 28 d. There were no significant differences in plant height, leaf length and width and shoot flesh weight among the lighting treatments. The total VDL and CAT content in the leaves was significantly greater in the plants grown in R than in the RB and B treatments. Thus, cultivation of Madagascar periwinkle under red light alone would enhance production of these important resources for anticancer drugs.
[240] Effect of Light Regimen on Yield and Flavonoid Content of Warehouse Grown Aeroponic *Eruca sativa*

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**Keywords:** LED, flavonoid, spectrum, HPS, irradiance

**Abstract**

Aero Farm Systems has developed a hydroponic module for growing leafy greens. One 400 watt high pressure sodium (HPS) light per 1.8 m$^2$ growing area created poor light uniformity and required lamp heights that limited stackability of modules. Experimentation was conducted to determine if LED arrays could provide necessary light quality and irradiance without affecting plant yield and quality. Flavonoids were the chosen qualitative proxy due to their known nutraceutical properties. A custom computerized LED array (Lighting Research Center, Rensselaer Polytechnic Institute, Troy, NY, USA) with an aeroponic growing system was used to provide differing intensity regimens of blue (460 nm, 8% of total light) and red (620 nm, 92% of total light) light to grow baby Arugula (*Eruca sativa* ‘Astro’). Four light irradiance regimens were compared to an HPS control (mean PPFD of 113 µmol m$^{-2}$ s$^{-1}$). The experiment was replicated over time for a total of 5 replicates. LED light regimens measured in µmol m$^{-2}$ s$^{-1}$, using a 24 hr photoperiod from day 3 to 18, were L1, constant light at 150; L2, light decreasing from 225 to 75; L3, increasing from 75 to 275; and L4 increasing from 75 to 325. 25 g of seeds were spread across each 1 m$^2$ test area and covered for 2 days. A commercial water soluble fertilizer was used with EC 2.0-3.0 dS m$^{-1}$ maintained at pH 5.0-5.5. Canopy air temperature was 18-24 ºC. Harvestable fresh weight was not significantly affected by light treatment. However, some patterns were evident. All LED regimens, except L2, gave a harvestable fresh weight equal or greater than control; and L4 gave the highest harvestable yields. Flavonoid content was greatest for L1, least for C, and was not significantly different for the L2-L4. Based on these results, LED arrays were found to be a suitable replacement to HPS, ideally with light levels increasing over developmental time.
**Abstract**

An experiment in environment-controlled chamber was conducted to investigate the effects of light intensity in a short-term continuous lighting by using artificial illumination of red and blue light-emitting diodes (LEDs) with the peak wavelength of 630nm and 460nm respectively on nutritional quality of hydroponics lettuce. Four light intensity treatments, including 50, 100, 150 and 200μmol·m⁻²·s⁻¹, were designed. The results showed that the nitrate concentration in lettuce shoot decreased significantly after being treated with short-term (48h) continuous lighting illuminated with LEDs, while the content of soluble sugar and vitamin C increased substantially. Moreover, it was observed that the improvement efficiency of nutritional quality of lettuces was greatly affected by the light intensity of short-term continuous lighting. When lettuces were treated with the light intensity of 50 μmol·m⁻²·s⁻¹, the decrease rate of nitrate concentration and the increment of soluble sugar content in lettuce shoot were very low. When light intensity was elevated from 50 μmol·m⁻²·s⁻¹ to 200 μmol·m⁻²·s⁻¹, the decrease rate of nitrate concentration and the increment of soluble sugar concentration in lettuce shoot were increased. However, the promotion efficiency in nutritional quality of lettuce decreased gradually with light intensity of short-term continuous lighting from 100μmol·m⁻²·s⁻¹ to 200 μmol·m⁻²·s⁻¹. Thus, the results indicated that the light intensity range from 100 μmol·m⁻²·s⁻¹ to 150 μmol·m⁻²·s⁻¹ is more feasible and economical to regulate the nutrition quality of hydroponic lettuce. In conclusion, the light intensity range from 100 μmol·m⁻²·s⁻¹ to 150 μmol·m⁻²·s⁻¹ could efficiently improve the nutrition quality of hydroponic lettuce by decreasing the concentration of nitrate, increasing the concentration of vitamin C and the concentration of soluble sugar contents in lettuce shoot.
Effects of Blue and Red Light on Stem Elongation and Flowering of Tomato Seedlings

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Keywords: blue/red ratio, closed plant production system, LED, morphogenesis, photosynthesis

Abstract

Year-round tomato cultivation needs high-quality seedlings of which stem length and node position of the first flower truss are controlled at suitable values. The objective of this study was to develop a method for controlling stem elongation and flowering of tomato seedlings in a closed seedling production system using light emitting diodes (LEDs). To this end, we measured the growth parameters of tomato seedlings grown under a mixture of blue (B; peak wavelength, 450 nm) and red (R; peak wavelength, 660 nm) LEDs to determine the optimum light conditions. We conducted two experiments to investigate whether the blue/red (B/R) ratio or blue and red light quantity affects morphogenesis. In experiment 1, the stem length at a 1.0 B/R ratio was shorter than that at a 0.1 B/R ratio. The node position of the first flower truss at the 0.1 B/R ratio was lower than that at the 1.0 B/R ratio. The net photosynthetic rate increased upon the decrease of the B/R ratio. Therefore, it appeared that flowering promotion was affected by photosynthesis. In experiment 2, stem elongation under 25, 50, and 75 \( \mu \text{mol m}^{-2} \text{s}^{-1} \) of red light with a constant quantity of blue light remained similar regardless of red light quantity. These results suggested that stem elongation depended on blue light quantity. Thus, LED irradiation at 75 \( \mu \text{mol m}^{-2} \text{s}^{-1} \) of blue light and a B/R ratio of <1.0 would suppress spindly growth and promote flowering during tomato seedling growth.
[168] Effect of Photoperiod Prolongation with Red or Far red Light Irradiation at Low Intensity on Shoot Elongation Cessation and Flower Formation of One-year-old Japanese Pear

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Keywords: far red light, flowering, Japanese pear, red light, shoot elongation

Abstract

The purpose of this study was to investigate whether prolonged photoperiod with different light quality could control shoot elongation and flower bud formation of pear plants. One-year-old trees of Japanese pear (Pyrus pyrifolia ‘Kosui’) received natural day light for 8 h per day (8:30 – 16:30) but were shaded for remaining 16 h using blackout screens. During the shading hours, plants were subjected either of following treatments: kept dark (SD), lit with red (R)-rich light (LD(SD+R)) or lit with far red (FR)-rich light (LD(SD+FR)). R-rich light was supplied with LED bulbs, and FR-rich light with FR-rich fluorescent tubes. In both treatments, photon flux densities were set to 2 μmol m\(^{-2}\) s\(^{-1}\). Light treatments were given for four months to the plants from Apr 5 in 2010 when plants were still in ecodormant state. Shoot elongation in all of the treatments once ceased approx. one month after the light treatment started. After the cessation, second flush (budding) occurred in LD(SD+FR), but second and third flushes were observed both in SD and LD(SD+R). In addition, after four months of light treatments, 40% of LD(SD+FR) plants have formed flower in the shoot apical, whereas all plants in SD and LD(SD+R) remained vegetative. Quantitative real-time PCR analysis revealed that the expression of floral meristem identity genes LEAFY and APETALA1 was upregulated in the shoot tip of LD(SD+FR) plants than in that of SD or LD(SD+R) plants, and their expression negatively correlated to the expression of a flowering repressor gene TFL1. On the other hand, expression of a flowering promoter gene FT negatively correlated to the shoot elongation rate. Our results suggested that LD(SD+FR) treatment advanced shoot cessation and the subsequent flower formation in shoot apex, probably by modulating aforementioned flowering-related genes. We further discuss possible roles of flowering-related genes in pear.
Control of Continuous Irradiation Injury on Tomato Plants with a Temperature Drop

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Keywords: Lycopersicon esculentum Mill., continuous light, chlorosis, fluctuating temperature

Abstract

Using continuous light (CL) is the focus of current research programs. Some CL-grown plants show increased productivity. However, in several plant species including tomato continuous light induces severe injury, which is only poorly understood so far. It is known that diurnal temperature fluctuations (thermoperiods) prevent CL-induced injury in tomato. The present study was undertaken to establish if a daily short-term temperature drop can prevent CL injury in tomato. Our research has revealed that after 3 weeks under CL (150 µmol-m²-s⁻¹) control tomato plants grown at 26°C developed light injury symptoms but a temperature drop from 26 to 10°C for 2 h produced healthy plants. Drop-treated plants were more compact and had higher dry weight (DW), larger leaf area (LA), doubled net photosynthesis, considerably higher values of maximum photochemical efficiency of PSII (Fv/Fm), higher chlorophyll a, b content and lower electrolyte leakage compared to control. The developmental rate did not differ significantly in control and drop-treated plants. A daily short-term temperature drop also showed a benefit compared with thermoperiod (26°C for 12 h and 10°C for 12 h). Thus, drop-treated plants had higher plant DW, larger LA and greater number of leaves compared to plants treated by thermoperiod, although the latest ones did not develop the light injury symptoms either. This study demonstrated that a temperature drop treatment could prevent physiological disorders of tomato plants grown under continuous light, while enhancing growth without delaying plant development. The information obtained supports the hypothesis that a circadian clock entrained by temperature fluctuations can prevent CL-induced injury.
**[185] Spectral Sensitivity of Flowering and FT-like Gene Expression in Response to a Night Break Treatment in the Chrysanthemum Cultivar ‘Reagan’**


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**Keywords:** light quality, night interruption, phytochrome, red/far-red photoreversibility, wavelength

**Abstract**

A night break, a short exposure to light near the middle of the night period, inhibits flowering in chrysanthemum (*Chrysanthemum morifolium* Ramat.), a short-day plant. We studied the effect of light quality (wavelength) of night break on flowering and on expression of the *FLOWERING LOCUS T (FT)*-like gene *CmFTL3*. Night break treatment with wavelengths from yellow to red showed strong inhibitory effects on flowering. Further study using monochromatic light from LED panels showed that the maximum effectiveness for the inhibition of flowering was near 596 nm, not 660 nm, and that levels of *CmFTL3* mRNA were reduced in a pattern consistent with the observed inhibition of flowering. Wavelength regions from ultraviolet-A to blue and far-red light had no inhibitory effect on flowering. Our results also showed that the inhibitory effect of red light on flowering responses could be reversed by far-red light and confirmed that red/far-red photoreversibility occurs in chrysanthemum. These results suggest that phytochromes are involved in night break responses, and the absorption spectrum of leaf extracts suggests that the effect of wavelength is distorted by the screening effect of other plant pigments found in green leaves.
[229] Red and far-red light control flowering in long-day woodland strawberry ‘Hawaii-4’

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Keywords: Fragaria vesca, flowering genes, light quality, photoperiod, phytochrome

Abstract

We studied the role of light quality in the control of flower induction in woodland strawberry Fragaria vesca, the model plant of Rosaceae family. Seedlings of long day flowering ‘Hawaii-4’ were subjected to non-inductive short day (SD) which was extended by blue (B), far-red (FR), red (R) and inductive incandescent light (INC). Plants flowered in INC and FR treatments early. In contrast, R inhibited flowering similarly to SD. Flowering response to B was intermediate as plants flowered clearly later than in INC, but earlier than in R or SD. In all light quality treatments the expression of Arabidopsis flowering integrator gene homologues F.vesca FLOWERING LOCUS-T 1 (FvFT1) and SUPPRESSOR OF OVEREXPRESSION OF CONSTANS 1 (FvSOC1), and meristem identity gene homologues FRUITFUL1 (FvFUL1) and FRUITFUL2 (FvFUL2) correlated with flowering time. In FR and INC FvFT1, FvFUL2 and FvSOC1 were upregulated after one week. In contrast, in the flowering inhibitive treatments R and SD FvFT1 and FvSOC1 were either not detected or the expression was extremely low. In B, FvFT1, FvSOC1 and FvFUL2 were expressed at low level after five weeks of treatment period. When the plants were transferred to long-day conditions all these genes were activated within one week. We showed that FR causes rapid activation of FvFT1 and putative downstream genes FvSOC1 and FvFUL2, and consequently flower induction. R inhibits flowering completely. Our results indicate that flower induction is under phytochrome control in the LD genotype F. vesca. Flower induction in B was enabled but delayed. Further studies are needed to reveal photoreceptors responsible to this effect.
[282] Impact of Light Intensity on Leaf Initiation in Young Cucumber and Tomato Plants: A Matter of Photosynthates Availability?

