Chapter

# Greenhouse Requirements for Soilless Crop Production: Challenges and Prospects for Plant Factories

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## Abstract

This chapter discussed the greenhouse requirement for soilless crop production. It further introduced soilless crop production and elucidated the equipment required for an efficient production system covering greenhouse environmental control and management of temperature, humidity, lighting, and nutrients using innovative strategies. Also, the energy required for the control of the greenhouse environmental conditions during the crop production cycle was explained. Identification and management of pests and diseases using wireless network sensors and the Internet of Things for efficient and safe food production were also highlighted. Finally, the challenges facing greenhouse crop production itemized, and the prospects of greenhouse technology for sustainable healthy food production were proposed.

**Keywords:** greenhouse crop production, hydroponics, greenhouse energy requirement, pest management, wireless network sensors

## 1. Introduction

Greenhouse crop production is an agricultural management technique employed nowadays for increasing food production under a controlled environment. It is an emerging, efficient, and feasible alternative guaranteeing food supply throughout the year without any hindrance from the external environmental factors. In recent years, technological advancements such as wireless sensor networks and agricultural robots have been able to handle the challenges facing greenhouse farming by overcoming its limitations, mitigating adverse impacts from the climate and environmental changes, and ensuring system sustainability [1, 2]. In greenhouse crop production, two methods of farming crops are employed; namely, crop production that involves soil as the growing medium and soilless crop production popularly referred to as hydroponics, which utilizes nutrients in a liquid medium.

Soilless crop production refers to any technique of growing crops in the absence of soil as a rooting medium to boost the yield, quality, and safety of food products that meet the demands of consumers. The main advantage of this method is reducing the problems associated with soil, including soil salinity, poor soil structure and quality, soil-borne pests and diseases, and non-arable soil [3]. For soilless crop production in the greenhouse, one has the leverage to control many limiting factors that crops encounter, including temperature, light, and a large degree of pest and disease problems, and soil-related problems mentioned above. Moreover, soilless crop production in the greenhouse can be practice all year-round, including during the winter months, where good-quality crops are guaranteed. This chapter will discuss soilless crop production in the greenhouse under the following sub-sections.

## 2. Greenhouse production system

In recent years, the agricultural sector has witnessed a rapid increase in the use of the greenhouse production system (GHPS) as an alternative to the growing demand for food around the globe. The controlled environment in the greenhouse system guarantees food safety and high crop yield in limited space, especially in populated areas. With this closed-field cultivation, simple rows of vertical or open-fields crops are cultivated in nutrient media under a highly controlled environment. The advent of smart farming (precision technology, wireless sensors, and data processing) is changing the crop cultivations from conventional greenhouses to advanced high-tech plant factories for the optimization of human labor and boosting crop productivity. High-tech greenhouse production systems such as the one shown in **Figure 1** are also refered to as controlled environment plant production systems, controlled environment agriculture, or phytomation systems [4].

Traditionally, GHPS uses natural or artificial light to optimize growth conditions of horticultural crops, fruits, and vegetables, or plant research programs, thereby reducing the food threat projected by the United Nations. However, there is a need to promote scientific solutions that can lead to more efficient production of crops in the greenhouse via optimization of various environmental conditions and subsystems and the understanding of the external factors that should be integrated into the system. In this way, the technical aspects of the GHPS, including automation, culture, and environment, need to be integrated so that the system and its goals could lead to a conclusion regarding the system's performance indicators. These cultural and environmental factors comprise crop cultivation procedures based on plant physiognomies, growth responses, and microclimate requirements. It also constitutes physiological, planting, and post-harvest processes, harvesting, and packaging. The strategies for using affordable and energy-saving facilities as

**Figure 1.**
*View of a high-tech greenhouse facility in the Netherlands (source: Meteor systems BV).*

covering materials and lighting and microclimate control systems are necessary for a viable GHPS. This will reduce the cost of automated energy management and environmental impact and maximize the use of natural resources.

