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Integrated Greenhouse Microclimate Management: A Review

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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Review Article

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ABSTRACT

The normal development of plants and an increase in yield depend on the microclimate in a greenhouse being controlled. Key microclimate factors, like carbon dioxide, temperature, sunlight and relative humidity could be altered by a variety of control actions such as humidification and dehumidification, heating, natural or forced ventilation and concentration of carbon dioxide. Factors like effective natural ventilation in greenhouses, considering factors like temperature differences, wind velocity, and appropriate ventilator area, are crucial for regulating internal climate, reducing

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energy use, and ensuring healthy plant growth. However, these modifications result in higher energy and fuel consumption throughout the manufacturing process. Thus, appropriate management is obligatory to perform the intricate operations related to balancing energy, *i.e.,* lowering the emanations and reducing the cost of production, even though severe climatic conditions could adversely affect the microclimate inside the greenhouse. This review document will provide concise information on the management of greenhouse microclimate, focusing on different factors that affect crop growth and how these factors can be managed.

Keywords: Carbon dioxide, greenhouse; microclimate; relative humidity; temperature.

1. INTRODUCTION

The use of artificial environments for crop production has been increasingly popular during the past two decades [62 and 78]. There is a growing awareness of the importance of enhancing intensive agricultural systems to provide for the expanding requirements of the world's population without depleting the finite supply of renewable resources [9,17 and 65]. Producing food crops outside of their growing season and with greater yield than that produced with conventional growing systems is made possible by greenhouse agriculture [31,62 and 70]. Protected agriculture is a method of increasing agricultural productivity while maintaining a plant-friendly environment [13,14 and 26,27]. This has led to an increase in the popularity of growing vegetables in greenhouses. Planting an improved variety and keeping climatic conditions ideal are both necessary for increasing crop yield and quality. Different plant types and phases of development require slightly different microclimates [32]. When plants are grown in a protected environment, abiotic stresses that reduce growth but boost quality are sometimes seen as an asset [22]. In order to grow plants year-round and harvest them reliably, specialised structures called greenhouses are used [29 and 76]. Light, temperature, humidity, the concentration of carbon dioxide and air composition are just some of the aspects that affect the greenhouse's internal environment and, as a result, must be managed to ensure optimal plant growth and development [64 and 68]. The impact of greenhouse conditions on crop growth, maturation and yield are the subject of a great deal of research. Principally, the production of crops is governed by response crop plants to the growing conditions [6,7 and 18]. Light is the most reliable predictor of crop growth and output [15] and plant reactions to temperature have a significant impact on harvest time and yield [19 and 55,56]. The light transmission ability of the covering material also affects the internal environment of the greenhouse [1,5,12 and 53].

Since poor temperature management, greenhouse humidity and carbon dioxide additions can significantly affect crop output or even lead to crop loss, microclimate control in the greenhouse is of the utmost importance even when crops have great genetic features. There are several internal and external variables that affect the greenhouse's microclimate [64]. Environment variables like as temperature, humidity, solar radiation, wind speed and direction and cloud cover are examples of external elements; internal variables include greenhouse geometry, heating and ventilation placement, soil type, crop variety and genetics [16 and 52]. It is possible to improve harvest by a factor of several by careful management of the greenhouse's microclimate while plants are being grown [20]. By creating a climate-controlled environment and making optimal use of resources like water, fertiliser, seeds and pesticides, greenhouses make it possible to grow four or five crops every year [36]. Increased agricultural yields can be achieved using a variety of protective structures. Low poly-tunnels, on the other hand, can be an inexpensive solution for marginal farmers to establish a suitable growing state around the crops by altering temperature and reutilizing the released carbon dioxide inside the tunnels, thus enhancing the plants' photosynthesis and the productivity of the crops [37]. Additionally, the adaptation of plants developed through tissue culture under the project of pioneering research and the production of top quality crops under protected conditions can be automated with the help of computers and artificial intelligence by irrigating or fertigating automatically, applying precise or need-based amounts of other inputs and regulating environmental conditions.

2. MICROCLIMATE PARAMETERS IN GREENHOUSES

Maximizing growth and yield of the growing crops is a primary objective of controlling microclimate inside the greenhouse [58]**.** Several climatic factors are required to promote plant growth and development through photosynthesis. Some critical microclimate parameters like temperature, sunlight, carbon dioxide and humidity inside the greenhouse are important factors that are discussed as under in detail.