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Keywords: carbohydrates, Cucumis sativus, respiration, Shoot apical meristem, Solanum lycopersicum

Abstract

Presence of light per se is essential for triggering the process of leaf initiation in the shoot apical meristem (SAM). Light is also essential for photosynthates production and thus its intensity largely determines the energy available for plant growth and development. The aim of this study is to quantify the effect of light intensity on leaf initiation in tomato and cucumber. In greenhouses these two species are grown under almost similar conditions. However, previous research indicated that, in contrast to cucumber, leaf initiation in tomato is hardly affected by photosynthates availability. In this study vegetative plants of both species were subjected to a range of low to intermediate light intensities (40 - 240 $\mu$mol PAR.m$^{-2}$.s$^{-1}$) and leaf initiation rates were quantified. Higher rates were observed in cucumber. Both species showed no change in leaf initiation rate above 100 $\mu$mol.m$^{-2}$.s$^{-1}$ and a similar relative decline in leaf initiation rate below $\sim$100 $\mu$mol.m$^{-2}$.s$^{-1}$. At 80 and 40 $\mu$mol.m$^{-2}$.s$^{-1}$ leaf initiation rate was reduced by $\sim$10% and $\sim$20% respectively compared to 240 $\mu$mol.m$^{-2}$.s$^{-1}$. Additional measurements were conducted at the highest (240 $\mu$mol.m$^{-2}$.s$^{-1}$; HL) and lowest applied light intensity (40 $\mu$mol.m$^{-2}$.s$^{-1}$; LL). Both species showed a decline of about 80% in shoot biomass between HL and LL. Diel respiration, indicator of the photosynthates utilization, was measured on terminal buds (SAM + surrounding folded leaves). Respiration was substantially lower at LL than at HL in both species. For both species total soluble sugars and starch concentrations in the 6$^{th}$ leaf (sunlit leaf) and in the terminal bud were significantly lower at LL than at HL, indicating a lower carbohydrates availability. Our results suggest that leaf initiation rates in vegetative cucumber and tomato are only affected when light intensity is very low, implying priority of these species in producing new leaves.
[207] Determining the Minimal Daily Light Sum for Forcing Azalea

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Keywords: Photosynthesis, assimilation light, daily light sum, forcing, azalea, rhododendron

Abstract

Azalea (Rhododendron simsii) is forced until flower buds show color. Forcing conditions require temperatures of 21°C and supplementary light is usually given by high pressure sodium lamps at 80 µmol.m⁻².s⁻¹ at plant canopy for 16 hrs. To reduce the energy cost of the supplementary light, light conditions should be optimized for a good post-greenhouse performance. A uniform and continued opening of the flowers in the post-greenhouse phase will be influenced by the starch levels at the end of the forcing period, since light levels at consumers home are too low (5-20 µmol.m⁻².s⁻¹) to drive photosynthesis. Our research aims to determine the relation between the daily light sum during greenhouse forcing and the carbon balance of the plant. Two genotypes, the early flowering ‘Nordlicht’ and the late flowering ‘Thesla’ were used. Plants were grown according to standard cultural conditions up to the development of the flower bud. As azalea needs a cold treatment to break flower bud dormancy, plants received an artificial cold period at 7°C in darkness. A first set of photosynthesis measurements was performed four days after the start of forcing the plants in the greenhouse (21°C). The daily carbon balance was measured on plant level. In a computer controlled growth chamber with plant cuvettes, a day was simulated starting in darkness, followed by a period of light (duration depending on the light compensation point of the plants) and ending with a dark period again. The light period varied from 6 to 10 hours with an intensity of 80 µmol.m⁻².s⁻¹. CO₂ gas exchange of six plants was measured in six cuvettes simultaneously. The measurements were repeated when plants were at the color showing stage as bud opening increases the sink activity. Higher sink activity might affect the net photosynthesis and thus the carbon balance of the plants.
[215] Photon Efficiency of Photosynthetic Biomass Accumulation by means of Microalgae in Photobioreactors using the Example of \textit{Chlorella vulgaris}

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\textbf{Keywords}: Microalgae, \textit{Chlorella vulgaris}, photobioreactor, biomass accumulation, photon efficiency

\textbf{Abstract}  
\textit{Chlorella vulgaris}, a fast-growing green microalga, was cultivated in a cylindric photobioreactor using High-Power-LEDs as light sources. The incident light onto the culture surface (PPFFR, Photosynthetic Photon Flux Fluence Rate) was measured with a Spherical Quantum Sensor and translated it to an energy scale. The heating value of the algae dry matter was determined in a calorimeter. Daily spectrometric measurements of the Optical Density of the algae culture were performed to calculate the dry matter concentration in the culture broth. Then, Photosynthetic efficiency, defined as percentage of energy recovered as biomass heating value per energy supplied to the algae culture in the form of photons, was calculated. \textit{Chlorella vulgaris} was cultivated at 25 °C under PPFFRs of 15 and 37 µmol m\(^{-2}\) s\(^{-1}\), respectively. Two different light cycles were tested: 16 hours light/8 hours dark cycle and 2 hours light/1 hour dark cycle. Photosynthetic efficiencies did not significantly differ in the two light intensities and reached a maximum value of 3.18 % under the lower irradiance with 16/8 cycle. Additionally, the different light cycles did not result in substantially varied photosynthetic efficiencies.
[268] Improving Tomato and Pepper Transplants Quality Using Photoselective Filters

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Keywords: light conditioning, photomorphogenesis, transplant height control

Abstract
Physio-morphological characteristics of tomato (*Solanum lycopersicum* L.), and pepper (*Capsicum annuum* L.) seedlings grown under 10 different blue, red and white light combinations, using photoselective filters were evaluated. The seedlings were grown for 6 weeks under light treatments. Greater stem diameter of both tomato and pepper seedlings was obtained under red, or combinations of red with blue light, while blue light alone, or in combination with red, reduced transplant height. The less number of leaves preceding the first cluster in tomato plants was obtained under red light alone or in combination with blue or white light regimes during transplant production. This occurred in pepper transplants when higher ratios of red light were applied. For both plants the rates of first cluster formation and first yield were higher when combinations of blue and red lights (regardless of their ratio) were used. There appear to be beneficial effects due to exposure of plants during seedling development to light spectra that extends beyond transplanting.
[269] The Effect of Daily Integrated Irradiance on Composition of Lettuce

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Keywords: Lactuca sativa, light, malate, nitrate, sugars.

Abstract

The relationship between daily integrated irradiance and tissue composition was examined in hydroponic lettuce (Lactuca sativa L. var ‘Buttercrunch’) grown at various times of year under natural sunlight in a greenhouse. Daily integrated irradiance varied from 5 to 24 Mj m\(^{-2}\) day\(^{-1}\). Tissue composition was measured for plants that varied in size from 4 to 300 g fw/plant at high irradiance, and 2 to 180 g fw/plant at low irradiance. Irradiance was normalized per unit leaf area by dividing by LAI when LAI > 1. Whereas reduced nitrogen and potassium showed an increase with irradiance on a fresh weight basis, they showed a decreasing trend on a dry weight basis. Sugars, which increased rapidly with irradiance for small plants on a fresh weight basis, showed no trend for larger plants on a dry weight basis. Of all of the metabolites observed, nitrate and malate showed the greatest relative change with daily integrated irradiance, when expressed on either a fresh or dry weight basis. Nitrate decreased with irradiance, and the change was greater on a dry weight basis. Malate increased with irradiance, and the trend was greater on a fresh weight basis. Large plants had more nitrate and malate, and the contents were more sensitive to irradiance in large compared to small plants. The trends with plant size and irradiance for nitrate were equal and opposite those for malate. There appeared to be compensation between nitrate and malate within the plant. However, in other studies comparing nitrate-sufficient and nitrate-depleted plants, nitrate depletion lowered malate, and sugars were the metabolite that increased to compensate quantitatively for the depletion in tissue nitrate.
[272] Development of Leaf Parameters of Bell Pepper under Different Light Spectrum

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Keywords: bell pepper, light spectrum, leaf, morphological, stomata, photosynthesis, pigments

Abstract

Light and its spectrum is well known factor which influences plant growth and development. The aim of study was to clarify the effect of light spectrum on the leaf morphological, anatomical and biochemical development. Experiments were arranged at phyto-cameras of Institute of Soil and Plant Sciences of Latvia University of Agriculture. Experiments were established to detect the effect of luminescent lamps of various light spectres on bell pepper. Lamps of white (control), red, green and blue colour were used. Six varieties of bell peppers were examined. Leaf area, thickness, number of stomata and leaf pigment content was examined during juvenile stage of plant development. Morphological parameters of bell pepper leaves depended on the plant developmental stage and variety. The largest amount of stomata was detected under white light. Significantly different content of photosynthesis pigments was observed in plants, which were grown in control in comparison with red, green and blue illumination. Bell pepper leaf parameters changed proportionally to changes of light absorption curve of photosynthesis pigments.
Examining the use of energy saving bulbs in providing daylength control in ornamental horticultural species

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Keywords: Photoperiod, day-extension, supplementary lighting, tungsten, compact fluorescent, LEDs, flowering

Abstract
Tungsten bulbs (T) have traditionally been used for day-extension (DE) and night-break (NB) lighting as they are cheap to purchase and are rich in red (R) and far-red (FR) light. The UK government has declared that ‘inefficient’ tungsten bulbs will be phased by 2012. They are likely to be replaced with compact fluorescent lamps (CF). However, a number of recent studies have used CF lamps for day-extension and night-break lighting, without promoting the expected flowering response. We have examined the suitability of energy-saving lamps for daylength control by investigating flowering responses to light quality and quantity. A range of important horticultural species was grown with night-break and day-extension lighting given by T or CF lamps. The effects of light level and light quality were examined in a range of different Long-Day Plant (LDP) or Short-day Plant (SDP) species by growing plants in a suite of automated daylength controlled chambers where plants were exposed to 8 hours of daylight and then wheeled into light-tight chambers where the daylength was manipulated using T or CF lamps as NB or DE and compared with short-day controls kept in darkness. The effect of irradiance was also examined on fixed benches using light gradients to extend the natural short daylengths over winter. Flowering and/or tuber formation in chrysanthemum, poinsettia, begonia and fuchsia were controlled as well by CF lighting as they were by T lighting. However, for antirrhinum, Christmas cactus, lisianthus, pansy and petunia the light spectrum from CF lamps did not match that from T lamps well enough to control flowering effectively. The experiments were repeated using LEDs with different ratios of R and FR instead of the CF lamps. The results from the experiments will be discussed with respect to spectral quality for DE and NB treatments for LDP and SDP horticultural species.
Carrying-over Effects of Light Quantity and Quality during Raising Seedlings on the Growth and Flowering in Petunia

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Keywords: after-effects of light, artificial light, light emitting diodes, Petunia × hybrida Vilm., photomorphogenesis

Abstract

Recently, using various kinds of LED as light sources, studies to examine influence of light quality on the growth and flowering of plants had been performed. However, a part of results of those studies showed some disagreements. We expected that the reason was the difference in conditions for raising seedlings, and carried out following experiments. At first, effects of light quantity during raising seedlings (3 weeks after sowing) were examined. Using cool white fluorescent (FL) lamps, petunia seedlings were cultivated under following 5 light conditions, such as, PPFD (μmol m⁻² s⁻¹) / photoperiod / integrated radiation = 33 / 24 /61, 100 / 8 / 61, 100 / 16 / 122, 100 / 24 / 161, 150 / 16 / 161 at 23°C. The growth of seedlings was superior under high integrated radiation value. However, the growth at the 24 hr photoperiod was superior than under 8 or 16 hr photoperiod when the integrated radiation level was the same. After raising, each of seedlings was transplanted into 3.5 cm pot, and cultivated for 38 days under 16 hr-photoperiod at 100 μmol m⁻² s⁻¹ PPFD with FL lamps at 23°C. There became no difference in top dry weight after each of transplants cultivated on the same condition. However, plants raised at high integrated radiation value were superior in vegetative growth. On the other hand, a tendency toward reproductive growth was seen in plants raised at low integrated radiation value. Secondary, effects of light quality were examined. Seedlings were raised under respective lights of blue, green and red LEDs at 80 μmol m⁻² s⁻¹ PPFD for 3 weeks. There were differences in shoot length and number of lateral branches at the end of raising, but the differences almost disappeared when those were cultivated under the same condition with FL lamps.
[271] Effect of Light Source and DIF on Growth of *Salvia plebeia* R. BR. under Controlled Environment

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**Keywords:** combined LED, leafy medicinal plant, vegetative growth

**Abstract**
Effect of light source and DIF on the growth of *Salvia plebeia* R. BR. was examined in growth chambers. The plant was grown under 140 µmol·m⁻²·s⁻¹ PPF provided by either cool white fluorescent lamps (F, control), white (W) light emitting diodes (LEDs), or a mixture of red, blue and white (RBW) LEDs. Temperatures during the light-/dark-period were maintained at either 24/16 (+8 DIF), 22/18 (+4 DIF), or 20/20℃ (0 DIF) with a daily mean temperature of 20℃ in all treatments. Plant height, leaf width, chlorophyll, and top fresh and dry weights were significantly affected by both light source and DIF. Leaf width, leaf area, number of leaves, chlorophyll, and top and root dry weights were affected more by light source than DIF. Top fresh and dry weights were the greatest under RBW LEDs and +8 DIF. The results suggested that a combination of RBW LEDs with +8 DIF was the most growth promoting among the treatments used.
[274] Aspects on Light and Flowering of Poinsettia (Euphorbia pulcherrima Willd.)