### 2.1 Greenhouse cover materials

Although GHPS is widely accepted in Europe and China, the initial cost seems to be the main factor limiting its acceptability to low-income farmers, especially in developing countries that needed the technology the most. The materials used to support foundation, shape, and framings for establishing a geographical direction and optimal light entrance add to the high initial cost of GHPS. Greenhouse structures and covering enclose the cultivation area and space. Transparent materials such as polyethylene (PE) films, ultraviolet stabilized PE-films, and numerous transmitting cover materials were reported elsewhere [5]. A study found that the combination of PE cover and silicon double glazing photovoltaic panels reduced solar radiation by 35–40% as against PE cover alone. The researchers further observed that the silicon double glazing photovoltaic panels shading reduced the air temperature of the protected cultivation of tomatoes and peppers crops. Screen-houses are often used in greenhouse operating on natural ventilation in the tropical lowlands regions to control insects, intense solar radiation, risk of heavy rainfall, and strong wind [6]. A comprehensive review of the challenges with the use of photovoltaic panels in the greenhouse crop production system is available in [7]. Insect-proof nets are employed to cover the greenhouse and maintain the inside and outside temperatures at a required level.

On the other hand, photo-selective films increase the temperature during the summer. Studies showed that greenhouses covered with net-screen are more prevalent in tropical regions because of the climate conditions that have optimality degrees near the plants' desired levels. Greenhouses covered with insect-proof net-screens and operate on natural ventilation have their internal and external air temperatures maintained at the same level [4]. Also, shading nets can protect plants from excessive sunlight, heavy rains, and wind and facilitate the natural ventilation process. What is now needed is to synthesize these materials from renewable source materials.

### 2.2 Light control in greenhouse systems

Light control and interception of radiance in GHPS are by using shading screens, planting density, and artificial lights [6]. Since light conditions and air temperature are the most critical environmental factors for plant growth. Analyzing optimal air temperature without discussing plant evapotranspiration and the light condition does not generate any useful data to maximize productivity and high-quality yield. The correlation between light and air temperature is high such that one cannot be optimized without consideration of the other. For instance, the quality of tomato (yield, lycopene content, and productivity) is not only influenced by the microclimate parameters and cultural practice but also by the photosynthetic photon flux density. The photosynthetic photon flux density is a condition of the optimal combination of light, relative humidity, and air temperature, resulting in maximum yield.

## 3. Requirements of a modern greenhouse for crop production

Greenhouse production systems demand an efficient strategy to control microclimate conditions, including humidity, temperature, and gas level, to maintain an optimum ambient setup for crop cultivation [8]. One of the most important technologies of the 21st century is the wireless sensor network (WSN), which is very suitable for distributed data collection and monitoring in complex environments such as greenhouses. Many measurement points are needed to trace down the local climate settings in various locations of the greenhouse to ensure proper operation and automation of the production cycle. Cabling this measurement operation is expensive, vulnerable, and challenging to relocate once installed [9].

In emerging greenhouses, technological advancement such as WSN has brought solutions in precision agriculture (PA). Modern agricultural management practices require WSN-enabled equipment to efficiently manage the various microclimate parameters to achieve high-quality agricultural produce. These WSN gadgets utilize Low-Power Wide-Area Networks (LPWANs) as a wireless technology for long-distance data transmission with minimal power consumption. Because greenhouses are liable to several changes and interference, they require a better WSN design scheme to manage and process data. Long Range Wide Area Network (LoRaWAN) is a low data rate and among the most successful LPWAN technologies used nowadays due to its low deployment and management costs [10].

Greenhouse operations depended on the technologies employed in the covering materials, structure orientation, shape, dimensions, and microclimate control [11]. Modern greenhouses are faced with challenges due to intricate structural design. The other challenges encountered in the greenhouse include design adaptation with respect to different crops, the impact of the metal structures, and the technology employed for PA. These challenges have a significant influence on the growth of crops, which necessitated an adaptive precision monitoring solution. WSNs provide an effective solution in managing greenhouses, with an efficient strategy in different fundamental aspects of sensors types, connectivity, network optimization, and power source [12]. Meanwhile, LPWANs are low power consumption and long-range communication gadget suited for wireless communication in greenhouse PA [13]. However, there are some crucial challenges in WSN deployment that have restricted its real benefits in PA, including maintaining coverage, optimal deployment scheme, long-range connectivity for communication, and energy-efficient network for extended battery life [14].

