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设施园艺科技创新进展

——2018第五届中国·寿光国际设施园艺研讨会论文集

Advances in Innovation Technology of Protected Horticulture

—— Proceedings of 2018 the Fifith International Forum on Protected Horticulture (Shouguang · China)

杨其长 （日）古在丰树（Kozai Toyoki） （荷）伯特（Gerard P.A. Bot） 主编

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前 言

PREFACE

自2009年以来，借助中国（寿光）国际蔬菜科技博览会平台，中国农业科学院和寿光市人民政府先后于2009年、2011年、2013年、2015年在博览会期间连续举办了四届“中国·寿光国际设施园艺高层学术论坛”（High-level International Forum on Protected Horticulture，HIFPH）。论坛主要以“低碳、节能、高效、安全”为主题，汇聚了国内外数十位知名设施园艺专家以及数百位参会代表，就设施园艺科技进展、节能与新能源利用、温室结构工程、环境模拟与优化控制、LED光源、设施高效栽培、植物工厂技术等专题进行深入研讨，论坛取得了圆满成功。作为论坛的成果之一，四届论坛还汇集与会专家的200余篇论文，正式编辑出版了四本论文专集，受到业内同行的广泛关注。

近年来，设施园艺产业发展迅速,为改善城乡居民的生活质量、增加农民收入做出了重要贡献。但是随着耕地的不断减少、化石能源的日益紧缺、劳动力成本的持续上升以及人们对食品安全的高度关注，设施园艺产业也面临着诸多亟待解决的难题。如何利用现代科技成果解决设施园艺生产中面临的资源、环境与可持续发展问题，是摆在世界设施园艺专家面前的重大课题。为此，本届论坛选择以“节能、高效、绿色、智能”为主题，邀请了来自美国、荷兰、日本、法国、希腊以及国内的40余位知名专家作大会主题报告和专题报告，并围绕设施结构工程、环境模拟与调控、高效栽培、节能与新能源利用、LED光源、新型材料与装备、太空农业、物联网技术以及植物工厂等热点内容进行交流与研讨，探讨实现设施园艺绿色安全、提质增效的技术途径，并汇集与会专家的50余篇论文，正式编辑出版。

在论坛组织过程中，得到了中国农业科学院、山东省寿光市人民政府、荷兰瓦赫宁根大学（Wageningen University）、日本千叶大学（Chiba University）、山东省农业大学、山东省农业科学院、中国园艺学会设施园艺分会、中国农业工程学会设施园艺工程专业委员会等单位的大力支持，在此表示衷心感谢。本书由中国农业科学院科技创新工程（农业环境与可持续发展研究所“设施植物工程”团队）和“863”课题（2013AA103004）资助出版。

由于时间仓促，论文集难免会有错漏之处，恳请各位同仁和读者批评指正。

编　者

2018年3月

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ROTECTED CULTIVATION THEORY AND TECHNOLOGY

综　述

REVIEW PAPER

Towards Sustainable Smart Plant Factories with LEDs, Artificial Intelligence and Phenotyping Unit

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Abstract: The benefits, unsolved problems and challenges for plant factories with artificial lighting (PFALs) are discussed. The remarkable benefits are high resource use efficiency, high annual productivity per unit land area, and production of high-quality plants without using pesticides. Major unsolved problems are high initial investment, electricity cost and labor cost. A major challenge for the next-generation smart PFAL is the introduction of advanced technologies such as artificial intelligence with the use of big data, genomics and phenomics (or methodologies and protocols for noninvasive measurement of plant-specific traits related to plant structure and function). Finally, the concept and methods of plant cohort research for production in PFALs are discussed. In plant cohort research, the time courses of plant traits (i.e., phenomes) are measured for plant individuals together with the data on environments, human and machine interventions, and resource inputs and outputs. The components of the plant cohort research system for a PFAL include the cultivation system module (CSM), phenotyping unit, database or data warehouse and application software for the collection, analysis and visualization of the data. Possible applications of the plant cohort research system are very briefly discussed.

Key words: Artificial intelligence (AI); Big data; Light emitting diodes (LEDs); Phenotyping

1 Introduction

We are facing a trilemma in which there are three almost equally undesirable alternatives:①shortage and/or unstable supply of food; ②shortage of resources; and ③degradation of the environment. This trilemma is occurring at the global as well as local and national level amid an increasing urban population and a decreasing and/or aging agricultural population.

To help solve this trilemma, transdisciplinary methodologies based on new concepts need to be developed by which the yield and quality of food are substantially improved with less resource consumption and environmental degradation compared to current plant production systems. Plant factories with artificial lighting (PFALs) are one such system expected to achieve this mission. The benefits of the PFAL include high resource use efficiency, high annual productivity per unit land area, and production of high-quality plants without using pesticides (Kozai et al., 2015). Current major problems to be solved are the high initial investment and the electricity and labor costs.

The next-generation 'smart' plant factories with artificial lighting (smart PFALs) are expected to help solve food, resource and environment issues concurrently, by significantly reducing the initial and operation costs. This article is a reduced version of Kozai (2018a) and Kozai (2018b).

2 Potential and Actualized Benefits of the PFAL (Kozai, 2018a; Kozai, 2018b)

The PFALs that have actualized most of the potential benefits described below are making a profit and expanding their production capacity; however, the number of such profitable PFALs is currently limited. To actualize the potential benefits of the PFAL, the concepts behind the benefits and the methodology for their actualization must be thoroughly understood before designing and operating the PFAL. At the same time, the vision, mission and goals of the PFAL design, operation and business model must be clearly established and shared with the team members.

(1) High Resource Use Efficiency (RUE) which reduces resource consumption and waste, and thus lowers production costs. RUE is defined as the amount of resource fixed or utilized in the plants (F) divided by the amount of resource supplied to the PFAL (S) (Kozai et al., 2015). Essential resources to be supplied regularly to grow plants in the PFAL are light energy, CO_2, water, fertilizer (nutrients), seeds/transplants and labor only. The light energy, CO_2, water and fertilizer (nutrients) are essential resources for seeds/transplants to grow by photosynthesis (Kozai, 2013).

The first, Water use efficiency (WUE) is the amount of water fixed or held in the plants divided by the net amount of water supplied to the culture beds and absorbed by the plant roots. In the airtight PFAL, almost all the transpired water is condensed and collected at the cooling panels of the air conditioners and returned to the nutrient solution tank. Then, the net consumption of water is the difference in amount between the irrigated water and the water returned to the nutrient solution tank. WUE for the PFAL is around 0.95 (= the fresh weight of plants divided by the difference in weight between the irrigated water and the water returned to the nutrient solution tank) (Kozai, 2013; Kozai et al., 2015). This high WUE (95% water saving) of the PFAL is a big advantage in arid regions and other water-scarce areas.

The second, CO_2 and fertilizer efficiencies of the PFAL are also relatively high (0.80 ~ 0.90) compared with those of CO_2-enriched and soil-cultivation greenhouses with ventilators closed (0.5–0.6 for both) (Kozai et al., 2015).

The third, Light energy use efficiency of the PFAL, however, is still very low (0.032 ~ 0.043), although it is higher than that of the greenhouse (0.017) (Kozai et al., 2015). Use efficiencies of electric energy, light energy, space and labor in the current PFALs need to be considerably improved in the next-generation PFALs through the application of LEDs, intelligent lighting systems, better environmental control, and the introduction of new cultivars that grow well under low photosynthetic photon flux densities (PPFD).

(2) High annual productivity per unit land area. Over 100-fold annual productivity per unit