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Keywords: light quality, light intensity, day length, temperature, anthesis

Abstract
Poinsettia (Euphorbia pulcherrima) is known as a short day plant. Many aspects of light e.g. light quality or day length are influencing flowering and bract development. Commercial growers use different light applications for initiation and prevention of flowering as well as for increasing photosynthesis and bract development. Even if there are informations in general less is known about details of critical day length and of specific effects of light quality and intensity for flower induction of modern cultivars. New cultivars of poinsettia are cultivated under different photoperiodic day lengths combined with different temperatures. Critical day length of new cultivars is up to 13.5 hours and is strongly modified by temperature. Low temperatures of 16 °C accelerate flowering whereas high temperatures of 24 °C extend the critical day length for anthesis. Light intensity and light quality is as well important for initiation or prevention of flowering. With different lamp types (incandescent and fluorescent lamps, LED (blue, red, far-red)) the effect of light quality and critical values for the intensity should be examined. Recent results will be shown.
[289] Potential Use of Long Photoperiods Including Continuous Light for Production of Cucumber Transplants

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Keywords: *Cucumis sativus* L., daylength, chlorosis

Abstract

Cucumber (*Cucumis sativus* L.) plants were grown for 14 and 21 days under 8, 12, 16, 20 and 24-hour photoperiod with a photosynthetic photon flux (PPF) of 160 µmol m$^{-2}$ s$^{-1}$ in growth chambers. Air temperature was 23°C. During first two weeks after germination continuous light enhanced growth rate and biomass accumulation compared to other photoperiods. Physiological disorders were not observed under the 24-hour photoperiod. In three weeks after germination extension of daylength from 20 h to 24 h gave no further increases in growth rate and dry matter accumulation. Moreover, plants under 24-hour photoperiod developed the light injury symptoms (mottling, reversible chlorosis). Extension of daylength from 20 to 24 h with dim light significantly reduced light injury, but did not completely eliminate it. Daily short-term temperature drop treatments (12°C for 2 h) did not eliminate chlorosis as was the case with tomato seedlings, but slightly alleviated injury. These results suggest that although long term use of a lighting regime with continuous illumination is detrimental for cucumber plants, a 24 h photoperiod with relatively low PPF can be used for growing cucumber transplants (plants with three true leaves) in order to reduce initial and operational costs for transplant production. However, before long photoperiods are implemented, the after-effects they impose on the plants during post-transplant stage need to be studied.
[100] Control of the Shoot Elongation in Bedding Plants Using Extreme Short Day Treatments

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Keywords: Calibrachoa, growth control, Pelargonium, Petunia, photoperiod, Scaevola, timing

Abstract

Plant growth and shoot elongation in ornamental crops is often controlled using chemical growth retardants. Such chemicals are undesirable from an environmental and occupational health perspective, so alternative methods for controlling growth are required. This study examined control of shoot elongation by photoperiod manipulation using blackout screens. The common bedding plant species Calibrachoa, Pelargonium, Petunia and Scaevola were grown using light regimes incorporating an extreme short-day period (8 h photoperiod day\(^{-1}\)). Shoot growth was recorded weekly and plant height, width and flower development were measured at the end of experiment. A period of short-day treatment at the end of crop growth suppressed shoot elongation significantly compared with plants grown under a natural photoperiod. High-quality, fully marketable plants were obtained with no use of chemical growth retardants. However, for the long-day species there was a reduction in the number of flowers and a delay of flowering due to the short-day treatments. Short photoperiod treatment proved effective as a strategy for reducing shoot elongation in bedding plants, and also as a method for timing the crop. A positive side-effect was the reduction in greenhouse heat requirement when the blackout screens were closed.
[219] Growth Rate and Flowering Promoted by Night Interruption in Two Cymbidium Hybrids, ‘Red Fire’ and ‘Yokihi’

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Keywords: orchid, photoperiod, vegetative growth, light intensity

Abstract

\textit{Cymbidium} has long juvenile period and delayed transition from vegetative to reproductive development. The shortening of cultivation period is needed to produce commercial varieties. The effects of night interruption (NI) were examined on the vegetative growth and flowering of \textit{Cymbidium} ‘Red Fire’ and ‘Yokihi’. Lighting treatments were 9 hour ambient light (control), LNI; ambient light plus a NI (3-7 $\mu$mol m\textsuperscript{-2}s\textsuperscript{-1}; 2200 to 0200 h) or HNI; ambient light plus a NI (120 $\mu$mol m\textsuperscript{-2}s\textsuperscript{-1}) using high-pressure sodium lamps. The leaf number, bulb number, bulb diameter and dry weight of shoot and root increased in LNI and HNI in both cultivars. The second bulb appearance started approximately two or four months earlier in LNI or HNI, respectively, than under control in both cultivars. Decreasing days to the second bulb appearance under NI could be attributed to fast growth rate of \textit{Cymbidium} in vegetative growth stage. While none of the control plants flowered within 2 years, 100% of the ‘Yokihi’ and 80% of the ‘Red Fire’ plants grown under HNI condition flowered. In the LNI group, 60% of the plants flowered in both cultivars. Flower diameter, as well as inflorescence length and diameter increased with increasing light intensity under NI conditions. High light intensity during NI increased observable reddish color, as evidenced by an increased $a^*$ in plants grown under these conditions relative to those grown under LNI conditions. To obtain high quality plants within 2 years in \textit{Cymbidium} cultivation, NI with low or high light intensity strategies could be suggested.
[132] **Photoselective Netting of Fruit Trees: Multiple Benefits Requiring Crop-specific Adjustments**

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**Keywords:** light scattering, spectral manipulation, productivity, vegetative vigor, fruit size, fruit quality, apples, table grapes

**Abstract**  
The netting of fruit-tree orchards and vineyards has markedly expanded during the last decade, due to an increasing need for protecting against hostile environmental events. Photoselective (colored) netting is an innovative concept, by which additional functions of light-quality manipulation had been introduced into the netting. The threads of the colored net products selectively screen out defined spectral bands of the solar radiation in the UV, visible, FR, or NIR spectral ranges, concomitantly with transforming direct light into scattered/diffused light. The spectral manipulation is aimed at specifically promoting desired physiological responses, while the scattering improves the penetration of the spectrally-modified light into the inner plant canopy, thus increasing the efficiency of light-dependent processes. Additional aspects of the technology relate to photoselective effects on plant pests and diseases. Our 14 years of netting studies of fruit tree crops, traditionally grown un-netted (e.g. apples, pears, table-grapes, citrus) revealed multiple benefits of the netting. The photoselective responsive tree parameters (that depend on the chromatic properties of the net) include photosynthesis, vegetative responses, stress responses, fruit set, time of maturation, fruit size, color and quality, etc. Details will be presented. Yet, even though our understanding of the photoselective technology has advanced a lot, the choice of the optimal net for different species, and sometimes different cultivars of the same species, cannot always be predicted. For example, the Blue net, which restrains vegetative growth, and the Red net, which promotes vigor, each induced opposite responses of the fruit maturation rate in a weak vigor, Vs. strong vigor cultivars of table grapes. The photoselective netting has proven to potentially yield multiple benefits for fruit tree growers. Nevertheless, field experimentation is required for optimally fitting this technology to particular crops, according to their horticultural traits, climatic region and market demands.
[153] The Effect of Spectrum Conversion Covering Film on Cucumber in Soilless Culture

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Keywords: mineral element, photo-selective covering material, photosynthesis, red light region, wavelength

Abstract

It is known that the effective wavelength range of light for photosynthesis is 400–700 nm, and that assimilation in the red region is higher than in other regions. Recently, we harnessed this characteristic for the development of a spectrum conversion covering film which changes light from the low active region (green light) for photosynthesis to the effective region (red light). The effect on plant growth of conversion film changing sunlight to the red region had not been clarified because of the difficulty of developing a lasting weather resistant spectrum conversion film. We improved the film and carried out studies on nursery stage vegetables. In this experiment we used a cucumber crop, in which the quantity of photosynthesis is greatly influenced, since the growth rate of the plant and fruit is fast, and investigated growth, yield, and nutrient absorption under the spectrum conversion covering film. The results show that total yield, growth and fruit dry matter rate of cucumbers grown under the spectrum conversion covering film were greater than for cucumbers grown under non-conversion film, but there was no difference in fruit length, level of bent fruit and average fruit weight between the two films. The P concentration in the 10th leaf and in the fruit under the spectrum conversion covering film was higher than under the non-conversion film. The concentrations of other mineral elements under the spectrum conversion covering film tended to be higher than under the non-conversion film. The light transmission characteristics of covering conversion film did not change after 42 months. The spectrum conversion covering film is effective for stable cucumber production because of high yield and good nutrient absorption.
Effect of Photoselective Screens in the Development and Productivity of Red and Yellow Sweet Pepper

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Keywords: Capsicum annuum var. annuum, protected cultivation, crop ecology, photosynthetically active radiation

Abstract
Photoselective screens promote better solar radiation quality and attenuate the extreme climatic conditions allowing greater efficiency in the vegetables production in protected crops. In Brazil the sweet pepper is traditionally cultivated in the field conditions, but recently there have been investments in screenhouses and greenhouses. This research evaluated the effect of photoselective blue and red screens on the vegetative development and productivity of yellow and red sweet peppers. The experiment was conducted from June 19th to October 29th, 2011, in Goiânia, Goiás, Brazil (16°35’47”S, 49°16’47”W, 730 m). The Eppo (yellow) and Margarita (red) hybrids from Syngenta Seeds were cultivated in three treatments: two shading screenhouses with field plots as control. Stem diameter and length, number of leaves, leaf area, total plant mass and mass of leaves were measured. At 40 days the total number, weight, length, diameter and number of fruits lost by sunscald or rotting were measured. The blue and red screens have promoted greater stem growth and smaller number of leaves and fruits. There was no statistical difference for leaf area, showing there is compensation between number and leaf area. The total fruit production per plant occurred in decreasing order from field conditions, to red screen followed of blue. However, the losses by sunscald and rotting was greater than 35% in field conditions, while in the screenhouses the losses were less than 5%. In this way, the production of commercial fruits per plant was higher under red screenhouse than under the blue screenhouse and in the field. The photoselective red screen promoted greater plant growth and a slight increase (4%) in the commercial fruits yield for Brazilian Midwest climatic conditions.
[252] Response of Photosynthetic Parameters of Sweet Pepper Leaves to Light Quality Manipulation by Photoselective Shade Nets

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Keywords: net assimilation, stomatal conductance, effective quantum yield, stomatal size, leaf morphology, specific leaf weight, photosynthetic pigments

Abstract

Photoselective nets provide a new tool for light-quality manipulation in protected horticulture. We have studied the photosynthetic activity and leaf characteristics of sweet pepper (Capsicum annuum L., ‘Tirza’) grown under Pearl, Yellow and Red ChromatiNets® of the same shading factor. Their transmitted light is enriched by diffused light of 390 nm-, 520nm-, and 590nm- and up, under the Pearl, Yellow and Red net, respectively, compared to an equivalent black shade net. Leaves of the same age and position were found to respond to this light quality manipulation in the following way: The highest net assimilation (A_{net}) and stomatal conductance (g_{sw}) at midday were obtained under the Pearl net, followed by the Red and Yellow nets; the effective quantum yield (\Delta F/ F'_{m}) was lowest under the Red net; despite of no significant difference in stomatal density, stomatal width was largest under the Pearl net, and smallest under the Yellow; both leaf thickness and palisade/sponge ratio were lowest under the Yellow net; the specific leaf weight (SLW) was largest under the Pearl net; chlorophyll content was lowest, while chlorophyll/carotenoid ratio was highest under the Red net. Therefore, photoselective shading can differentially affect leaf parameters and activities in sweet pepper. From the aspect of photosynthesis, the Pearl net appears to be more suitable for sweet pepper summer production in Israel, or equivalent areas.
[281] Improving Tomato and Pepper Transplants Quality Using Photoselective Filters

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Keywords: light conditioning, photomorphogenesis, transplant height control

Abstract
Physio-morphological characteristics of tomato (Solanum lycopersicum L.), and pepper (Capsicum annuum L.) seedlings grown under 10 different blue, red and white light combinations, using photoselective filters were evaluated. The seedlings were grown for 6 weeks under light treatments. Greater stem diameter of both tomato and pepper seedlings was obtained under red, or combinations of red with blue light, while blue light alone, or in combination with red, reduced transplant height. The less number of leaves preceding the first cluster in tomato plants was obtained under red light alone or in combination with blue or white light regimes during transplant production. This occurred in pepper transplants when higher ratios of red light were applied. For both plants the rates of first cluster formation and first yield were higher when combinations of blue and red lights (regardless of their ratio) were used. There appear to be beneficial effects due to exposure of plants during seedling development to light spectra that extends beyond transplanting.
[260] Test of a Greenhouse Covered by Polyethylene Film that Reflects Near-Infrared Radiation

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Keywords: crop production, greenhouse cooling, NIR radiation

Abstract

The aim of this work was to study the effects of a new polyethylene (PE) ‘silver’ film [with high reflection and absorption in the Near Infrared Radiation (NIR)] on greenhouse microclimate and on growth and production of a hydroponic tomato crop. The experiments were carried out from November 2004 to July of 2005 in two similar greenhouses covered by different PE films: one covered by a PE film with high reflection and absorption to NIR radiation (NIR-PE) and one by a common PE film (control greenhouse, C-PE). The spectral properties of the cover materials were measured by a portable spectroradiometer equipped with an integrating sphere. The Greenhouse and the outside microclimate parameters were recorded. Furthermore, tomato crop growth and production and quality measurements were also carried out. The reflectance and absorbance of the films to radiation from 700 nm to 1100 nm were found to be 20% and 16% for the NIR-PE and 12% and 5% for the C-PE, respectively. The respective values of the transmittance to 400-700 nm were 62% and 79%, for the NIR-PE C-PE, respectively. However, the results of the microclimate measurements showed that the air temperature and vapour pressure deficit levels were similar in both greenhouses. The mean height of the tomato plants measured during winter was higher in the C-PE greenhouse while during summer was higher in the NIR-PE greenhouse. No differences were found in the number of nodes of plants. The leaf area index of the tomato crop was higher under the NIR-PE greenhouse during the summer period. The total crop production was similar between the two greenhouses for both winter and summer period. However, marketable tomato production was higher in the NIR-PE greenhouse. In conclusion, the lower solar radiation levels observed under the NIR-PE covered greenhouses did not affect the growth and production of tomato plants but increased slightly the marketable production of the crop.
[108] Effects of Exogenous Hydrogen Peroxide on the Growth and Contents of Antioxide Compounds in Leaf Lettuce Grown under an Artificial Light Source

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Keywords: ascorbic acid, hydroponic solution, oxidative stress, reactive oxygen species, signaling factor