Nowadays, as the internet has become inevitable in daily life, all devices need a network to function and communicate with other devices. This is brought about by the Internet of Things (IoT), which is another promising technology of the 21st century that finds excellent applications in farming and makes the life of a farmer easier. IoT is used in the connection, control, and management of intelligent devices connected to the internet [15]. The technology enables people to access different data over the internet from any remote location. It is considered the third wave of information technology after the internet and mobile communication network, with more intelligence and comprehensive interoperability [16]. Thus, numerous sensors and controllers are used in collecting environmental data in a greenhouse and send it to the control station over the internet.

Different seasonal crops are grown only under certain conditions. Onions, garlic, and shallots are winter crops that require cold conditions for their growth, whereas cucumbers and melons are summer crops that require moderate or hot climatic conditions. IoT and various sensors help bring solutions to many of the existing practical problems over the years [16]. Numerous sensors and controllers have been utilized in greenhouse environmental data collection and send such data to the control station over the Internet. Therefore, three crucial factors of WSN are considered during operation, namely; power consumption, the accuracy of measurement, and network connectivity. Besides, there are other considerable aspects of WSN, including stability, cost, and data security that are of importance [17, 18].

## 4. Management and control of pests in the greenhouse

### 4.1 Some greenhouse pests

Various insect pests and other arthropods attack greenhouse crops during the soil or soilless cultivation. These insect pests are categorized into chewing insects and sucking arthropods depending on the type of attack and damage they cause to crops. The chewing insect pests of greenhouse crops mostly feed on leaves and plant roots. The larvae of these insects include Lepidoptera, Coleoptera, Diptera, and Hymenoptera. Others are larvae of fungus gnats that tunnel into the stems of many crops or feed on the roots of plants. All these cause severe damages to seedlings and cuttings, whereas large crops are minimally impacted. Control of such infestations is problematic in the greenhouse due to the over-lapping and tunneling behavior of these pests [19].

On the other hand, sucking arthropod pests in greenhouse crops feed on host plants by piercing and sucking liquid biomaterial from the plants, thereby damaging their tissues. These type of pests used their needle-like mouthparts to penetrate the plants' tissues. They include many pest species such as Western flower thrips, mealybugs, *Bemisia tabaci* (Genn.) scales, aphids, mites, and whiteflies [19, 20]. Damages caused by these pests include feeding on new leaf clusters, leaf undersides, or in developing flowers of mature plants. The pests mostly hide and protect themselves from direct pesticide spray applications and pierce and suck liquid contents underneath the epidermal cells, thereby developing pale or yellowish-white leaves, a condition of insufficient chlorophyll and with visible fruits deformities in some plants. Some pests attack greenhouse vegetables and ornamental crops by feeding on phloem-sap, thereby excreting abundant excess water and sugars that encourage molds growth and transmission of plant viruses. Some sucking pests (aphids) damage greenhouse crops by causing stunted and abnormal growth in host crops by injecting toxic substances [19].

### 4.2 Pest control in greenhouse

#### *4.2.1 Pests control using conventional methods*

The control of pests in the greenhouse is a critical management practice to ensure food safety, quality, and bumper harvest. In greenhouse crop production, control measures are essential in soilless crop cultivation since the greenhouse provides an excellent environment for different pests to thrive [21]. The prevention of pest attacks on crops is much easier than trying to control the infestation after the attack. The control and management of pests practice include biological, chemical, and physical methods. In the physical method, light has been employed to attract insect pests to control devices or adjust light wavelengths to control insects and diseases [21, 22]. Nowadays, biological control is preferred over chemical control due to health concerns. El Arnaouty et al. [20] reported that the application of the biological control method, such as the use of different parasitoids and predators, has yielded an appreciable safe production of sweet pepper in the greenhouse as compared with the recommended chemical control method during the same period. The biological control method has increased the yield of sweet pepper by 35.06 and 17.88% as against the untreated and chemical control method, respectively [20].