Solar radiations: The amount of dry matter produced by plants decreases linearly as sun radiation decreases. In high latitudes during the winter, dry matter synthesis is unlikely to be effective without the aid of artificial lighting [24]. The merely minimum sunlight is need for ensuring optimum growth and development. In order to stimulate flowering in long-day plants, it is common practise to supplement natural light with artificial sources [61].

Impact of temperature and its regulation: The temperature is the utmost important component, which should be regulated inside greenhouse as it regulates the normal functioning of all terrestrial plants, *i.e.*, germination, respiration, transpiration, photosynthesis and flowering *via* opening and closing of stomata. The basic determinant of greenhouse temperature requirements is the type of crop being grown [57]. Temperature characteristics, such as the maximum and minimum day and night temperature and the variation in temperature of day and night, should be prominently considered [28]. Many of the warm temperature requiring crops that are well acclimatized to 20 to 30°C temperature with lower and upper limits of 10 and 35°C temperature, respectively, are cultivated in the greenhouse [79]. If the minimum temperature outside the greenhouse is less than 10°C, the atmosphere inside the greenhouse needs to be warmed up, while the outside greenhouse temperature is >27°C, ventilation should be increased for maintaining optimum temperature inside the greenhouse in daytime, though the greenhouse inside temperature goes beyond 27-28°C, unnatural cooling is needed [64]**.** Several crops are damaged if temperature inside the greenhouse becomes more than 35°C. Greenhouses are used for growing most types of warm-season crops, which thrive in temperatures ranging from around 10 to 35°C (50 to 95 Fahrenheit) [79]. When the outside temperature drops below 10°C, heating the greenhouse is necessary; when the outside temperature rises above 27 °C, ventilation keeps the internal temperature from increasing too much in daytime though the temperature inside the greenhouse goes beyond 27-28°C, lowering of temperature by non-natural means is necessary [64]. When the temperature inside the greenhouse rises above 35°C, most of the plants inside are affected.

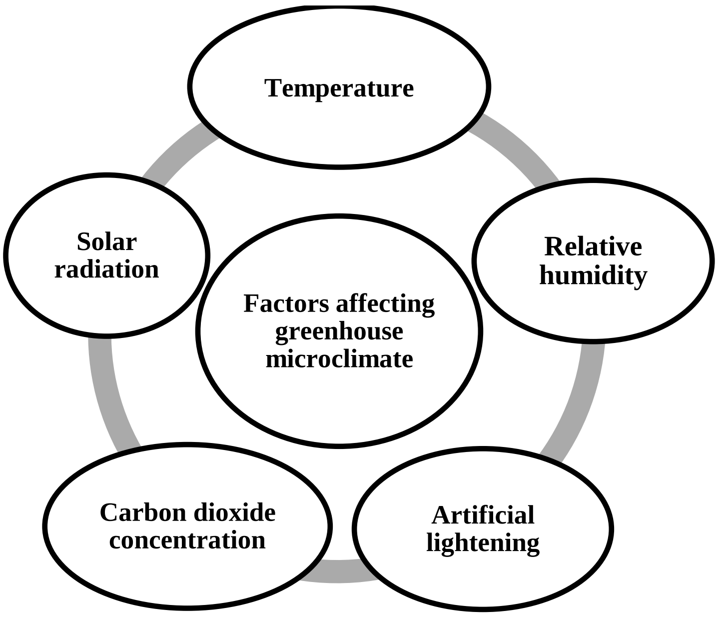

Fig. 1. Factors affecting greenhouse microclimate

Relative humidity: Transpiration rate in plants is closely associated with relative humidity of the air, hence humidity has a significant impact on the progress and maturation of a harvest [28]. Humidity levels between 60 and 90 percent are optimal for plant growth. Humidity levels above 95% inhibit photosynthesis, slow plant growth and promote the spread of pathogens like *Botrytis cinerea*. However, low humidity (below 60%) can have adverse impacts on plant growth through mechanisms including dehydration, water stress and stunting [35 and 64]. Daytime humidity levels can be lowered by using greenhouse ventilation. Most plant diseases do not cause noticeable development problems until after prolonged exposure to high humidity, thus we tend to ignore the detrimental effects of moisture on plant growth until disease onset [23]. Regulating humidity inside the greenhouse is essential for making the cultivation of vegetable crops in greenhouse successful since it affects the growth, flowering and yield of every vegetable crop in greenhouse [8].