Abstract
The objective of this study was to control growth and antioxidant content of plants grown under artificial light by adding low oxidative stress continuously. Oxidative stresses are induced by environmental stresses, resulting in harmful changes in normal physiological and biochemical processes, including photosynthetic ability, membrane stability and respiration levels. The oxidative stress induced by reactive oxygen species (ROS), such as superoxide anion, hydrogen peroxide, singlet oxygen and hydroxyl radical, is a result of environmental stresses and is the major cause of injury in plants. ROS are present in all plants as cytotoxic metabolites and are mediators of the stress response. Complex antioxidant systems, especially antioxidant enzyme systems, are very important as a defense mechanism to protect cellular membranes and organelles against ROS, which are generated by environmental stress in plants. In this experiment, hydrogen peroxide, which is one of the reactive oxygen species, was added to the nutrient solution for the hydroponics system. Leaf lettuce (Lactuca sativa L. ‘Red Fire’) was grown hydroponically in a growth chamber under artificial light with a 16/8 h photoperiod and a light intensity of 150 µmol m\(^{-2}\) s\(^{-1}\). During the experiments, the temperature was kept at 25 ± 1 °C. Sixteen-day-old seedlings were transplanted to the DFT hydroponic apparatus containing 10\(^{-6}\) to 10\(^{-4}\) M H\(_2\)O\(_2\), and then grown for 21 days. The results of the study show that high concentrations of H\(_2\)O\(_2\) treatments suppressed growth, while significantly decreasing the concentration of antioxidants. On the other hand, 10\(^{-5}\) M H\(_2\)O\(_2\) treatments significantly increased the amount of growth evidenced by both the increased above ground fresh weight and the root dry weight. Treatments with 10\(^{-5}\) M H\(_2\)O\(_2\) increased ascorbic acid and anthocyanin contents in comparison to the control. These results indicate that treatment with low concentrations of H\(_2\)O\(_2\) increase the final biomass and antioxidants of lettuce.
[112] Effects of UV Irradiation on Plant Growth and Concentrations of Four Medicinal Ingredients in Chinese Licorice (*Glycyrrhiza uralensis*)

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Keywords: fluorescent lamp, glycyrrhizic acid, UV light stress, medicinal herb, secondary metabolites

Abstract

The main root of Chinese licorice (*Glycyrrhiza uralensis*) is used worldwide as a medicinal material and flavoring agent. This study aimed to determine UV light stress conditions effective for increasing the concentrations of four medicinal ingredients—glycyrrhizic acid (GL), liquiritin (LQ), liquiritigenin (LG), and isoliquiritigenin (ISLG)—and the main root dry weight of Chinese licorice. All UV treatments were compared to exposure to a white fluorescent lamp as a control. For UV treatments, the white fluorescent lamp was supplemented with either UV-A or UV-B fluorescent lamp or a combination of both. Low intensities of UV-A and UV-B were applied for longer treatment periods, while high intensities of UV-A and UV-B were applied for shorter periods. The control was set in each UV treatment for a same period. The dry weights of the main roots as the medicinal part in each UV treatment were not significantly different from the weights of the controls. The concentrations of the four medicinal ingredients in the high intensity UV-B irradiation treatments (BH and AHBH) over 5 or 6 days were 50%–70% higher than those in their respective controls. LG and ISLG concentrations in the medium intensity combined UV irradiation treatments (AHBL and ALBH) over 10 days were 140% and 350%, respectively, greater than the levels in their respective controls. These results suggest that UV-B or combined UV-A and UV-B irradiation with white light over 5 to 10 days is more effective than irradiation of white light alone in increasing the contents of GL, LQ, LG, and ISLG in dried main roots without inhibiting the growth of the main root.
[121] Effects of Light Quality of three different PPF Levels on Growth and Polyphenol Contents of Lettuce Plants (Lactuca sativa L.)

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Keywords: chicoric acid, chlorogenic acid, cyanidin-3-glucoside, Lactuca sativa, LED, light quality, plant growth

Abstract
Using ten types of light-emitting diodes (LEDs, peak wavelengths: 405, 450, 470, 510, 520, 530, 620, 640, 660 and 680 nm), we investigated the effects of light quality and photosynthetic photon flux (PPF) level on growth and polyphenol contents of 'Banchu Red Fire' lettuce. Seedlings were hydroponically grown under 100 μmol m⁻² s⁻¹ PPF for 14 h with white fluorescent lamps (FL) until 10 days after sowing. The seedlings were transplanted to cultivated panels and irradiated with different light spectra at three PPF levels (100, 200 or 300 μmol m⁻² s⁻¹), respectively. Photoperiod was 24 h in all treatments including white fluorescent lamp control (FL). After 7 days of light treatment, growth and phytochemical concentration of lettuce were significant affected by light treatments. Shoot growth was lower under violet (405 nm), blue (450 and 470 nm) or green (520 and 530 nm) LED light than under FL at all PPF levels. On the other hand, shoot growth was the same or high under blue-green (510 nm) and red (620, 640, 660 and 680 nm) LED light as compared with FL at PPF 300. Growth of lettuce plants irradiated with 680 nm was the highest of all light sources at any PPF, while the plants irradiated with 405 nm was strongly inhibited at high PPF. Liquid chromatography mass spectrometry analysis of a methanolic extract of plants revealed the presence of cyanidin-3-glucoside, chicoric acid, chlorogenic acid, caffeoylmalic acid, dicaffeoyltartalic acid and 3,5 dicaffeoylquinic acid. Polyphenol accumulation in lettuce irradiated with blue LED light was high of all light sources at any light intensity. These results indicated that long wavelength red LED light and blue-green LED light were effective to promote plant growth. On the other hand, blue LED light was effective in increasing polyphenol content of lettuce plants.
[122] Effects of Light Quality on the Concentration of Human Adiponectine and Bovine α-Lactalbumin in Transgenic Everbearing Strawberry Fruit

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Keywords: closed plant production system, fluorescent lamp, functional protein, light period

Abstract
With an aim of producing functional proteins that enhance human immune functions by using transgenic strawberry in a closed plant production system, we studied the effects of light quality on plant growth and the concentration of human adiponectine (hAdi) and bovine α-lactalbumin (bα-LA) in transgenic everbearing strawberry fruit (Fragaria × ananassa Duch. ‘HS 138’). hAdi plants were cultivated hydroponically until the flowering stage and exposed to 3 different light qualities (White [W], Blue [B], and Red [R]) for a 16-h light period by using fluorescent lamps. bα-LA plants at the flowering stage were exposed to 4 light qualities (W, B, R, and Green [G]) for a 16-h or 24-h light period. We measured plant growth, fruit yield, fruit size, and days to harvest, and sampled 5–8 fruits from each plant for analysis of the functional proteins. In both hAdi and bα-LA plants, the W and R treatments promoted plant growth and fruit yield, irrespective of the light period. In hAdi plants, hAdi concentration at the fresh weight (FW) base in the R treatment was significantly the highest among all treatment. In bα-LA plants, bα-LA concentration at the FW base in the G treatment for a 24-h light period was the highest among all treatments and significantly higher than that in the W treatment. We did not find any effect of plant growth, fruit yield, fruit size, and days to harvest on the functional protein concentration with the abovementioned treatments. However, exposure to R light for a 16-h light period and that to G light for a 24-h light period were the optimal light conditions for production of functional protein in hAdi and bα-LA plants, respectively. The R light, in particular, was found to be the best light quality for both fruit and functional protein production in hAdi plants.
[135] Changes of Aromatic Compound Contents in Perilla and Rocket Grown under Various Wavelengths of LED Light Conditions

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Keywords: anethol, benzaldehyde, light emitting diodes, light quality, perillaldehyde, secondary metabolites

Abstract

The previous studies have indicated that light is an important environmental factor on plant growth and photomorphogenesis. While effects of non-visible radiation, such as ultraviolet (UV) radiation, on secondary metabolites have been studied, little is known about how visible radiation might induce plant secondary metabolite contents. The objective of this study is to investigate the effects of different light quality on the growth and aromatic compound contents in aromatic herbs. The light sources used in this study were white fluorescent lamps (W), red LEDs (R; 660 nm) and blue LEDs (B; 445 nm). The plants utilized were perilla (Perilla frutescens) and rocket (Eruca sativa). The seedlings were cultivated on a NFT hydroponic apparatus for either 35 days for perilla or 21 days for rocket. The artificial light conditions used in this study were; W, B, R and B+R. Light intensity was adjusted to 200 µmol m⁻² s⁻¹ and photoperiod of 16/8 hours was used. The contents of prillaldehyde, anethol and benzaldehyde as aromatic compounds of both plant species were quantified by gas chromatography. The results revealed that plant height was elongated when perilla and rocket were grown under blue LEDs. The number of leaves produced were greater when grown under either W or B+R conditions for both plant species. The contents of prillaldehyde in perilla were increased when those plants were grown under W or B+R conditions, rather than grown under monochromatic conditions such as R or B. The results indicated that W and B+R conditions stimulated the biosynthesis of perillaldehyde in perilla. Also, both W and B+R conditions increased the content of benzaldehyde in rocket. However, the content of anethol was increased in plants grown under B. These results suggest the balance of biosynthesis of anethol and benzaldehyde in rocket was affected by blue light.
[276] UV-A or B Lamp Improves Phytochemical Concentration in Red Leaf Lettuce Plants Grown in a Closed-type Plant Production System

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Keywords: anthocyanin, antioxidants, Fv/Fm, Lactuca sativa L., phenolics, phenylalanine ammonia-lyase

Abstract
This study was conducted to determine the effect of ultra-violet (UV) wavelength on the accumulation of phytochemicals in lettuce plants grown in a closed-type plant production system. Red leaf lettuce (Lactuca sativa L. cv. ‘Hongyeom’) seedlings grown under normal growing conditions (20°C, 12 hours photoperiod, 170 μmol·m⁻²·s⁻¹) for 16 days were transplanted into a growth chamber (20°C, 16 hours photoperiod, 185 μmol·m⁻²·s⁻¹) equipped with red, blue and white LEDs. In study 1, lettuce plants were continuously exposed to UV-A, or B lamps, which has a peak at 352 or 306 nm respectively, to determine the limitation period of irradiation for each UV lamp at 3 weeks after transplanting. In study 2, various UV treatments (UV-A: continuous irradiation for 7 days, repeated UV-B: 4 hours/day irradiation for 6 days, gradual UV-B: gradual irradiation from 1 hour to 7 hours for 6 days) were designed based on the result from study 1 and applied to lettuce plants to improve phytochemicals of the leaves. As a result, 7 days for UV-A and 24 hours for UV-B were determined as limitation periods of irradiation based on visual disorder and Fv/Fm ratio. Regarding phytochemicals, UV-A treatment significantly induced the accumulation of phenolic compounds and antioxidants until 4 days of continuous irradiation without growth inhibition. In addition, the lettuce leaves exposed to UV-A for 4 days had 2.4 times and 3.2 times higher phenylalanine ammonia-lyase gene expression and anthocyanin concentration than control, respectively. Both repeated and gradual UV-B treatments for 2 days produced at least 1.9 times and 1.4 times more total phenolics and antioxidants than control although the treatments inhibited lettuce growth. Thus, this study suggested that irradiation of UV-A or UV-B would be a strategy to improve phytochemicals of red leaf lettuce in closed-type plant production systems.
[107] In Situ Monitoring System for Chlorophyll Fluorescence Parameters of Tomato at Greenhouse in Northern China

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Keywords: Chlorophyll fluorescence, Monitoring system, Tomato, PAR

Abstract
Light pattern plays a crucial role in crop photosynthesis in different growth stages, and photosynthesis process can be reflected by the chlorophyll fluorescence parameters. The chlorophyll fluorescence monitoring system in this study is composed of a PC (host computer), a programmable constant current power supply and a MINI-PAM, which is a modulation fluorescence detector. The chlorophyll fluorescence parameters of tomato, such as Fs (Steady-state fluorescence), Fm (Maximal fluorescence in illuminated samples), ETR (Electron Transport Rate), PAR (Photosynthetically Active Radiation) and $\Phi_{PS II}$ (Quantum yield of PSII during exposure to light) were measured, then the light use efficiency was analyzed according to the measured light response curve of tomato in a fixed growth cycle, and the influence of light intensity on tomato growth mechanism was determined further. According to the relation model between light intensity and fluorescence parameters, the information of host computer was set to monitor the quantitative fluorescence parameters, so the light control environment was established to guide the dynamic output. The "liaoyuanduoli" tomato grown in greenhouse of North China was studied in this experiment. The results show that the change of fluorescent parameters depends on the change of the PAR closely. The increase of PAR makes Fs higher significantly while Fm lower correspondingly, thus the quantum yield of $\Phi_{PS II}$ was decreased. Therefore, the system can achieve monitoring in the quantitative fluorescence parameters, so as to realize the actual measurement and quantitative control of plant photosynthetic capacity.
[197] Long Time Analyses of Light Use Efficiency by Gas Exchange Measurement using Phytomonitoring Systems

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Keywords: PAR, stomatal conductance, light use efficiency