Geographical location, crop type, and method of crop cultivation determine the type of pest that can be found in a particular greenhouse. Therefore, specific control measures need to come in handy to farmers and familiarize themselves with the pest

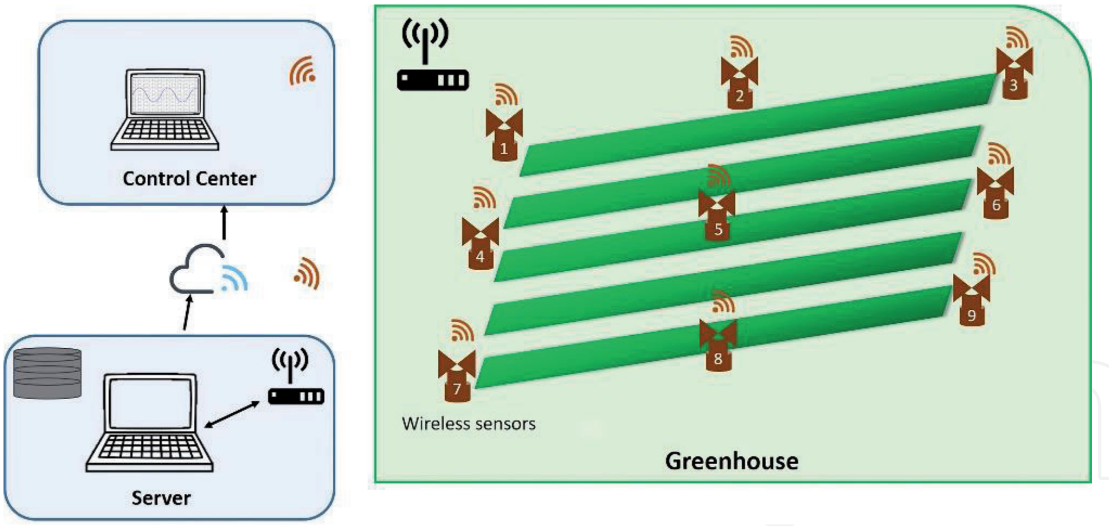


**Figure 2.**
*Wireless sensor network for greenhouse management of crop pests.*

in their locality and control measures to avoid damaging the crops. Fungicides and pesticides recommended for such an area should be available as at when needed in a timely manner to avoid economic catastrophe if pests are not urgently handled. Farmers should know all the levels of pest incidences by conducting daily routine monitoring to allow them to distinguish at which level a pest can be tolerated that might not require treatment [23].

#### *4.2.2 Pests control using smart approaches*

With the recent advancement in smart agriculture, noninvasive approach such as the use of sensors, Unmanned Aerial Vehicles (UAV), and artificial intelligent noses (electronic noses) have been deployed in open farms and greenhouses for real-time monitoring, identification, and control of crop pests and diseases [24, 25]. Different types of sensors employed for pests detection include gas detection, sound detection, and spectral remote sensors. A typical wireless sensor network deployed for greenhouse applications is showcased in **Figure 2**.

##### *4.2.2.1 Gas detection sensors*

Gas detection sensors utilize volatile compounds released by crops as a result of external stress from pests infestation, human disturbance, or environmental factors. During pests infestation, crops produce volatile chemical compounds to the surrounding that is recorded as gas or image. Numerous samples of the volatile compounds released by plants need to be gathered after different stresses to enable the identification of pest infestation in the area. Thermal imaging is also utilized in the characterization of volatile chemical compounds released because they have a specific spectral signature [25].

##### *4.2.2.2 Sound detection sensors*

This is a farm management (FM) practice in which wireless sensors coupled with antennas are mounted in greenhouses at strategic points to pick sound waves produced by pests as they fly, chew, or mate. The farmer then records the noise levels for the given period and analyzes the data on a computer. Pest-infested areas typically have louder sound than none or less infested areas. The farmer might opt to manage the pests instantly or wait until they reach the economic control threshold. This is an effective form of detection approach utilized by both large and small scale farmers with little cost of operation and higher than average performance. The only shortcoming is that environmental conditions might influence the data gathering during storms or heavy winds [26].