Intensity of light: Photosynthesis, photomorphogenesis and photoperiodism are the three key light-controlled mechanisms that drive plant growth. These are immediately affected by any shift in lighting conditions. The process of photosynthesis, which requires light, converts the CO_2 into biological compounds and then emits O_2, which is an essential reaction and sunlight is the foremost source of energy that makes the oxidative reaction possible. Plant responds to different wavelengths of light in unique ways and this process is called photomorphogenesis. Photoperiodism, on the other hand, is the study of how day length affects a plant's decision to blossom [64]**.** In many regions of the country, the amount of natural light is sufficient for the production agricultural crops and providing supplemental light is required for all agricultural and horticultural crop plants that need lengthier day. Size and weight of fruits are both increased by using supplemental LED lighting, which produces a positive impact on plant growth and its productivity [54]. More research is needed to fully understand the impact of light quality on plants because it controls various plant growth pathways and responses vary depending on the type of plant.

Carbon dioxide (CO_2) concentration: When the crop is cultivated very densely, the level of carbon dioxide in greenhouse is dropped down significantly than the outdoor carbon dioxide levels, even though the ventilation in greenhouse is properly maintained. Mornings see the highest concentration of carbon dioxide in the greenhouse and as the day progresses that concentration gradually decreases due to optimum rate of ventilation, reaching its lowermost level in noon hours [2]. Carbon dioxide lowers photosynthesis in most vegetable species, reducing productivity. Crop development and output appear to be maximised at a carbon dioxide concentration from 700 to 900 μmol per mol [14 and 64]. Increases in greenhouse carbon dioxide levels, either continuously or intermittently, have been shown to enhance the production of fruits by more than 20% [63]. Plants absorb carbon dioxide through opening and closing of stomata and how well they take in CO_2 in a greenhouse depends on a variety of factors, including the weather.

Tools to regulate greenhouse microclimate: Distinct kinds of protected structures are best suited for controlling microclimate in various climates [36]. The greenhouse's microclimate is regulated by adjusting the temperature of pipes and vents, as well as the position of the greenhouse's curtains [36], [64 and 68]. To maximise production, it is important to maintain the ideal values for each microclimate parameter based on the specifics of the crop and its location.

Ventilation cooling and shading: Air circulation is something that needs to be considered all through the year [31]. Management of climate inside greenhouse under hot conditions focuses on minimisation of heating load, which could be done via lessening the entering of sunlight in greenhouse and eliminating excess heat through air exchange. Roof vents, a front door and exhaust fans can all work together to keep greenhouse air circulating [58]. Currently, the most popular means for blocking the sun's rays include using shading nets or painting surfaces white. When air temperature outside the greenhouse is lower than temperature inside the greenhouse, aeration by opening ventilators can remove extra heat from the greenhouse effectively with the exchange of air. In order to decrease the sensible heat load, evaporative cooling is commonly used to increase portion of the dissipated heat [64]. Although heat evacuation pumps and heat exchangers exist, they are not commonly used due to their high initial cost, especially in India [35].

Natural-ventilation: When the level of solar radiation is high, it is important to remove surplus heat from the greenhouse by circulating air from out to inside consistently. One of the main ways is to reduce the amount of carbon dioxide inside greenhouse [42]. Lack of ventilation leads to overheating and excessive transpiration, causing water deficit condition and biological abnormalities like splitting or cracking of fruits, dropping of flower buds and fruits and other issues with the plant. Because hot air rises toward the ceiling and wind develop gradients of air pressure and air deficit on leeward side of the ridge, and simultaneously, wind plays an important role in ventilation [48 and 68]. Air exchange and humidity levels are maintained by opening the ridge vent in the greenhouse roof. If natural ventilation is used, the airflow from the fans should not be horizontal, as this would merely redistribute the heated air that has risen to the greenhouse's ceiling. Insects can be prevented from entering the greenhouse by covering the windows and vents with plastic mesh screens. The greenhouse's internal climate can be altered using natural ventilation [33]. Better temperature regulation and less energy use are two benefits of a thoughtfully planned ventilation system. In addition, the level of carbon dioxide in the air, the relative humidity and the temperature all have an impact on the development and growth of the crop, which is closely connected to ventilation [34]. The effectiveness of a greenhouse's natural ventilation system depends on factors such as outside-to-inside temperature difference, the velocity and direction of the prevailing winds, the greenhouse's layout and crop presence [50]. Ventilator area of the total floor-area for natural ventilation should lie between 15 and 30 percent, beyond which, the extra ventilation-area impact on temperature becomes minimal ([35]; [64]. When solar radiation intensity and temperature inside the greenhouse are high, adequate ventilation is extremely important for fostering healthy plant growth.