Abstract
For the description of interactions between light and net photosynthesis, gas exchange measuring systems are available to measure CO₂ gas exchange on single leafs. Most of these systems are working with hand held instruments with integrated PAR sensors to describe the light conditions while measurement. Since these measurements are selective on single leafs and running over short time periods, a description of the interaction of transmitted light and net photosynthesis of a canopy shows only restricted results. For a comprehensive evaluation of the system greenhouse – canopy – plant – leaf a long time measurement on different places in the canopy is an essential prerequisite. An advanced prototype of a phytomonitor was developed at Humboldt University. The measuring principle bases on the open system leaf cuvette gas exchange measurement. 10 leaf cuvettes were allocated to different leafs in the canopy to get a representative average of the gas exchange of younger and older leafs under shaded and nonshaded conditions. The cuvettes were constantly attached for about one week on the single leafs. Separately conducted experiments with chlorophyll fluorescence measurements had shown that there is no influence on the photosynthesis of the leaf segment inside the cuvette in this time period. For the evaluation of the light - photosynthesis interaction the light use efficiency (LUE) that means the ratio of net photosynthesis to the outside PAR was calculated. Two instruments were used to show the difference in the LUE in one greenhouse on different places in the canopy and two greenhouses with different light transmissions. The result of the measurements in one single greenhouse had shown a difference less than 4 %. The experiment in different greenhouses described the influence of greenhouse light transmission to the LUE very well. The obtainment of the LUE over longer time periods had shown fluctuation which are following the slope of daily average stomatal conductance. In consideration of these obtainments LUE potentially becomes an evaluation parameter for light conditions but also for the microclimate in greenhouses.
[224] Evaluation of efficiency of supplemental lighting based on Light Intensity Distribution on Canopy Surface Using Reflection Images

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Keywords: image analysis, light control, power consumption, PPFD histogram

Abstract
Supplemental lighting is one of effective ways to control light environment in greenhouse. However, as it consumes much energy and leads to an increase in the cost of crop production, it is desirable to improve the efficiency in lighting. In this study, in order to develop the way to evaluate the efficiency of supplemental lighting based on light intensity distribution on canopy surface, PPFD distributions estimated from reflection images were tried to be used to derive indices for evaluating the efficiency of lighting. Reflection images of tomato canopy surface under various supplemental lighting conditions (different light sources, lighting directions and distances) were acquired from several directions with a digital camera through a blue-green band-pass filter. The histogram of image pixel values after gamma correction was converted into the PPFD histogram by using the linear model predetermined. In addition, PPFD was measured on all illuminated leaves by a quantum sensor after imaging and the PPFD histograms were compared with those estimated from images. The averaged PPFD per unit power consumption and the integrated PPFD over all illuminated leaves per unit power consumption were calculated from the PPFD histogram as indices for efficiency of supplemental lighting. The histogram pattern depended on the light source and canopy structure. Histograms estimated from images could depict the differences, showing mean values and CVs close to measured values. The efficiency of supplemental lighting also depended on the light source, canopy structure, and the distance to the canopy surface. The estimated efficiency approximately agreed with the measured value in each case. These results suggest that reflection-image-based estimation of light intensity distribution can be used for simple evaluation of the efficiency of supplemental lighting.
[295] Dynamic Measurement of Photosynthetic Rate with Growth Stage at Various Combinations of Light and CO₂ Levels by Using Multiple Chambers using LEDs

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Keywords: growth stage, lettuce, light intensity, CO₂ level, photosynthetic rate, LED

Abstract
Photosynthetic process depends on environmental conditions, and particularly light intensity and CO₂ concentration are important factors, directly affecting plant productivity. For estimating the effects of these factors, a more sophisticated measurement of photosynthetic rate of whole plants (not leaf photosynthesis) is required. In plant factory, optimum environmental control with growth stage is essential for improving the energy efficiency and productivity. The objective of this study was to investigate dynamic response such as photosynthetic rate with growth stage at various combinations of light and CO₂ levels for efficient environmental control in plant factory. For this purpose, we developed a closed-acrylic chamber (1,000 x 800 x 500 mm), in which indoor temperature was precisely controlled from 15 to 35°C by using peltier-devices under LEDs with a 8:1:1 of R:W:B ratio. Total six systems were used for the experiment. Photosynthetic rates of lettuce (Lactuca sativa L. ‘Asia Heuk Romaine’) were measured at combinations of five levels of light intensity (60 to 340 µmol·m⁻²·s⁻¹) and CO₂ concentrations (600 to 2,200 µmol·mol⁻¹). Photosynthetic rates of whole plants could be obtained by measuring the decrement of CO₂ concentration in the chamber. Based on the database including short-term photosynthetic response of the plants, a dynamic model for control of light and CO₂ levels with growth stage is being conducted. With this result, more optimized control to improve energy efficiency and productivity is available in plant factory.
[297] 3-Dimensional Approach for the Estimation of Light Interception and Lettuce Growth with Light Intensity and Quality in Plant Factory

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Keywords: extinction coefficient, growth model, light interception, plant factory. 3-dimensional approach

Abstract

Despite the importance for planning and controlling production, estimation of plant growth is hardly covered topic for researches about plant factory with artificial lights. It mainly results from difficulties in estimating and quantifying the effect of various light spectra on biological and morphological aspects. Moreover, the pattern of light distribution inside cultivation site is significantly different from field or greenhouse. In this study, growth of lettuce was estimated by modifying parameters (light intensity, quality, and so on), and mathematical functions of previous modeling research. Lettuce plants (Lactuca sativa L.) were cultivated in LED plant factory under five different blue and red light ratios to quantify the biological and morphological characters of each treatment. As the blue light ratio increased, the photosynthesis, respiration, chlorophyll content increased following rectangular hyperbola curve. Pure red light showed poor ground coverage ratio of canopy which is generally regarded as light intercepting area. However, pure red showed the highest values of fresh and dry weights, although it showed less efficient and effective photosynthetic and light intercepting properties except for leaf area. Our research suggests that the proportion of diffusive radiation in plant factory is relatively high because the cultivation site is normally surrounded by reflective materials on the ground and walls. As results, the light interception is performed by not only horizontal surface of the canopy (2-dimensionally) but by vertical side (3-dimensionally). With 3-dimensional approach for the estimation of light interception, estimated plant growth was closely consistent with experimental observation.
[300] Measuring Whole Plant Light Absorption using a Spectrogoniophotometer

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Keywords: Goniometer, spectral, directional, reflectance, transmittance, absorbance, scattering

Abstract

There are two ways that light spectrum and intensity can affect plant productivity: through the regulation of the photosynthetic rates of leaves, and through the processes of photomorphogenesis that occur at either the leaf or the whole plant level. Regulation of plant morphology through the control of its photomorphogenetic processes strongly affects the total amount of light being absorbed and the way that light absorption is distributed over the whole plant. Light absorption, being the principal driving force behind plant photosynthesis, is an important factor for determining biomass production. It depends on plant optical and architectural characteristics, such as the scattering properties, number and geometry of organs, i.e. their shape, size and position within the plant. In order to study how plant architecture affects total light absorption, an accurate method needs to be developed to measure light absorption by whole plants. The aim of this research is to develop a method for quantifying the light absorption of a single tomato plant. A spectrogoniophotometric system was used to measure light absorption of an artificial plant having optical properties similar to the natural leaves. The plant was illuminated with a collimated light beam (Ø40 cm) produced by an array of white LEDs (400 – 800 nm). Incident light was reflected, absorbed or transmitted through the plant-body, and some radiation did not interact with it at all. A spectrophotometer was used to take measurements of the spectral light intensity (at sub nm resolution in the spectral range 400 - 800 nm) from 128 view angles around the plant, at a distance of 40 cm from plant’s centre. Light absorption was calculated by subtracting the amount of total reflected and transmitted radiation from the total incident radiation. This process was repeated for a number of different plant architectures, light incident angles and spectra.
Cucumber Seedlings Grown under High Red-to-far-red Illumination Shows Enhanced Resistance to Strong Light Stress

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Keywords: artificial light, chlorophyll fluorescence, Cucumis sativus, photo inhibition, R:FR

Abstract:
To evaluate the effect of high red-to-far-red ratio (R:FR) illumination on light-stress tolerance of transplants in photochemistry, we investigated the fraction of open photosystem II centers (qL) to high light intensity in cucumber seedlings. The qL is a chlorophyll fluorescence parameter defined as a function of the maximum quantum yield of photosystem II (Fv/Fm), the quantum yield of photosystem II (ΦPSII) and non-photochemical quenching (NPQ). In general, plant leaves suffered from a light-induced damage show a low qL value. The seedlings were grown under fluorescent lamps with high R:FR (=10.5; FH) or low R:FR (= 1.1; FL) at a photosynthetic photon flux (PPF) of 300 µmol m$^{-2}$ s$^{-1}$ with 12:12h day-night cycles. The growth conditions were maintained at an air temperature of 28 ºC. When the first true leaves were expanded, Fv/Fm, ΦPSII, NPQ, and qL of the leaves were evaluated at PPF of 1800 µmol m$^{-2}$ s$^{-1}$ for 30 minutes with a photosynthesis and fluorescence measuring system (LI-6400-40). The Fv/Fm of FH seedlings was almost the same as that of FL seedlings. The ΦPSII of FH seedlings was 1.90 times that of FL seedlings whereas the NPQ of FH seedlings was lower than that of FL seedlings. The qL of FH seedlings was 1.88 times that of FL seedlings. The results showed that seedlings grown under the high R:FR illumination was highly resistant to strong light, and this ability is mainly related to high ΦPSII value within the leaves of FH seedlings. We already reported that FH seedlings had thick leaves, high light absorptivity and high photosynthetic rates compared with FL seedlings. These results indicate that morphological changes induced by a high R:FR illumination would lead to such photosynthetic advantages through an increase in the chlorophyll density per leaf cross-sectional area.
[159] Light-Induced Colour Change in Two Winter-Grown Pepper Cultivars (Capsicum annuum L.)

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Keywords: CIELAB tristimulus model, LED, ‘Menta’, ‘Sondela’

Abstract
Coloured peppers generally fetch much higher market prices than green fruit, particularly in winter, when demand exceeds supply. However, peppers grown in winter take longer to change colour than those produced in summer, and may not change colour at all under winter conditions. This study was conducted to investigate the viability of eliciting preharvest colour change in dark green ‘Sondela’ and pale green ‘Menta’ pepper fruit, grown in winter under plastic, by illuminating fruit at the green mature stage with white LED lamps at 400 μmol m⁻² s⁻¹. Ripe fruit of ‘Sondela’ are typically red, while ‘Menta’ fruit are scarlet when ripe and red when overripe. Colour was assessed visually and also expressed in terms of the CIELAB tristimulus model. Illuminated ‘Sondela’ fruit had turned 80% black after seven days of treatment. This black colour gradually faded when fruit started turning brownish from day 24. By day 35, illuminated ‘Sondela’ fruit were red. Control ‘Sondela’ fruit remained dark green until colour break, first observed on day 29, and had reached final ripe colour (red with traces of green) by day 46, 11 days after illuminated fruit. Some illuminated ‘Menta’ fruit immediately showed traces of purple, but this colouration gradually faded as fruit ripened. Illuminated ‘Menta’ fruit had turned from pale green to yellow by day 11, and from day 16 gradually changed from yellow to orange. These fruit were scarlet by day 33 and red by day 40. Control fruit of ‘Menta’ remained pale green until day 27, when they changed from pale green to pale yellow-orange with traces of green. These control fruit were scarlet by day 40, seven days after illuminated fruit, and red by day 48, eight days after illuminated fruit. Accelerating colour change in green pepper fruit by illumination with LEDs could improve profitability by enabling producers to exploit early season prices, particularly with cultivars with pale green unripe fruit, and possibly with peppers that are yellow when ripe, rather than red.
[124] Uniformity in Seedlings Grown Densely under Different Light Sources

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Keywords: cucumber, light quality, red to far-red ratio (R:FR); shade avoidance, transplant population

Abstract
In transplant production, plants are generally grown densely in multi-celled trays. The uniform transplants are commercially desirable. In this study, we investigated effects of light sources with different red to far-red ratio (R:FR) on uniformity in dense cucumber seedlings to obtain a basic knowledge for growing transplants uniformly under artificial light. Seedling populations including seedlings of the same age but different heights (30 mm and 15 mm, called TS and SS, respectively) were prepared. Two seedling heights were adjusted by transplanting in medium at two different depths when cotyledons fully expanded. The different height seedlings were planted alternately in the tray. The seedling populations were grown under metal halide lamps with the spectrum similar to that of natural light (R:FR = 1.2; ML) or fluorescent lamps with high R:FR (R:FR = 10.5; FH) at PPFD of 300 μmol m\(^{-2}\) s\(^{-1}\) with photoperiod of 16 h d\(^{-1}\) until first true leaf fully expanded (for seven days under ML or eight days under FH). The height and shoot dry-weight of SS under ML were the same as those of TS at the end of treatment. In contrast, the height and shoot dry-weight of SS under FH were 0.8 times and 0.4 times those of SS, respectively. The height of SS under ML became the same as that of TS two days after the start of treatment. The R:FR decreased under the seedlings canopy due to the different transmissivities of leaves for R and FR. The shoot elongation of SS under ML was probably enhanced by the shade-avoidance response due to the relatively low R:FR (= 0.6) on SS leaf surfaces that were mostly covered with TS leaves. The R:FR on the SS leaf surfaces under FH was 5.5 and seemed to be still higher than the value for causing a such response.
[176] Monitoring of CO₂ Gas Exchange of Petunia Cuttings during Adventitious Root Formation (ARF) in respect to Different Light Intensities

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Keywords: photosynthesis, dark respiration, rooting, ornamental cuttings, root growth

Abstract

The vegetative propagation of petunia relies on sufficient adventitious root formation (ARF) of the cuttings, which are usually rooted under low irradiances during winter and early spring. Carbohydrate availability and, consequently, photosynthesis play a crucial role in ARF. We investigate the impact of irradiance on net photosynthesis (PN), dark respiration (RD) and ARF of cuttings in a non-disturbed rooting environment.