#### *4.2.2.3 Spectral remote sensors*

The technique of remote sensing is deployed in the processing, characterizing, interpreting, and displaying data as images using spectral remote sensors available as low-image sensors and high-image sensors [24]. Low-image sensors consist of cameras mounted at strategic locations to capture images and send them to a control station. They only capture visible images of pests since they are low-resolution cameras. The captured images provide information on the pests population on a particular crop and estimate the overall infestation in the greenhouse. These low-image sensors are frequently used by farmers because of their low capital investment and maintenance costs. The high-image sensors, on the other hand, detect the spectral signature of each crop and record it in a spectrum beyond the human spectrum. It includes x-rays, gamma rays, infrared, and ultraviolet rays. The image data produced can either be multispectral or hyperspectral. These high-resolution images can distinguish the physical and chemical components of the crop from thousands of kilometers away [24, 26].

Before the detection of crop pests, the imaging spectrometers are pre-loaded with spectral signatures of each crop on the greenhouse. Therefore, once pests attack the crops, their spectral signatures change because the pests absorb the crops' light and force them to reflect a divergent spectral signature than the pre-loaded ones. The pests' population and their exact location on the crop and lifecycle stage are known by analysis of the images. Compared to the low-image sensors, they are better in terms of accuracy and detection of multiple types of pests and diseases. Meanwhile, imaging spectrometers are expensive and require a significant outlay for maintenance.

#### *4.2.2.4 Fluorescence image sensing*

This approach requires analyzing the chlorophyll content in a crop. The images of crop leaves are captured and compared with images of noninfested leaves. The crop infestation is detected by variation in the chlorophyll pattern. This technique can only be utilized to identify pests on crops with chlorophyll [26].

## 5. Energy requirement for crop production in the greenhouse

### 5.1 Energy requirements

With the intensification of crop production, crop yield and quality are enhanced via control of the internal environment of the greenhouse using electricity. In this case, the reduction of fuel and electricity consumption to attain an optimum growth environment constitute the main concerns of greenhouse cultivation [27]. Heating and cooling systems for environmental control consume high electrical energy in regions with scorching weather conditions, such as Saudi Arabia, which recorded around 153 Wh $m^{-2}$ $d^{-1}$ for cooling systems, pad, and the air circulation

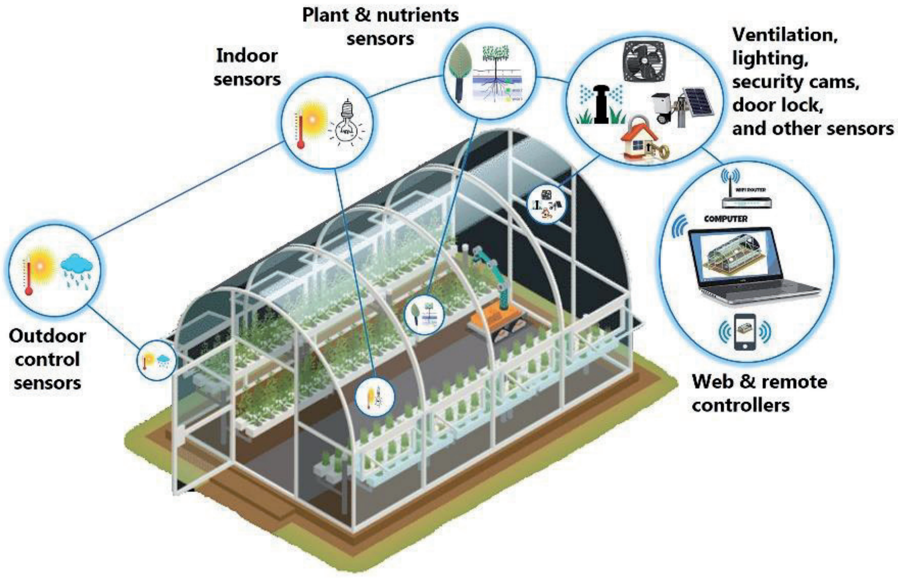


**Figure 3.**
*A remotely-operated greenhouse for monitoring of various external and internal greenhouse environmental conditions.*

fans [28]. In temperate regions, heating systems consume a large amount of electrical energy, such as in Canada, where supplementary lighting commands high electrical power, as reported by Bambara and Athienitis [29].