Forced ventilation: The purpose of forced ventilation is to mingle air in the whole greenhouse, with air circulation provided by the assembly of intake and exhaust fans [68]. Forced air circulation by using fans is one of the most impactful methods for removing heat and gases from the greenhouse, however, it is a procedure of intense energy consumption. Exhaust fans are installed to keep humidity and temperature constant inside the greenhouse. Fresh air is allowed to enter the greenhouse from one side, which replaces hot air from opposite side [64]. For efficient forced ventilation, the exhaust fans are installed on leeward side of the greenhouse. Capacity of the fans must be raised at least 10%. Forced ventilation works best when the fans are not more than 25 feet apart, and the open space is kept in front of them four to five times the diameter of the fan [48]. The maximum air velocity in a crop-containing greenhouse must not be more than 0.5 ms^{-1}. All the ventilators should close robotically when the exhaust fans are switched off [64].

Shading covers: Because of high temperature in the country, circulating cool air within greenhouses is one of the top priorities. Greenhouses gain most of their heat from the sun in this method. Unwanted light and heat can be blocked by employing shade or reflective measures. Greenhouses can be shaded in several ways, such as with paint, external shading cloth, mess of varying colour, partly reflecting shading nets, a water-film on the rooftop, or liquid foams in spaces between the walls of greenhouse [35 and 64]. However, lessening light and ventilation rates caused by shading may have negative effects on plant growth and photosynthesis. Therefore, care must be taken while selecting the type of shade and the accompanying control mechanisms. In hot, sunny climates, shading nets are more successful at reducing heat stress and increasing crop yields [1,4 and 11]. There is currently a plethora of plastic netting options on the market, each with its own unique set of optical qualities. Growers can enhance crop yields by using shading grids having unique visual quality to modify the entering of solar energy in greenhouse [49]. Absorption, reflection and transmission of short and long-wave radiations are affected by the transparency and colour of the plastic sheet [59,60]. Protected crops grown under coloured shade nets experience a range of beneficial morphological and physiological responses, leading to higher-quality harvests [66,67]. Even while shading nets lessen the greenhouse's radiation load, understanding how plants react to different levels of light is essential for successful greenhouse cultivation. Reduced sunlight will likely increase canopy temperature by slowing the rate at which leaves transpire.

Evaporative cooling: Greenhouses can be protected against overheating in hot weather using evaporative cooling systems, which regulate humidity and temperature [44]. High solar thermal load is a defining feature of greenhouse crop cultivation in hot climates and it presents significant challenges environment inside the greenhouse and severely restricts growth of crop plants [43]. The most effective way to deal with the weather is to use an evaporative cooling system, which relies on transferring of sensible to latent heat through the water evaporation introduced *via* fogging or misting inside the greenhouse through evaporative or wet pads [44]. For the fogging system to work, water must be sprayed in the form of extremely fine precipitations with too much compression into the air on top of above the cultivated plants. Too much evaporation efficiency of water is achieved while the foliage is kept dry due to sluggish freefall velocity of the droplets and air streams inside greenhouse effortlessly carrying them. There are several different fogging techniques that may be utilised to chill the greenhouse while increasing relative humidity. The cooling system is frequently employed in greenhouse for growing horticultural crops [35]. Although they do not require forced ventilation or an airtight enclosure fogging systems but they have one advantage over wet-pad system as in that they develop even conditions in the whole greenhouse [7 and 68]. The major bottleneck in this system is that the installation and operational costs are significantly high, including supply of water and electricity, upkeep charges, *etc.* [64]. In addition, the evaporative cooling of rooftop involves misting water on top of the roof, leaving a thin water film there. It functions best in hot and dry areas because it lowers the greenhouse's ability to transmit solar radiation and raises evaporation rates, which lower water temperatures and nearby air temperatures.