Petunia x hybrida ‘Mitchell’ cuttings were grown in perlite in covered rooting trays which were used as cuvettes for CO₂ gas exchange measurement and placed in a growth chamber for a 14-day rooting period at a photosynthetic photon flux density (PPFD) of 80 and 150 µmol m⁻² s⁻¹. Cuttings treated with 150 µmol m⁻² s⁻¹ exhibited a constantly higher PN of 4.1 and RD of 0.6 µmol m⁻² s⁻¹ compared to cuttings exposed to a lower PPFD with an average PN of 2.3 and RD of 0.4 µmol m⁻² s⁻¹. PN and RD of both treatments were maintained relatively constant during ARF while total and root dry matter increased. After seven days of growing at different PPFDs, light response curves of PN depicted differences in the upper range of the applied PPFDs; lower irradiances resulted in similar rates of PN regardless of the treatment. A PPFD of 150 µmol m⁻² s⁻¹ caused an increased maximum PN of 9.1 µmol m⁻² s⁻¹ compared to 7.1 µmol m⁻² s⁻¹ at 80 µmol m⁻² s⁻¹ PPFD. These results indicate that the CO₂ gas exchange of petunia under low irradiances used in the current study is not generally subject to root growth and adaptation to light intensity occurred already during the first days of ARF.
Effective Spectra for the Promotion of to Promote the Extension Growth of Tulips Grown with Night Lighting under a Natural Photoperiod

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Keywords: elongation, end-of-day lighting, far-red light, night-break lighting, spectral sensitivity

Abstract
The effect of light quality on the extension growth of tulips was investigated for 4 tulip (Tulipa gesneriana) cultivars ‘Leen van der mark,’ ‘Murasaki suisho,’ ‘Come back,’ and ‘Kikomachi.’ The exposure of tulips to ultraviolet-A, blue, red or far-red fluorescent tubes throughout the entire night (a process called “night lighting”) was found to promote lengthening of the stem and first internode of plants grown under natural photoperiod conditions in a greenhouse. The effectiveness of far-red night lighting was consistently observed across 4 cultivars, although the effectiveness of illumination within the ultraviolet-A, blue and red wavelength ranges was found to vary with respect to stem length, the first internode and among different cultivars. Elevated photon flux densities of far-red light were found to quantitatively increase the extension growth of ‘Leen van der mark,’ but the effect of far-red night lighting reached saturation point at 0.59 μmol m⁻² s⁻¹. A 4-h end-of-day lighting period and night-break far-red lighting period were also found to promote extension growth, but these effects were less pronounced than that induced by far-red night lighting. A 4-h end-of-night far-red lighting period had no effect on extension growth.
[198] Light Response Curves of Selected Plants under Different Light Conditions

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**Keywords:** leaf gas exchange, light compensation point, *Lactuca sativa*, *Plectranthus scutellarioides*, *Euphorbia pulcherrima*, high pressure sodium lamps, light-emitting diodes

**Abstract**

Photosynthesis rates under HPS light were measured on various plant species. *Euphorbia pulcherrima*, *Plectranthus scutellarioides* and *Lactuca sativa* were selected for more detailed experiments under natural light and artificial light provided by HPS lamps or LEDs under controlled environment conditions. Comparisons have been made between gas exchange characteristics including the light compensation point and the slope of light response curves under practical-relevant light intensities. Light compensation points under light qualities with input of red LEDs were between 13-15 µmol m$^{-2}$ s$^{-1}$ in all three model plants. Average photosynthetic rates at 100 and 200 µmol m$^{-2}$ s$^{-1}$ PPF red and blue/red LED light were above other calculated values for the other light qualities. The photosynthetic rates under blue/green/red LED light declined considerably less, than the purely energetic consideration would anticipate. Accordingly the green component in the spectrum contributed noteworthy to the photosynthetic performance of plants.
[210] Shading As an Effective Means for Crop Load Management and Fruit Quality Enhancement in Apple Trees

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Key words: shading, photosynthesis, source/sinks relationship, fruit quality, crop load

Abstract
Since carbon starvation due to photosynthesis inhibition may induce fruit abscission, four-year-old apple trees cvs ‘Golden Delicious’, ‘Elstar’ and ‘Gala’ on M9 at Bonn were shaded to achieve desired crop load viz thin. Whole trees were covered with shade cloth (80 % shade/PAR reduction, 90% UV reduction) for either 3, 6 or 9 days either at the end of bloom (EB) or 23 days after full bloom (DAFB); uncovered adjacent trees served as control. While shading for 3 days (23 DAFB) was optimal for fruit quality (fruit size, colour and sugar content) with only a slight decrease in yield, prolonged shading (for > 6 days) also led to fruit quality improvement, but also to a considerable decrease in yield, caused by a higher rate of June drop; fruit trees shaded earlier at the end of bloom showed weaker June drop and more fruit set with insufficient thinning efficacy. Later and prolonged shading (more then 6 days) increased fruit sugar content (SSC) by 1.0-2.3 % (and taste) by improving tree source: sink relationships, and fruit mass by 41 % in cv. ‘Gala’ and 13 % in cv. ‘Elstar’, with better (75-100 % red surface) colouration of 85-96% than ca. 65 % in the un-shaded control; the same shading treatment also induced the desired stronger return bloom viz less alternate bearing, with the least flowers in the un-shaded control. Thus, this study has shown that shading for 3-6 days at 23 DAFB due to its effects on source:sink relationships and tree carbon starvation may be an environmentally-friendly technology to obtain fruit of the desired quality in terms of firmness, size, colour and sugar content and prevent biennial bearing of fruit trees.
[211] The Effect of Constraining the Intensity of Solar Radiation on the Photosynthesis, Growth, Yield and Product Quality of Tomato

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Keywords: Carbon use efficiency, carotenoid, greenhouse, light use efficiency, Lycopersicon esculentum (L.) Mill., titratable acid, sugar

Abstract
Recent studies propose the combination of electrical energy and plant production in greenhouses. Often only radiation peaks were used for energy production. Then the effect on plant growth is assumed to be negligible. However, photosynthesis is known to be a monotonically increasing function of radiation. We studied the response of tomato to constraining the intensity of solar radiation. Tomato crops in greenhouse compartments were shaded when the outside photosynthetic photon flux density (PPFD) exceeded 640 and 1280 µmol m$^{-2}$ s$^{-1}$, resulting in a 57 and 34 % reduction in the PPFD integral over the growing period compared to the non-shaded control. Constraining the intensity of solar radiation significantly reduced photosynthesis, growth and yield of tomato plants. However, measured plant dry matter increment decreased only by 31 and 19 %, respectively, that is, light use efficiency increased markedly. This indicates a strong adaptation of the plant’s metabolism to cope with the limitation in light consumption such as increasing the specific leaf area and reducing respiration. Surprisingly, this was only of little concern to the fruits, because no effect of constraining PPFD on the concentration of total dry matter, sugars and lycopene in the fruits could be observed. The concentration of titratable acids was significantly increased, however, when constraining PPFD, while β-carotene was slightly decreased.
[249] Transpiration and Photosynthesis of Sweet Pepper Growing under differing Screenhouse Nets

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Keywords: leaf transpiration, water use efficiency, shading, insect proof screen

Abstract
The influence of three screenhouse nets differing in colour, shading intensity (SI) and porosity on photosynthesis, transpiration rate and light acclimation of sweet pepper plants was investigated at Velestino (Central Greece) from May to October 2011. The screenhouse nets consisted of two insect-proof white nets (W13 and W34, SI = 13% and 34%, respectively), and a green shading net (G36, SI = 36%). Climate variables were recorded continuously in the different treatments. Leaf photosynthesis and transpiration rate were measured fortnightly over different canopy layers. The results indicated that drastic changes in light regime induced by shading nets had only a slight effect on leaf gas exchange and water use efficiency. Ontogenic effects (leaf ageing) appeared to be the main factor responsible for the observed seasonal pattern of leaf photosynthetic attributes. Overall, sweet pepper plants grown under screenhouse treatments appeared to display a physiological response and light-acclimation across a large interval of SI that was close to that observed for the field grown crop, irrespective of the colour and porosity of the nets.
[265] Effect of Shading by Date Palm Leaves on Growth and Yield of Potato under Different Irrigation Levels

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Keywords: shading, chlorophyll content, dry matter

Abstract
This study was conducted during 2002 and 2003 seasons at the Experimental Farm of the College of Agriculture and Veterinary Medicine, Qassim University to evaluate the effect of shading by date palm leaves on the performance of potato plants under different irrigation levels {80, 100 and 120% of Potential evapotranspiration (ETo)}. The results revealed that shading by plastic green shades (40% light reduction) gave the highest potato yield under 80% irrigation levels. Moreover, shading by date palm leaves increased potato yield under 120% irrigation level. The shading by green shades or date palm leaves increased leaf area of potato plants. However, the shading decreased both chlorophyll content and percentage of tuber dry matter. The highest leaf area, chlorophyll content and the percentage of tuber dry matter were observed with the plants grown under 80% irrigation level. Therefore, the shading could enhance water use efficiency and increase potato yield under semi-arid conditions such as central Saudi Arabia conditions where the study conducted.
[187] **Effect of Shade on yield, quality and photosynthesis-related parameters of Sweet Pepper Plants**

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**Keywords:** *Capsicum annum* L., solar radiation, high temperature, shading, chlorophyll fluorescence

**Abstract**

To avoid the problem of too high temperature and high radiation during late spring and summer period, growers reduce the incident radiation with several methods, like with the use of shading screens and whitening. To determine the effects of shade, simultaneous comparisons were carried out among greenhouses that were either not shaded (control treatment) or shaded with reflective aluminized shade cloth positioned below the roof, which attenuated 40 (T40) or 60% (T60) of direct sunlight. The shade was applied at the beginning of hot weather in early May. The shading screens were kept until the end of the crop cycle and fruit was picked until August. Leaf CO$_2$ assimilation rate, relative (SPAD) and absolute chlorophyll content, Fv/Fm, transpiration rate, stomatal conductance, internal CO$_2$ concentration and water use efficiency were measured. Plants cultivated under 40% and 60% of shading significantly decreased the net CO$_2$ assimilation rate, stomatal conductance, and transpiration. Plants cultivated under 60% of shading had higher contents of chlorophyll a, b. Under 40% of shading, plants yielded 1.26 kg·m$^{-2}$ more than under control. However, the yields of T60 and control treatment were similar (8.9 kg·m$^{-2}$). The use of shading decreased the unmarketable yield.
[193] Counteracting Low Light Levels in Protected Strawberry Cultivation using Reflective Mulches

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Keywords: Strawberry, *Fragaria x ananassa*, protective cultivation, reflective mulch, reduced light, compensated yield

Abstract

Plastic mulches of various types are used to influence the yield and quality of strawberries in protected cultivation. In this study a white and an aluminised plastic mulch have been used in an attempt to compensate for low light levels not uncommon in more northerly latitudes. Plants of the everbearing cultivar ‘Flamenco’ were raised in growing bags under 50% shade netting, with the reflective mulch covering the entire space between plants. Control plants were grown with and without the shading using a black, non-reflective mulch of a similar material to the reflective ones. The plants were glasshouse-grown in SE England and fruits harvested, weighed and graded between the end of July and the end of October. For fruit with a diameter >25mm (commercial Class 1) there was a significant negative difference in cumulative yield over the season between plants grown without shade and those under shade with a non-reflective mulch (*P* ≤ 0.01). There was no significant difference in yield between the unshaded control and fruits harvested under shade either over white or aluminised mulch, and no significant difference between these reflective treatments. The use of mulches did not alter the distribution of yield across the season. These data indicate that simple reflective mulches can be used to support strawberry yield, under protected cultivation, when environmental light levels are low, and can reduce seasonal variation. Their use might also help to extend the harvesting season or expand the growing region into regions with lower irradiance.
[169] Effect of Different Light and Two Polysaccharides on the Proliferation of Protocorm-like Bodies of *Cymbidium* Cultured in Vitro

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**Key words:** chitosan, energy efficient light source, hyaluronic acid, LED, PLBs

**Abstract**
Light is one of the most important abiotic factors that influences the successful establishment and subsequent development of a plant culture. The aim of this study was to examine the effect of light quality (white, red, blue and green) and two polysaccharides; chitosan (Chitosan H) and hyaluronic acid (HA9) on proliferation of the protocorm-like bodies (PLBs) *in vitro* grown *Cymbidium*. Chitosan H and HA9 have of recent been suggested as important components of *Cymbidium in vitro* culture media. The highest PLBs formation, shoot formation rate (90%) and root formation rate (50%) were found amongst explants cultured on medium supplemented with 0.1 mg/L Chitosan H under green light. After 11 weeks of culture, fresh weight of PLBs was higher (241.3 mg) at HA9 (1 mg/L) treatment with green light. The average number of PLBs (5.7) was higher under green light at HA9 treatment. PLBs under white light showed the highest number of shoot (1.2) at Chitosan H treatment. These results suggest that this newly developed light source could be used as an energy efficient light source for the propagation of *Cymbidium* PLBs *in vitro* and also green light plays an important role of PLBs, shoot and root formation.
[237] **Disentangling the Effect of Light Quantity and Light Quality on Bud Break in a Rose Crop**

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**Keywords**: rose, light spectrum, light intensity, bud break, phytochrome photostationary state, far-red LEDs