Moreover, the electrical energy demands of greenhouses rely on the types and operational periods of the loads, energy requirement, and efficacy of the appliances, and overall, the climatic conditions of greenhouse location. Plant species influenced electrical energy demand, and this was attributed to the respective optimal growth temperature required by different crops. For example, in Turkey, the heating demand of tomatoes, lettuce, and cucumber production in a greenhouse were 105, 29, and 217 Wh $m^{-2}$ $d^{-1}$, respectively, for the maintenance of corresponding greenhouse temperatures of 20, 14, and 26°C during winter season [30]. Ntinas et al. [31] reported a substantial amount of electrical energy of 352 Wh $m^{-2}$ $d^{-1}$ consumption in mid-winter greenhouse during the cultivation of tomatoes in Central Macedonia. This energy consumption was recorded during heating, irrigation, and air-circulation operations [31]. Other studies stated electrical energy consumption for greenhouse cultivation of tomatoes, eggplant, cucumber, basil, and pepper as 10.2–17.1, 14.4, 9.7–29.1, 178.7, and 9.0–12.5 GJ $ha^{-1}$, respectively [28]. In some situations, if the costs of investments for environmental control equipment cannot be recovered from the profit gained due to the costs of fuel and electricity, it is suggested not to use the environmental control equipment in the greenhouse [28, 32]. **Figure 3** is a smart energy-saving greenhouse environmental control system for soilless crop management.

### 5.2 Control of greenhouse environmental conditions

Factors such as temperature, humidity, carbon dioxide, light, and other parameters influence the cultivation of crops in the greenhouse, and therefore these parameters need constant monitoring.

#### *5.2.1 Temperature*

Due to the transparent nature of roofs and walls of the greenhouse, sunlight infiltrates without hindrance. These covering materials prevent thermal leakages from the greenhouse, resulting in higher internal temperature compared to that of the outside environment. Meanwhile, in temperate climates, fuel-assisted heating and grid electricity inputs enabled the extension of the cultivation period in colder seasons. This allowed the location of greenhouses even in colder areas, leading to improve crop quality in winter. The amount of energy consumption in greenhouse crops cultivation increases with increased latitude due to heating and additional lighting [28, 33]. Greenhouse internal temperatures rise during summer in temperate regions. These high temperatures have a great impact on crop growth and development, thus, reducing economic yields [28].

#### *5.2.2 Humidity*

The humidity in the greenhouse environment has a strong influence on crop transpiration and disease infections. Plant stomata close to prevent extra transpiration in the surrounding dry air, which suppresses $CO_2$ exchange between the air and leaves, thus reducing the net photosynthetic rate. Therefore, managing humidity is necessary to provide an optimum environment for crop growth. Electricity is used to automatically control the environment concerning real-time variations of interior microclimate and plant conditions, which also add to the electrical energy consumption.

#### *5.2.3 Carbon dioxide*

$CO_2$-concentration in greenhouse fluctuates based on the respiration and photosynthesis of crops. In some instances, the concentration reaches peak levels in the morning since $CO_2$ generated during the nighttime respiration remained in the greenhouse. In the daytime, with insufficient ventilation and plant photosynthesis proceeds, the $CO_2$ level in the greenhouse declined compared to the outside environment. Ventilation devices play a critical role in maintaining the $CO_2$ levels in the greenhouse. Also, $CO_2$ supply systems are usually used for providing adequate $CO_2$ for sustaining crop cultivation [28].