Greenhouse heating: A properly planned and installed heating system will allow for consistent temperatures in the entire greenhouse. Both the intended crops and the proposed window materials will dictate the heating system that will be required [3 and 31]. In colder parts of the country, greenhouse heating is required by law and the high cost of heating has a major impact on greenhouse output and profitability. [51] They stated that a wide range of heating technologies are utilized to keep up with the cooling and heating demands of modern greenhouse. Unit heater is utmost prevalent and affordable heating option. Unit heaters with their own fireboxes are strategically placed around the greenhouse to distribute heat evenly, with each heating system responsible for an area between 180 and 500 square metres [35 and 64]. An annual inspection of your unit heater is necessary to guarantee its continued reliability. Maintenance of cooling system before the start of hot summer is ideal. It is important to check the exhaust vent, fuel lines, valves and blower [48].

Central boiler systems, in contrast to unit heaters, distribute some of their heat to the root of the crops and the crown zone, where it can have a positive effect on crop growth and disease prevention. Wall pipe coils can assist create a more consistent temperature throughout the greenhouse by providing heat to the perimeter walls. Overhead piping coils running the greenhouse length provide loss of heat through gables and roofs. The location of these coils above the plants makes them an unappealing heat source. It is more efficient to heat the plants through pipe coils below the beds than in overhead coils, as this allows for better air circulation and results in less dampness around the plants' roots [35] and [64]. The microclimate around plants is positively impacted by the consistent heating provided by pipe/rail heating systems. Such systems are suitable for the production of vegetable crops in greenhouse where heating system is used to prevent the freezing of their crops. Keeping the greenhouse's air temperature above condensation limits is another application [64].

Solar radiation filtration: Three types of solar radiation, *i.e.*, near-infrared, photosynthetically active and ultraviolet light make up the total amount of sunlight that enters a greenhouse from the entire planet. Much of the sun's ultraviolet rays are absorbed by Earth's atmosphere. Plants' photosynthetic function can deteriorate from prolonged exposure to UV light. Only the photosynthetically active part of the incoming radiation is utilized by plants as it is essential for photosynthetic reactions and plant growth, signifying that alteration of radiation entering the greenhouse can be useful [40 and 76]. Due to the increased absorption of near-infrared radiation by the structure of greenhouse and installed equipment instead by the plant, the temperature inside the greenhouse rises. The temperature inside the greenhouse can be regulated by switching out the cover. Some types of plastic cellophane, movable screens and NIR filtering shading paint can also be used to block out the sun's rays in the near infrared spectrum.

Carbon dioxide enrichment: The systems that increase carbon dioxide have been demonstrated to upsurge the growth crop plants by enhancing photosynthesis in several scientific investigations. Liquid carbon dioxide, pumped from containers through a fertigation-style pipeline network, is the purest type of CO_2 enrichment [36]. To detect potential gas threats, special gauges measure the quantity of carbon dioxide in the distribution pipes [46]. Very high price of containers for transporting gas is one major drawback of the technique. By-products of the fuels' burning of kerosene, propane-butane gas, or natural gas include carbon dioxide during gas emanations through the burners. The heat production is usually a driving force behind the need for such an arrangement. The systems' constraint is that carbon dioxide can only be introduced in the greenhouse when heat is needed. Fuel selection depends on several factors, including the ease of acquisition, the unit price and quality of the gas emanations. Dosing in the greenhouse must be accurately managed as per the environmental factors such as lighting, temperature and air circulation. In order to keep the greenhouse's carbon dioxide concentration at the same as outside, some researchers approve the supply of CO_2 even when the ventilation system is functional [47] and enriching the greenhouse with CO_2, *i.e.*, 700-800 μmol per mol, when the greenhouse is kept closed, typically in late afternoon and early morning [35].

Lighting system: Light intensity has a major effect on the greenhouse's temperature and humidity. When natural light is insufficient, or when the space is too heavily shadowed, people turn to artificial illumination [58]. Where the daily average sunshine duration is lower than 4.5 hours, commercial greenhouse output benefits greatly from the use of supplemental illumination [64]. The usage of special lights is essential throughout the winter and on overcast days to ensure that crops receive the necessary amount of light for optimal growth. A few examples of efficient lighting systems are light emitting diode-bulbs, fluorescent-lamps, heating lamps, metal-halide lamps and tube lamps.