**Abstract**

Both light quantity (intensity) and light quality (spectrum) reaching the bud may affect bud break on a shoot remainder resulting from harvesting a flower shoot. In a rose canopy, both light quantity and light quality change with canopy depth. An experiment was set up to determine whether light quantity or light quality is more important in stimulating bud break. Four treatments were applied: two light intensities at plant base (different light quantities) in combination with two red-far red ratios (different light qualities). Light intensity was changed by applying grey crepe paper over the plant base and shoot remainder on which bud break was observed. This did not change light quality. Red-far red ratio was altered by application of far-red LEDs. Bud break was observed (buds longer than 3mm), and light intensity and red-far red ratio at the position of the buds were measured. The phytochrome photostationary state (PSS) was calculated from spectrum measurements. There was no interaction between effects of light intensity and red-far red ratio. High light intensity (no paper) resulted in PAR levels at the bud of 123 µmol m⁻² s⁻¹, compared to 17 µmol PAR m⁻² s⁻¹ when shaded with crepe paper. Red-far red ratio was 1.4 when no far-red LEDs were present and 0.31 when far-red LEDs were present; PSS was 0.79 and 0.67, respectively. Bud break was higher (2.6 broken buds) under high light intensity than under low light intensity (2.0 broken buds), compared to 2.4 and 2.3 broken buds under high and low red-far red ratio, respectively. Differences in bud break between the treatments corresponded to differences in light intensity. Similar trends were obtained in two other experiments where light quantity and light quality were varied. Hence, bud break in a rose crop was more affected by light quantity than by light quality.
[247] Effect of Light Quality and Cytokinin on Shoot Regeneration from Nodal Explant of *Rhododendron brachycarpum* D. Don

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**Keywords** Anderson medium, endangered species, in vitro propagation, nodal explants, light quality, *Rhododendron brachycarpum*

**Abstract**

*Rhododendron brachycarpum* is an evergreen hardy shrub species in Korea. It has been traditionally used as a garden plant and the plant used in this study was found as a rare dwarf variant in the natural habitat. Hence, the plant seems to be a good specimen as a garden plant and we wanted to develop efficient techniques that allow large scale multiplication and preservation of this rare plant. Tissue culture techniques have been established as a useful approach for the conservation of rare and endangered plant species. The influence of light quality and cytokinin on shoot regeneration from nodal explants of *R. brachycarpum* was studied. The explants were excised from greenhouse-grown plants and cultured on Anderson’s basal salt (AM) medium with different concentrations of 2-isopentyl adenine (2-iP), 6-benzyl adenine (BA) or thidiazuron (TDZ). All cultures were maintained at 25 ±1°C under 16 h photoperiod (45 μmol m\(^{-2}\) s\(^{-1}\)) using blue, red (LED) or white fluorescent light, unless otherwise stated. Among the three cytokinins studied, 2-iP was found to be the most effective cytokinin for multiple shoot induction. The greatest percentage of shoot induction was achieved when nodal explants were cultured on the MS medium supplemented with 2.0 mg·L\(^{-1}\) 2-iP with an average of 9.8 shoots per explant. Light quality had a significant effect on shoot induction and multiplication. For shoot growth, white light showed better response followed by red and blue lights. Elongated shoots were rooted on a half-strength AM medium supplemented with 0.5 mg·L\(^{-3}\) indole-3-butyric acid (IBA). The in vitro-grown plantlets were successfully acclimatized in a greenhouse. This protocol could be utilized for in vitro clonal propagation of this plant species.
[262] Supplementary Light and higher Fertigation EC Improve Quality and Accelerate Growth in the Cultivation of many Bromelia

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Keywords: Photoperiod, flower induction, quality, succulence, inflorescence, branching, light damage, ornamental value, Aechmea, Guzmania, Vriesea, Tillandsia, Neoregelia

Abstract

In order to provide Bromelia growers with lacking information about optimal levels of supplementary light and nutrient EC, two consecutive greenhouse experiments were conducted by Wageningen UR Glasshouse Horticulture in Bleiswijk (The Netherlands). In the first experiment a light intensity gradient (17 - 155 µmol m$^{-2}$ s$^{-1}$ PAR) was installed in the length direction of two 144 m$^2$ greenhouses. In the width direction four mineral nutrition levels were supplied (EC of 0.6, 1.0, 1.5 and 2.0 dS m$^{-1}$) to three plant species: Guzmania, Vriesea and Neoregelia (a CAM Bromelia). Each greenhouse had a different (supplementary) photoperiod: 12 or 16 hours. It was concluded that the optimum intensity of supplementary light was 43 µmol m$^{-2}$ s$^{-1}$ PAR for Vriesea, and 80 µmol·m$^{-2}$·s$^{-1}$PAR for Guzmania and Neoregelia applied during 12 hours. The corresponding optimum EC of the nutrient solution was 1.5. At higher light levels, longer photoperiod, or the same light levels but nutrition with a lower EC, signs of light damage appeared (chlorotic leaves, reduced plant diameter, red spots on leaves). Neoregelia was tolerant to the 16 hour photoperiod. These optima were validated and compared to a non-lighted control by means of a second experiment with 10 varieties of 4 different genera grown at a EC of 1.5 dS m$^{-1}$ under three light levels: 43 µmol m$^{-2}$ s$^{-1}$ PAR (applied to all Vriesea, and Guzmania ‘Hilda’), 80 µmol m$^{-2}$ s$^{-1}$ PAR (applied to Aechmea, Tillandsia, Guzmania ‘Rana’ and Guzmania ‘Tempo’) and no supplementary light (as reference for all varieties). Compared to the reference, the use of supplementary light enhanced plant growth and ornamental quality and it shortened the time to commercial development stage for most studied varieties, with the exception of Vriesea ‘Miranda’ and Vriesea ‘Stream’.
[278] The Role of Phytochrome B in Organogenesis Control in Young Cucumber Plants Under Continuous Lighting

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Keywords: *Cucumis sativus* L., main shoot, lateral shoots, number of leaves, number of flowers

Abstract

Phytochrome B (phy B) is needed for a complete thermoperiodic reaction, regulation of stomata development, freezing, cold and drought tolerance. The aim of the study was to investigate the involvement of phy B in the processes of organogenesis in apical and lateral shoot meristems. Experiments were conducted in growth chambers with the cucumber (*Cucumis sativus* L.) phy B deficient mutant (*lh*-mutant) and a near isogenic wild type line (WT) at the early stage of ontogenesis under photoperiod of 16/8 h and continuous lighting. The air temperature was maintained at 30°C for germination, 23°C after emergence of seedlings until the end of cotyledon unfolding and 20°C until the fully unfolded first true leaf. Organogenic activity of meristems was estimated by the number of leaf primordia on the main and lateral shoots and the number of flowers at IVth stage of organogenesis. No differences in organogenic activity were established between *lh*-mutant and WT under the photoperiod of 16/8 h. However, under continuous lighting phy B deficient mutant had less leaves on main and lateral shoots and less flowers at the IVth stage of organogenesis than WT. It is probably that phy B is involved in organogenesis control in the cucumber plants under continuous lighting.
[290] Analysis of $\Phi_{PSII}$ and NPQ during Slow Phase of Chlorophyll Fluorescence Induction Phenomenon of Tomato Leaf

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Keywords: electron transport, heat dissipation, photosynthesis, plant diagnosis, quenching

Abstract

Measurement of slow phase (the P-S-M-T phase) of chlorophyll fluorescence induction (CFI) phenomenon is a prospective candidate of plant diagnosis in greenhouses. We applied a methodology, the consecutive measurements of photochemical efficiency of photosystem (PS) II ($\Phi_{PSII}$) and non-photochemical quenching (NPQ) during a CFI phenomenon, to clarify the contributions of photochemical and non-photochemical quenching on the slow phase of CFI curves of mature tomato leaves grown in a semi-commercial greenhouse. The $\Phi_{PSII}$ increased significantly between the inflection points of P and S and decreased between the inflection points of S and M. On the other hand, the NPQ kept at low values during the inflections of P, S and M, and then increased exponentially. These results proved that the shape of CFI curve during the inflections of P, S and M is dominantly determined by the changes in the status of the photosynthetic electron transport chain and the shape of CFI curve after the inflection of M is strongly regulated by non-photochemical quenching, especially of the xanthophyll cycle. Furthermore, the two CFI measurements conducted at an interval of nine days proved that the slight changes in the photosynthetic functions, i.e. decreases in the abilities of the photosynthetic electron transport and the xanthophyll cycle, were detectable by measuring the slow phase of CFI phenomenon.
[213] Analysis of the Effect of Light-Emitting Diode (LED) Light with Eight Different Peak Wavelengths on Growth, Metabolites and Minerals of Brassica rapa var. perviridis “Komatsuna”

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Keywords: LED lighting, light response, metabolites, antioxidants, minerals

Abstract

Light environment is one of important factors in affecting qualitative and quantitative aspects of all crops. Artificial light sources can be used for not only for supplementary lighting but also for specific lighting. LED lights can create specific wavelengths and a narrow bandwidth compared with filters with broad-spectrum light sources. We analyzed growth, metabolites and minerals of Brassica rapa var. perviridis “Komatsuna” irradiated with eight kinds of LED light sources (peak wavelengths; 405, 450, 470, 510, 520, 620, 660 and 680nm) or a white fluorescent lamp (FL) as a control during the growing period. The surfaces of leaves irritated with red lights (620, 660 and 680nm) were crepe-like morphology. Blue lights (450 and 470nm) significantly elongated plant length and decreased dry weight compared with FL lighting. Fresh weights were the maximum values among all light sources when plants were irritated with the 520nm LED light at PPFD 150μmol m^-2 s^-1 or the 510nm one at 200μmol m^-2 s^-1, respectively. The content of some polyphenols varied in response to specific LED lighting. Almost of them increased with using blue rights, but a few of them increased with using green and red lights. The content of reduced ascorbate in the plants irritated with the 405nm LED light significantly increased more than those of any other lights. This increase was also detected in the plants that grew in 405nm LED lighting for two days after FL lighting for seven days. Only few attempts have so far been made at the analysis of the relationship between light response and mineral contents. We revealed that mineral contents also varied depending on the LED lighting.
[222] Temperature Modification of UV-B-induced Changes in Flavonoid Content and Morphology in Pea

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Key words: anthocyanin, flavonoids, Pisum sativum, temperature drop, UV-B

Abstract

Elevated UV-B radiation (280-315nm) induces changes in chemical composition and morphology of plants. However, the effect depends on the level of UV-B, exposure time and interaction with other climate factors. In this study we investigate the interaction between UV-B and temperature on morphology and production of UV-screening compounds like flavonoids and anthocyanins. The experiments were conducted in growth chambers using pea (Pisum sativum) as a model plant. Plants were grown with or without 0.27 W m⁻² s⁻¹ UV-B exposure (Q-PANEL, UVB-313) for 6 hr in the middle of a 12 h photoperiod at a photosynthetic photon flux of 100 µmol m⁻² s⁻¹ provided by fluorescent tubes (Phillips TL 65 W/83). The plants were grown at similar average temperatures but with two different temperature regimes: (1) constant temperature (20°C) and (2) a temperature drop (21 → 13°C) for 6 hr in the middle of the light photoperiod. A non contact optical sensor (Multiplex R 3 FORCE-A 91893) was used to quantify flavonoids, anthocyanins and chlorophyll content in fully developed leaves. The results show that a combination of 6 hr exposure of plant to UV-B and a temperature drop treatment increased the amount of flavonoids and chlorophyll compared to the other treatments. However, the effect on anthocyanins was not significantly different between the treatments. The interactive effects between UV-B exposure and temperature of stem and leaf expansion and general plant morphology will be discussed.
[228] Impact of Temporarily Reduced Irradiation on Anthocyanin Content of Lettuce

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Keywords: irradiation reduction, anthocyanin concentration, Lactuca sativa

Abstract
Thermal insulation shields save energy in greenhouses but are likely to decrease PAR-intensity and thereby lower the plants’ anthocyanin content as their biosynthesis is induced by light. It may play an important role in which growing stage the light intensity is reduced because plant metabolism alters during ontogeny. To test these hypotheses, Red Oak Leaf lettuce (Lactuca sativa) was grown in phytocambers under average light intensities of 410 (“unshaded”) and 226 µmol m⁻² s⁻¹ PAR (“shaded”), respectively. After two weeks, one third of the plants were harvested, one third were exchanged between treatments and one third remained in their respective treatment. This resulted in four different treatments after four weeks when all remaining plants were harvested: plants growing unshaded or shaded for four weeks and plants growing unshaded the first two weeks and shaded the last two weeks and vice versa. At both harvest dates, plants were weighed and anthocyanin concentration was analyzed by HPLC-DAD-ESI-MS³. Cyanidin 3-O-(6”-O-malonyl)-glucoside was the major anthocyanin in all treatments. At the first harvest, head mass did not differ significantly between treatments, whereas anthocyanin concentration was higher in unshaded plants. At the second harvest, plants grown unshaded or first shaded then unshaded had a significantly higher average head mass and higher anthocyanin concentration than those grown shaded all the time or first unshaded then shaded. Those grown shaded all the time gained the lowest head mass. Our study supports the hypotheses that generally reduced PAR intensity results in decreased head mass and anthocyanin content. Interestingly, shading limited to early growing stages did not lower anthocyanin content or head mass of lettuce ready to sell.
[256] Effects of Supplemental UV-A and UV-C Irradiation on Growth, Photosynthetic Pigments and Nutritional Quality of Pea Seedlings

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Keywords: UV-A, UV-C, pea seedling, nutritional quality, supplemental lighting