#### *5.2.4 Light*

Sunlight is among the most important energy sources for crop photosynthesis. This energy is absorbed, transformed, and stored by crop chlorophyll molecules in the form of photon energy for their growth. It has been reported that producing 1 kg of fresh tomatoes would require an average of 6 MJ of sunlight with 90 mol of photosynthetically active radiation (PAR, 400–700 nm wavelength range) photons, which is equivalent to 900 MJ of sunlight for 1 kg dry weight of tomatoes [28]. For the cultivation of high light-demanding vegetable crops like tomatoes, the greenhouse cover design should be in such a way to deliver efficient sunlight to the crops. In Mediterranean regions, light-diffusing films are utilized to prevent leaf burning due to extreme direct sunlight on greenhouse crops. The sunlight radiation is absorbed into the crops, thus, improve the photosynthesis performance. On the other hand, complementary lighting is applied in the high-latitude regions due to the less intensity of sunlight. Also, lighting during nighttime is used to regulate flowering to enhance food product supply to markets [28, 34].

### **5.3 Adaptive analysis framework**

Recently, computer-based microclimate control systems and simulation software for knowledge-based decision making have been deployed. Adaptive Analysis

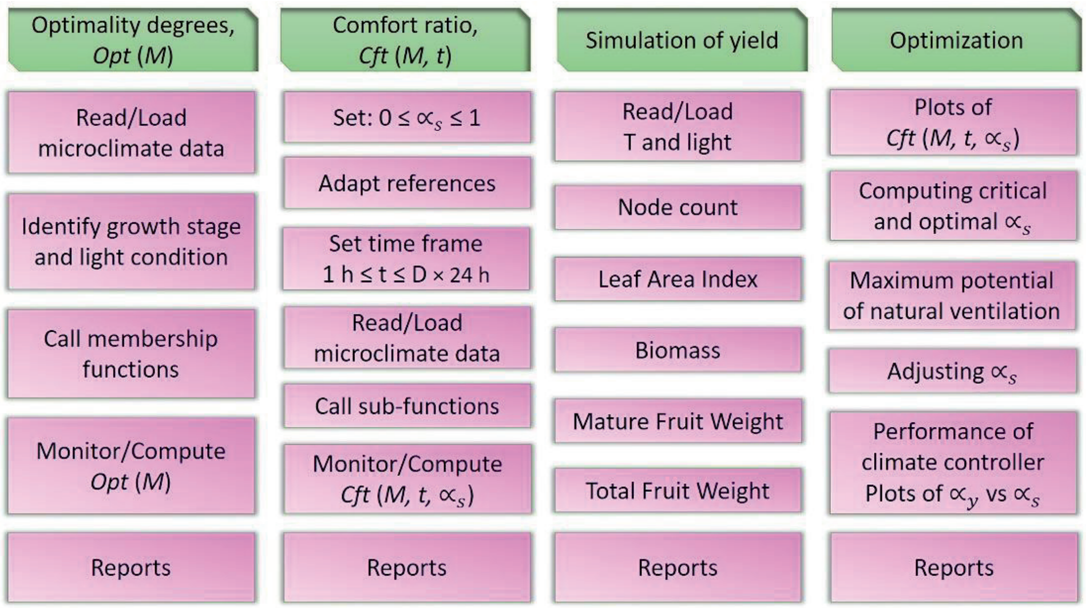


**Figure 4.**
*An interphase of adaptive management framework toolbox redraw from [35].*

framework utilizes a custom-designed data acquisition and control system [35] that has been built based on ESP32 microcontroller board for monitoring and manipulating of the microclimate parameters. Three computer models were employed by the framework for evaluation and adjusting of optimality-degrees $Opt(\mathcal{M})$, comfort ratio $Cft(\mathcal{M}, t, \alpha)$, and prediction of the expected yield as depicted in **Figure 4**. The framework was implemented in MATLAB® (The MathWorks Inc., Natick, MA, USA) environment through Simulink blocks and coding of various main functions and sub-functions that were stored as "m-files". Different toolboxes were developed for the immense data analyzing tasks. The framework structure was designed in a way that end users can create (or update) entries in database, select report type (one-day or multi-days report), and proceed with a specific analysis procedure. The database is a dynamic flat file type that can be created by entering collected data, either manually from previously stored sources such as excel sheets, or directly from the hardware interface. The computer models presented in this chapter are focused on tomato (*Lycopersicon esculentum*); however, with slight modification the framework can be reprogrammed to work with other greenhouse crops provided that their yield prediction and growth response models are available. Results of microclimate evaluation and set point manipulation generated by different Simulink blocks of the AAF can contribute to dynamic greenhouse climate control strategies [36], such as the one in [37].