Air humidifier: Humidification in a closed greenhouse will be accomplished in the same way as in an open greenhouse; that is, by heating the area and then introducing water vapour to it using fogging system. Humidification devices were categorised by [68] as either cold water humidifiers, hot water humidifiers, or nebulizers. In cold-water humidifiers, the air is filtered via the water in the tank. The temperature may be steady or fluctuate very slightly. A cold-water humidifier works on a simple and affordable concept. A hot water humidifier is like a cold-water humidifier in that both utilise water to create moisture in the air but hot-water humidifiers employ a heater for the creation of saturated vapours at outlet [36 and 75]. The nebulizers will not generate water vapour but rather a mist of water droplets that are supersaturated. In this technique, water droplets are formed into an aerosol by an oscillating plate at an ultrasonic frequency [75]. In colder climates, boilers for steam production are frequently installed for generating heat or regulating humidity in greenhouse in addition to fogging system installation for cooling and humidity control. These heaters generate saturated vapour injected into the greenhouse. The commonly used overhead watering pulsators add moisture to the air in the greenhouse.

Dehumidification: Since ventilation cannot be employed in a closed greenhouse, dehumidification is the primary climate management difficulty [73 and 75]. However, in a semi-enclosed greenhouse, ventilation can serve as a dehumidification method. There are two main types of dehumidification systems: refrigeration and desiccant. Condensation occurs in a refrigeration-based system, which cools the air to the point of saturation in order to remove moisture and then reheats the air once this process is complete [36]. Therefore, dehumidification and cooling can be done simultaneously in many instances. Desiccant systems, on the other hand, remove moisture from the air in its vapour phase directly, without producing a cooling effect, leading to air that is hotter than normal due to the heat of adsorption and hence has a lesser humidity level [21].

Automatic climate control system in greenhouse: Computerization in greenhouse is all about precise, cutting-edge, intense farming that makes good use of all available resources, reuses data inside the system and makes bold claims about increasing output without negatively impacting the ecosystem [68]. Growing managers can benefit from better ventilation and heating systems and designers can create more efficient structures, if they can anticipate the microclimate inside a greenhouse [71 and 72]. Internal microclimate can be studied by experimentation and modelling. Simulation approaches are more efficient than doing actual experiments because of their speed, low cost and replicability. Energy and mass balance would be much improved if transpiration by the crop and ventilation were more accurately accounted for than in most current models [36]. The primary goal of the earliest greenhouse microclimate studies was to quantify the thermal behaviour of a greenhouse [77]. To characterise the typical behaviour of a given component in greenhouse, the researchers used numerous simple models with static energy balancing [30]. If the response time of greenhouse is analogous to time change rates of the borderline conditions, then a static model becomes less useful. Therefore, several models for climate change inside the greenhouse have been developed [80].

The microclimate dynamic behaviour is the outcome of various processes including transfer of energy and mass balancing. External environmental conditions, greenhouse construction, crop kind, crop growth stage and the impact of control actuators all have an impact on these procedures. Because of the system's intricacy, growers have had to rely heavily on empirical principles based on their own understanding when designing climate control systems. Adaptive control [69], optimal control [74] feed-forward control [61], robust control [45] and predictive control have been employed in recent years to address such issues. Many people have worked on creating high-tech greenhouse climate control systems that are run by computers. Important optimal control approaches have been proposed [25] to implement cutting-edge methods like adaptive, non-linear, predictive and robust control, including the use of artificial intelligence, fundamental, imitative and relative controller tools like artificial neural networks, fuzzy logic systems and genetic algorithms.

Low-priced greenhouse with microclimate regulation: Most western forcing systems, including as greenhouses, polyhouses and net houses, are too expensive for small and marginal farmers [36]. Another strategy for maximising crop yields and profits is using low tunnel technology to protect the crop from frost and catch early market before peak of the growing season [41]. The ability to easily set up and break down poly-tunnels is another benefit of this technology [38 and 39]. As a result of the increased heat and trapped carbon dioxide, photosynthetic activity and yield are increased in plants grown in these tunnels. The microclimate they produce around the plants is conducive to growth, shielding them from frost and pests while also limiting water evaporation [10]. To give seedlings a head start and warm their environment, low tunnels are employed in the spring ([37]). These tunnels are used to grow high-quality crops including tomato, cucurbits and sweet pepper. Even though these covers are perforated to facilitate airflow, it is nevertheless recommended that they be removed when temperatures rise.

