Plant Production in Controlled Environments

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Abstract: Crop production in open fields is increasingly limited by weather extremes and water shortages, in addition to pests and soil-borne diseases. In order to increase crop yield, quality, and productivity, controlled environment agriculture (CEA) can play an important role as an alternative and supplemental production system to conventional open field production. CEA is any agricultural technology that enables growers to manipulate the growing environment for improved yield and quality. CEA production systems include high tunnels, greenhouses, and indoor vertical farming, as well as hydroponics and aquaponics. Currently, ‘low-tech’ CEA techniques such as high tunnels (plastic greenhouses with minimum or no cooling and heating) are primarily utilized in developing countries where labor costs are relatively low, and China has by far the largest area covered by high tunnels or ‘Chinese-style’ solar greenhouses. The most control-intensive ‘high-tech’ CEA approach, namely indoor vertical farming, has gained tremendous attention in the past decade by researchers and entrepreneurs around the world, owing to advancements in lighting technology, including use of light emitting diodes (LEDs), and increasing urbanization with new market opportunities. This special issue covers some of the CEA topics such as LED lighting, substrate, and hydroponics.

Keywords: controlled environment agriculture (CEA); indoor vertical farming; LED; hydroponics; plant factory

1. Introduction

Traditionally, crops are produced in soil-based open field systems. Due to seasonality, environmental extremes, and soil-borne diseases, crop yield and quality varies significantly, and year-round production is impossible in most regions for most crops. Controlled environment agriculture (CEA) is a technology for plant production in environmentally-controlled structures such as high tunnels, greenhouses, growth chambers, or indoor vertical farming (warehouse farming). The aim of CEA is to provide protection from pests and diseases and maintain growing conditions for optimizing plant growth and quality. The environmental conditions inside greenhouses and high tunnels are still dependent on outside conditions such as temperature and solar radiation, while those inside an indoor CEA can be controlled precisely at desirable levels because artificial lighting is used instead of sunlight. With the advancement of LED technologies, customized light spectra have been made possible. Thus, manipulating light quality (or the spectrum) and light intensity to enhance plant growth and quality has become one of the most popular research fields in recent years, and this special issue has three articles on this subject [1–3].

2. Manipulating Light in Indoor Vertical Farming

For indoor vertical farming, electrical costs for lighting are the highest among all operational costs [4]. Therefore, many researchers have devoted efforts to developing innovative and cost-effective

lighting strategies. Light is one of the most important environmental factors influencing plant growth and development. Plant growth increases with light intensity; however, plants use light less efficiently as the intensity increases [5]. For indoor vertical farming, it is imperative to determine the lowest possible light intensity or daily light integral (DLI), with corresponding lowest electricity costs, but with little compromise on yield and quality [5]. Researchers have attempted to manipulate light intensity, photoperiod, light spectrum, lighting direction (downward, sideways, or intra-canopy), and lighting with specific wavelengths delivered at specific timings [6–9]. In addition, others have tried different combinations of varying wavelengths of LEDs, which can be turned on simultaneously, alternating or with partial overlap of different LEDs [10]. The goal has been to use less electrical energy to achieve the same yield and quality. In this special issue, Chinchilla et al. [2] evaluated growth and physiological responses of two lettuce cultivars exposed to small changes in light quality and intensity within a 24-h period. They found that 1 h of low intensity end-of-day blue light has the potential to promote lettuce growth by increasing leaf area and shoot fresh mass when the main DLI from sole-source lighting is provided by broadband white LEDs.

Production of desirable secondary compounds, which affect color, flavor, and aroma, is also strongly dependent on both light intensity and quality [1]. The amounts of total anthocyanin, phenolics, and flavonoids in sweet basil were positively correlated to DLIs [5]. Plant morphology (height, branching, internode length, etc.) was influenced by both light quality and intensity. Therefore, management of lighting in indoor vertical farming system can be a powerful tool.

3. Other Environmental Factors in CEA

Regardless of CEA type, there are five essential environmental conditions that affect plant growth and development: temperature, light, CO₂, water, and nutrients. A significant number of studies were carried out more than two decades ago on controlling greenhouse temperatures for floricultural crop production. Supplemental lighting when natural light is low in winter months and low-light intensity photoperiodic lighting for flowering control have been common approaches. In this issue, the effect of elevated temperature and potassium (K) on biomass and quality of lettuce was investigated and results suggested that temperature is a stronger regulatory factor than increasing K in the determination of lettuce yield and quality [11].

In CEA, soilless substrates or hydroponics (water culture) have been used instead of soil. Solid substrates not only serve as a support of roots, but also affect water and nutrient use efficiency. In addition, some substrates are chemically inactive or inert, while others contain chemically active ingredients. Nevertheless, the 'best' substrate is often crop dependent. The availability and cost of ingredients of the substrates also play an important role in deciding if the substrate is suitable for commercial production. Arce and Rivera [12] evaluated different substrate mixes and quantities of fertilizers on the growth of citrus rootstocks. The results showed that different rootstocks responded differently, but rice husk substrate was not suitable for citrus tree production at the nursery level.

Biochar is a byproduct of thermochemical pyrolysis for bioenergy production and is considered a possible amendment to soilless substrates or soil in field. Peat moss is one of the most common ingredients in substrates for greenhouse production. However, most peat moss is harvested in Canada. Seeking a sustainable, locally available alternative for peat moss is vital. Guo et al. [13] conducted a greenhouse study to evaluate the growth and development of poinsettia grown in a commercial peat-based substrate amended with biochar at different ratios along with different fertigation regimes [13]. They concluded that up to 80% biochar could be used as an amendment to peat-based substrate with acceptable growth and no change in quality.

Growing crops in a hydroponic system under a controlled environment has gained interest among growers and entrepreneurs worldwide in recent years, especially for food crops such as leafy greens and herbs. Nutrient solutions in a hydroponic system are often recirculated, and thus high-quality water is often used. However, the availability of high-quality water is often limited. There is a need to evaluate the impact of water quality on nutrient solution management and on plant growth and

quality. Niu et al. [14] conducted two greenhouse experiments to examine the growth and mineral nutrition of four leafy vegetables in a nutrient film technique system with water of low to moderate salinity [14]. They found that the tested vegetables differed in response to various types of water used as a supplement or as source water. They also noted that N, P, and K depleted more rapidly than other macronutrients, and that nutrient solution replacement in the reservoir was needed only when the unwanted ion (e.g., sodium and chloride) concentrations reached harmful levels, which are crop dependent.

4. Conclusions

An increasing population, urbanization, and climate change have contributed to decreasing global stocks of water and arable land per capita. Under these circumstances, more ‘sustainable’ crop production systems are needed. In other words, more food needs to be produced with less arable land and less water. Innovative CEA is an essential future agricultural model, and the papers in this SI have addressed some of the key topics pertinent to advancing CEA. Current advanced CEA production systems (well-controlled greenhouses and indoor vertical farming) face challenges of high initial investment and high operational costs. We envision future CEA will employ more advanced technologies such as automation, nanotechnologies, and artificial intelligence to increase crop productivity and optimize cost efficiency.

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