## 6. Challenges and prospects of crop production in greenhouse

### 6.1 Challenges facing crop production in greenhouse

The use of greenhouses for the cultivation of crops has been described as an innovative way of mechanically and scientifically controlling the natural outdoor climatic conditions, such as torrential rainfall, high and low temperature, relative humidity, pests, and diseases [38–40]. Ventilation systems are an integral part of most greenhouses in the Mediterranean regions; thus, greenhouses in those areas are not heated at all [39]. One of the most pressing issues facing the use of greenhouse in those regions is insufficient ventilation during the summer and no heating during the winter, which causes an imbalance on the side of the optimum temperature and relative humidity conditions required for the wellbeing of the crops [39, 41]. Hence, the conception and implementation of air conditioning systems for the direct control of the climate, especially the most important variables (temperature and humidity), are inevitable [38].

Moreover, mimicking an ideal and real environment by ensuring indoor ventilation and other factors mentioned earlier poses a challenge, especially as the proliferation of pests and diseases is favored due to the conducive atmosphere created in the greenhouse [41]. Besides the challenges posed by ensuring a balanced micro-climatic condition, the development of pest and disease resistance is also promoted in the greenhouse by other conditions such as the cultivation of only one type of crop (mono-culture). Mono-culture encourages the acclimatization of pests and diseases when one particular crop is cultivated continuously. Likewise, insufficient ventilation and low temperature in the rhizosphere might lead to the multiplication of crop diseases. Other challenges facing greenhouse crop production are the low-cost of agricultural produce compared to the cost of production, which sometimes discourages small and medium-scale farmers [42].

Other non-environmental challenges facing greenhouse production included:

i. High energy consumption in sophisticated greenhouses that operate entirely on air-conditioning, heating, and ventilation systems, lighting, sensors, and other wireless gadgets.

ii. Need for skilled personnel to precisely control the required conditions in the greenhouse, including temperature, humidity, different crop nutrient requirements, and pest management.

iii. In a non-automated greenhouse, the fast and constant depletion of essential nutrients in the liquid media requires careful monitoring and quantification, followed by replenishing the lost nutrients immediately so that additional stress will not be added to the crops.

### 6.2 Prospects of crop production in greenhouse

The emergence of aquaponics farming systems in the greenhouse indicates a promising prospect in crop production. The aquaponics technique is an intelligent strategy for integrating soilless crop production and fish farming [43]. In this system, the waste generated by the fish after feeding is then broken down into useful nutrients by numerous bacteria species. The nutrients produced in the fish effluents are assimilated by the crops raised in the hydroponics beds. The wastewater becomes clean and then recirculated continuously to the fish tank for reuse with minimal water loss and healthier crops free from chemical fertilizer [44]. Similarly, the incorporation of hydroponics technique into the aquaponics helps in geometrically increasing the production output from a small area of land as crops can be raised in a cascaded manner (either vertically or horizontally) on sterile layers [41], as well as dramatically reducing the spread of diseases that are associated with soil cultivation [38].

Furthermore, the use of an integrated system of wireless sensors, actuators, and robots, eases the stress being faced by farmers as the nutrients levels and other requirements (pH, soil moisture, temperature, humidity) by the crops can be monitored remotely and accurately in real-time, with few physical visits to the greenhouse. Also, the introduction of the Integrated Production and Protection (IPP) method, which is the rational way of combining both the biological and chemical methods of crops disease control with other control measures (good agricultural practice and injection of plant extracts), will in the future enhance crops cultivation in the greenhouse [38].

Soon, a fully automated unmanned greenhouse operated by various energy-saving advanced technologies, including WSN, UAV, and IoT for real-time management of crops, will boost food production and ensure sustainable food safety to consumers.

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