BURLEIGH DODDS SERIES IN AGRICULTURAL SCIENCE

Advances in plant factories

New technologies in indoor vertical farming

Edited by Toyoki Kozai and Eri Hayashi

burleigh dodds SCIENCE PUBLISHING

Contents

Part 3 Phenotyping

Part 4 Spectral manipulations for controlling the growth and quality of leafy greens

Chapter 1

Characteristics, potential and challenges of plant factories with artificial lighting (PFALs): Introduction

Toyoki Kozai and Eri Hayashi, Japan Plant Factory Association, Japan

1 Introduction

This chapter provides a brief overview of opportunities and challenges for plant factories with artificial lighting (PFALs). Section 2 discusses:

1 global and local issues we are facing;
2 the contribution of PFALs;
3 reducing resource consumption and CO_2 emission by PFALs;
4 the aim of PFAL research and development; and
5 the airtight and thermally insulated scalable cultivation room with sensors.

Section 3 discusses some important challenges in PFAL research and development:

1 Initial investment cost and production capacity per floor area;
2 Virtual and dual PFALs;
3 Global and local features of PFALs;
4 Spatial distributions of environmental factors in a plant canopy;
5 Plant phenotyping; and
6 Expanding the target plant types for the PFALs.

For detailed information on each topic, including the references, refer to the corresponding chapters of this book.

http://dx.doi.org/10.19103/AS.2023.0126.01

2 Background and aim of plant factories with artificial lighting

2.1 Global and local issues currently being faced

We are facing:

1. an increasing urban population;
2. decreasing agricultural land and rural populations;
3. decreasing availability of river water and groundwater for irrigation;
4. degradation of agricultural soil (e.g. erosion, salt accumulation);
5. increasing extreme weather events causing droughts, floods and storm damage;
6. increasing demands for reductions in the consumption of fossil fuels, agrochemicals and chemical fertilizers;
7. an increasing need to reduce emissions of greenhouse gas (GHG) (e.g. CO_2, ethylene and nitrous oxide); and
8. occasionally unstable international trading conditions, disrupting stable supply of foods and resources for food production.

A diverse solution must be developed and applied to solve the aforementioned issues. PFALs are one such solution.

2.2 Contribution of plant factories with artificial lighting

An increasing number of people have recently become interested in PFALs or vertical farms, which are seen as contributing to solving the global and local issues mentioned earlier with respect to:

1. food safety and security;
2. restoring, protecting and enhancing the environment (and the ecosystem services it provides) through reductions in land area used for agriculture, use of water for irrigation and reduced use of fertilizers and pesticides;
3. increasing demands for higher quality, fresh, nutritious and pesticide-free foods with potential nutraceutical benefits;
4. reducing food mileage and food loss; and
5. increasing job opportunities in urban areas.

Compared to open-field production, PFALs can reduce:

1. water consumption per kg of produce by about 90%;
2. land area per ton of production by about 95%;
3. application of pesticides and herbicides by nearly 100%;

4 damage to produce due to adverse weather by 100%; and
5 reliance on agricultural machines and fuel for open-field cultivation by 100%.

2.3 Reducing resource consumption and CO_2 emission by plant factories with artificial lighting

Existing PFALs consume significant amounts of:

1 electricity for lighting, air-conditioning (cooling is always necessary during the photoperiod) and other electric equipment;
2 plastic products for cultivation beds and panels, trays, bags, boxes, films and strings;
3 chemical fertilizers for hydroponic nutrient solution; and
4 metals, cement and other materials for constructing the buildings and cultivation racks.

Additional CO_2 is also emitted to manufacture and transport these resources. Considerable reductions in consuming these resources and the use of alternative resources that emit much less CO_2 are therefore crucial to making the PFALs sustainable.

The most effective and immediate way to reduce CO_2 emissions per kg of produce is using electricity generated from natural energy sources such as solar energy, wind power and hydropower, instead of fossil fuels. The CO_2 emission factor of electricity generated by solar energy is around 50 gCO_2/kWh, which is about 1/15th of that of electricity generated by power plants using fossil fuels (Imamura et al., 2016; see Chapter 5 of this book). The cost of electricity generated by natural energy is currently comparable to or lower than that of fossil fuel. Electricity consumption per kilogram of produce for lighting and air-conditioning can be reduced considerably by improving lighting and air-conditioning systems (see Chapter 5 of this book), breeding cultivars suited to high CO_2 concentration and low photosynthetic photon flux density (PPFD) and uniform spatial environments in a plant community. Energy-autonomous PFALs powered only by natural energy are one of the essential goals of PFAL design and management.

The consumption and thus costs of chemical fertilizer, plastic products, metals and cement can also be reduced significantly by using plant-derived alternatives and improving the design and operation of PFALs. A hydroponic cultivation system with no drain of nutrient solution to the outside will reduce fertilizer consumption by around 20%, compared to the current hydroponic cultivation systems.

2.4 Aim of plant factories with artificial lighting research and development

PFAL research and development aims to establish basic concepts, methodologies and system modules for achieving ecologically, environmentally, economically and socially sustainable plant production systems. This goal can be realized by achieving the highest resource and monetary (or economic) productivities with the highest resource use efficiencies by realizing the highest annual yield with the highest quality, with minimum use of resources, and minimum emission of waste and GHGs, in the face of changing social, economic and technological conditions (Kozai, 2019).

PFALs can be seen to support the Sustainable Development Goals adopted by the United Nations (UN) in 2015, which the UN aims to achieve by 2030. Environment, Society and Corporate Governance (ESG) is another set of global standards used by socially conscious investors to analyze company performance on ethical and environmental grounds and to decide whether to invest. In addition to environmental benefits, PFALs can provide benefits to workers and other stakeholders. PFALs can offer full-time and part-time jobs opportunities for safe and less arduous work in relatively comfortable environments all year round to all adult citizens, including the disabled, elderly and young people. Routine jobs are conducted manually in small-scale PFALs, while these are mostly automated in large-scale PFALs. Mini-PFALs are used at schools, at home and in public spaces as an educational, self-learning or hobby tool to enjoy growing plants and learn the principle of agricultural ecosystems in a simplified form. Pest management in a large-scale PFAL for commercial production of leafy vegetables resembles that in the food factory rather than integrated pest management in the greenhouse. Pest management in a small-scale PFAL is not as strict as in food factories if produce is served after washing, boiling or heating.

2.5 Airtight, thermally insulated and scalable cultivation rooms with sensors

One of the core technologies of the PFAL derives from the use of an airtight and thermally insulated cultivation room with sensors for measuring all resource inputs, product outputs, environmental factors and plant traits or phenotype (e.g. plant canopy architecture and concentrations of chemical components; see Chapter 10 of this book). This means that plant environmental factors can be controlled at an optimum point with minimum resource inputs and waste outputs, regardless of local weather, soil and ecosystem conditions. Resource inputs, product outputs, environmental factors and plant phenotype are automatically recorded with high accuracy. In these cultivation room conditions, observability, controllability, traceability and reproducibility of most data are

Index