Abstract

A pot cultivation experiment was conducted in a glasshouse to investigate the effects of one-hour supplemental UV-A (365nm) and UV-C (254nm) irradiation during night on growth, photosynthetic pigments and nutritional quality of pea seedlings. The results showed that supplemental UV-A did not have any effect on the shoot, root and total biomass of pea seedlings compared with control treatment, while supplemental UV-C significantly decreased shoot and root biomass of pea seedlings. In addition, UV-A did not change photosynthetic pigment content of shoot, but UV-C remarkably reduced photosynthetic pigment contents. Furthermore, supplemental UV-A did not affect vitamin C, nitrate, anthocyanin and flavonoid contents of pea seedling shoot. However, supplemental UV-C notably reduced vitamin C content, but increased flavonoid content, while did not affect nitrate and anthocyanin contents of pea seedling shoot compared with the control treatment. To sum up, supplemental UV-A irradiation during night had no effect on growth, photosynthetic pigment and nutritional quality of pea seedlings, while supplemental UV-C irradiation inhibited the growth, and decreased photosynthetic pigment content of shoot, also altered shoot nutritional quality of pea seedlings.
[275] Growth and Accumulation of Phytochemicals in Two Leaf Lettuce Cultivars Grown under Monochromatic Light-emitting Diodes

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Keywords: antioxidants, Lactuca sativa L., light quality, phenolic compounds, phenylalanine ammonia-lyase

Abstract

As an artificial light source, light-emitting diode (LED) with a short wavelength range can be used in plant factories. Individual light spectrum within visible light spectra plays an important role in plant growth and development. In this study, we determined the effects of monochromatic LEDs on leaf shape index, growth and the accumulation of phytochemicals in red leaf lettuce (Lactuca sativa L. ‘Sunmang’) and green leaf lettuce (Lactuca sativa L. ‘Grand rapid TBR’) plants. Lettuce seedlings grown under normal growing conditions (20°C, fluorescent lamp + high pressure sodium lamp, 130±5 µmol·m⁻²·s⁻¹, 12 hours photoperiod) for 18 days were transferred into incubators at 20°C equipped with various monochromatic LEDs (blue LED, 456 nm; green LED, 518 nm; red LED, 654 nm; white LED, 456 nm + 558 nm) under the same light intensity and photoperiod (130±7 µmol·m⁻²·s⁻¹, 12 hours photoperiod). The leaf shape indexes of both lettuce cultivars subjected to blue or white LEDs were similar with those of control during whole growth stage. However, red and green LEDs induced significantly higher leaf shape index than the other treatments. Most of growth characteristics such as fresh and dry weights of shoots and leaf area were the highest in both cultivars subjected to red LED. In case of red leaf lettuce plants, shoot fresh weight grown under red LED was 3.8 times higher than that grown under green LED at 23 days after transplanting. In contrast, SPAD value, total phenolic concentration, and antioxidant capacity of lettuce grown under blue LED were significantly higher than those grown under the other LED treatments. In addition, phenylalanine ammonia-lyase (PAL) gene was remarkably activated by blue LED at 9 days after transplanting. Thus, this study suggested that the manipulation of light quality by LEDs is a crucial factor for morphology, growth, and phytochemicals of lettuce plants.
[142] The Impact of Supplementary Short–term Red LED Lighting on the Antioxidant Properties of Microgreens

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Keywords: anthocyanins, ascorbic acid, DPPH, phenols

Abstract

Microgreens are very specific type of vegetables and are considered to be in the group of “functional foods” which are products that process particular health promoting or disease preventing properties that are additional to their normal nutritional value. The aim of this study was to evaluate the impact of supplementary short–term red LEDs lighting on the antioxidant properties of microgreens. Different species of red and green leaf microgreens (amaranth, basil, mustard, spinach, broccoli, borage, beet, kale, parsley, pea) were grown to harvest time in a greenhouse in a peat substrate under daylight with supplementary lighting provided by standard high-pressure sodium lamps (HPS). At pre-harvest stage of 3 days, HPS lamps were supplemented by 638 nm LEDs, whereas reference plants continue staying under lighting conditions identical to those of growth. PPFD generated by illuminator was 170 µmol m$^{-2}$ s$^{-1}$ and net PPFD generated by the illuminator in combination with HPS lamps - 300 µmol m$^{-2}$ s$^{-1}$ (16-h; 19-22/15-18°C). Due to the increased activity of the metabolic system for the protection from a mild photooxidative stress antioxidant properties of microgreens were changed. Natural antioxidant compounds were in order: pea>broccoli>borage>mustard=amaranth>basil =kale>beet=parsley=tatsoi. Total phenols concentration increased with supplemental red in all microgreens from 9.1% in mustard to 40.8% in tatsoi, except of amaranth, where decrease of 14.8% was observed. Ascorbic acid content increased in amaranth (79.5%), pea (65.2%), kale (60.6%), broccoli (59.1%) and mustard (25.0%), but decreased in basil (53.9%) and borage (46.9%), and had no significant effect in tatsoi, beet and parsley. Total anthocyanins significant increased in broccoli (45.1%), kale (44.0%), amaranth (38.0%), tatsoi (34.5%), parsley (27.0%) and pea (14.6%), significant decrease was detected in borage (51.8%), mustard (45.1%) and beet (43.3%) and was not significantly affected in basil.
[136] Solid-state Lamp for Lighting in Greenhouses

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Keywords: solid-state lighting, light-emitting diode, lamp, greenhouse, plant

Abstract

Fast development of the light-emitting diode technology continuously brings cheaper and more efficient LEDs to the market. The use of solid-state lighting technology based on high power LEDs for large scale horticultural lighting seems more and more feasible from an economical point of view. However, constructing of a solid-state lamp involves several important issues such as the selection of LEDs, means of heat management and the design of power supply. Here we present the prototype of 250-W solid-state lamp developed for replacement of high-pressure sodium (HPS) lamps used in greenhouses. The lamp consists of two identical luminaries. Each luminary features 40 pieces of high-power deep red (665 nm) AlInGaP LEDs and 8 pieces of high-power blue (447 nm) AlInGaN LEDs. The LEDs were assembled on metal-core printed circuit board (PCB) which is mounted on an aluminum heat sink with three perforated vertical ribs and with perforated lateral reflectors. A heat sink design was optimized using the computer modelling. The heat sink efficiency was assessed using the method of measurement of the junction temperature in LEDs from the high-energy wing of the electroluminescence band. The measured temperature of LEDs junction was 75°C. A transparent polymethylmethacrylate (PMMA) lid was used to protect light-emitting diodes against humid environment. The LEDs were driven by stabilized-current sources mounted on the tail of PCB. The photosynthetic photon flux density at a distance of 1 m is 300 μmol·m⁻²·s⁻¹. The lighting system containing 4 lamps was installed in greenhouse and plant growing experiments were made.
[233] Investigation of the Junction Temperature Influence on the Photon Flux Yield of High-Power-LEDs

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Keywords: High-Power-LED, photon flux yield, junction temperature, integrating sphere

Abstract

The Photon Flux Yield (PFY) permits the comparison of illuminants in horticulture. Therefore the entire emitted radiation of an illuminant has to be captured and brought in relation to the required electrical power. The operation conditions are very important to evaluate a High-Power-LED. The photon flux depends on the junction temperature ($T_J$) as well as the current. The higher one of the two factors, the lower is the PFY. A $T_J$ of 25 °C and a current of 350 mA are the standard operation condition for measuring High-Power-LEDs. It is easy to operate the HP-LEDs at certain currents in a calibrated integrating sphere, but it is difficult to measure the $T_J$. Latter is the temperature at the p-n-junction of the semiconductor. HP-LEDs have to be mounted on a board in order to connect them to the power supply. Instead of the $T_J$ one can measure the board temperature ($T_B$), which differs from and is always higher than the $T_J$. The present deals with the influence of an increasing $T_J$ and the correction of the data when measuring the $T_B$. $T_J$ can be calculated by $T_B$, the converted electrical power and the total thermal resistance between the semiconductor and the thermocouple. The thermal resistance is composed of the internal thermal resistance of the HP-LED, the thermal resistance of the board, and the thermal resistance between the board and the thermocouple. Due to the influence of the $T_J$ on the PPY, the measurements of the HP-LEDs at increasing currents and a constant $T_B$ have to be corrected. Thus the expected deviation of the PPY between the $T_B$ and the actual $T_J$ has to be considered in every single measurement of the current’s influence.
[270] Two Different Types of LED-Light Source Systems Available for Light Effects Research in Horticultural Science

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Keywords: artificial light, dynamic light, spectral irradiance, spectral power distribution

Abstract

We have designed and developed two different types of light emitting diode (LED)-light source systems to support various and advanced experiments for plant light-response studies. One is a light-source system (LS6) consisting of LEDs of six types: violet, blue, green, orange-red, red, and far-red (peak wavelengths: 405, 465, 530, 595, 660, and 735 nm), and the other is an LED-artificial sunlight source system (LS32) employing 32 different peak wavelengths. The present version of LS6 can produce light with different compositions of the six wavelength ranges and can provide photosynthetic photon flux density (PPFD) of 416 µmol m⁻² s⁻¹ for an area of 0.18 m² (30 cm x 60 cm) at a distance of 17.5 cm below the LEDs. This PPFD is sufficient for the cultivation experiments with most horticultural plants that are produced in greenhouses or under artificial light. The latest version of LS32 can produce a spectral power distributions (SPDs) almost the same level as full irradiation of ground level sunlight (GLS) at noon on a clear day, specifically, the irradiance of greater than 750 W m⁻² for 385-940 nm at the light outlet with an limited area of 7.07 cm². The LS32 manifests its usefulness when a GLS-base SPD and/or dynamic light control are required because the LS32 can also produce the desired static and dynamic SPDs and modified SPDs of GLS within the level of irradiation. We present the configuration of the two types of light source systems and the results of quantification tests of the systems.
[285] Multispectral LED Array for Plant Research

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Keywords: Light emitting diode, spectrum, photosynthesis, NCER, transpiration, LED, controlled environment, advanced life support

Abstract:
In recent years the advances in light emitting diode (LED) technology have made the prospect of combining a variety of monochromatic lights to create a light source specifically tailored to plant photosynthetic requirements a reality. Rather than the sometimes crude facsimiles offered by more conventional technologies, LED irradiation can be adjusted to specific plant requirements based on criteria such as species and/or growth stage. In collaboration with Intravision AS (Norway) and COM DEV International, the Controlled Environment Systems Research Facility at the University of Guelph has developed a multispectral LED array designed specifically for plant studies utilizing our BlueBox precision growth chamber technology. The 'snowflake' array, consisting of 512 Philips visible LEDs, is capable of providing a full photosynthetically active radiation (PAR) spectrum at 2000 μmol m$^{-2}$ s$^{-1}$ over a 0.5 m$^2$ area from a distance of 60cm. Individual wavelengths are fully addressable and dimmable and can provide up to 1000 μmol m$^{-2}$ s$^{-1}$ over the same 0.5 m$^2$ growing area. This light source will allow the systematic study of the effect of specific changes in spectral quality and quantity and their impact on productivity parameters including photosynthesis, water use efficiency, yield, time to flowering, and plant structure.
Design for High Production System for Baby Leaf using Hybrid Electrode Fluorescent Lamp (HEFL) in Plant Factory

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Keyword: high density, hydroponics, plant factory

Abstract
Because the market price of baby leaf is relatively inexpensive, we need to establish a new production system for plant factory condition, which requires the energy resulting high cost for baby leaf production. To solve this, we designed a new production system mounted HEFLs. The system used HEFLs as the light source. HEFLs were developed by combining the cold cathode fluorescent lamp (CCFL). HEFLs have a longer life and a lower surface temperature than fluorescent lamps or LEDs. The low surface temperature of the lights allows reducing energy cost for cooling plant surface by air conditioner. Also we tested the effect of high density cultivation to growth of baby leaf. In this experiment, we compared 2 plant densities (1600 and 4400 plants m$^{-2}$). We examined 3 species ‘Japanese Mustard Spinach’ (Brassica rapa L. var. peruviridis) ‘Leaf mustard’ (B. juncea L.) ‘Potherb Mustard’ (B. rapa var. nippoinica) for both experiment. The growth condition in plant factory was set at 20°C, RH60%, 200 to 250 µmol m$^{-2}$ s$^{-1}$ and 16h-photoperiods. As a result, even under high density regime (4400), fresh weights of each plant for 3 species were not decreased significantly. These plant species in this study can be grown at high density condition under HEFL. We demonstrate it is possible to decrease the baby leaf production cost with this system in a plant factory condition.
[119] Controllable Spectrum Plant Cultivation Light Source System using Five-Peak Wavelength LEDs

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Keywords: light response, LED, light control, photon flux density, irradiance

Abstract

We have developed an LED light source system with a controllable spectrum for emission of sufficient photon flux densities to support plant cultivation. The light spectra have five peaks ($\lambda_p$) at wavelengths of 405, 460, 630, 660, and 735 nm, which are the respective spectrum peaks of five types of LEDs used for the light source system. The LED array (40 cm $\times$ 70 cm) of the light source system comprises seven LED modules (40 cm $\times$ 10 cm). Each LED module has 400 LEDs of the five types. The intensity of light emitted from each LED module and each type of LED can be controlled independently using 35 (= 7 LED modules $\times$ 5 LED types) LED drive circuits. In the drive circuits, the base current of an NPN transistor controls the amplitude of the collector current, which is the forward current of the LEDs. The base current is provided from a computer through a D/A converter. The spectral photon flux density (SPFD) at a cultivation area below the light source system is controllable with the five $\lambda_p$, which can thereby produce equal SPFD values at all $\lambda_p$. A gradient SPFD spatial distribution is also producible. When the rated forward current was provided to all LEDs, the photosynthetic photon flux density at 17.3 cm below the LED array was 488 $\mu$mol m$^{-2}$ s$^{-1}$, which is sufficient for cultivation of leafy vegetables. These light control functions are useful for advanced studies of plant light responses.
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