3. CONCLUSION

The greenhouse farming industry is one of the most dynamic and competitive in the agricultural market. Protected buildings' form and function are greatly influenced by weather conditions. In this research, we looked at how to regulate the microclimate of a greenhouse to ensure optimal growth of crops. Temperature and humidity are the most important factors that affect plant growth. Temperature, humidity and other practical characteristics have proven difficult to control and maintain economically, despite much research in many different locales. However, automatic irrigation and fertigation system, data loggers and microprocessors make it possible to regulate every aspect of the growing environment, from the temperature and humidity to the fertiliser and watering schedules. As a result, scientists need to look at low-cost greenhouse designs that can be employed in many climates due to their ability to regulate their internal microclimate.

DISCLAIMER (ARTIFICIAL INTELLIGENCE)

Author(s) hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of manuscripts.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Abdel-Ghany AM, Al-Helal IM, Alzahrani SM, Alsadon AA, Ali IM, Elleithy RM. Covering materials incorporating radiation-preventing techniques to meet greenhouse cooling challenges in arid regions: A review. Sci. World J. 2012;1-11.
2. Akilli M, Özmerzi A, Ercan N. Effect of carbon dioxide enrichment on yield of some vegetables grown in greenhouses. Acta Horti. 2000;534:231-234.
3. Akpenpuun TD, Ogunlowo QO, Na WH, Rabiu A, Adesanya MA, Dutta P, Lee HW. Review of Temperature Management Strategies and Techniques in the Greenhouse Microenvironment. Adeleke University J. Eng. Technol. 2023;6(2):126-147.
4. Al-Helal AM, Abdel-Ghany IM. Responses of plastic shading nets to global and diffuse PAR transfer: Optical properties and evaluation. NJAS-Wagen. J. Life Sci. 2010;57:125-132.
5. Al-Helal IM, Alhamdan AM. Effect of arid environment on radiative properties of greenhouse polyethylene cover. Sol. Energy. 2009;83(6):790-798.
6. Allen Jr. LH. Plant responses to rising carbon dioxide and potential interactions with air pollutants. J. Environ. Qual. 1990;19(1):15-34.
7. Baeza EJ, Perez-Parra JJ, Lopez JC, Montero JI. CFD simulation of natural ventilation of a parral greenhouse with a baffle device below the greenhouse vents. Greensys. 2007;801:885-892.
8. Bakker JC. Analysis of humidity effects on growth and production of glasshouse fruit vegetables. Diss., Wageningen University, Wageningen. 1991;76.
9. Barea JM. Future challenges and perspectives for applying microbial biotechnology in sustainable agriculture based on a better understanding of plant-microbiome interactions. J. Soil Sci. Plant Nutr. 2015;15(2):261-282.
10. Bhat S, Kumar S. Conventional and recent approaches of integrated pest management in greenhouse cultivation. Prot. Cult. 2024;255-274.
11. Briassoulis D, Mistriotis A, Eleftherakis D. Mechanical behaviour and properties of agricultural nets - Part I: Testing methods for agricultural nets. Polym. Test. 2007;26:822-832.
12. Cemek B, Demir Y. Testing of the condensation characteristics and light transmissions of different plastic film covering materials. Polym. Test. 2005; 24(3):284-289.
13. Chimankare RV, Das S, Kaur K, Magare D. A review study on the design and control of optimised greenhouse environments. J. Trop. Ecol. 2023;39:26-28.
14. De Pascale S, Maggio A. Plant stress management in semiarid greenhouse. Acta Horti. 2008;797:205-215.
15. Demotes-Mainard S, Péron T, Corot A, Bertheloot J, Le Gourrierec J, Pelleschi-Travier S, Sakr S. Plant responses to red and far-red lights, applications in horticulture. Environ. Exp. Bot. 2016;121:4-21.
16. Dix BA, Hauschild ME, Niether W, Wolf B, Gattinger A. Regulating soil microclimate and greenhouse gas emissions with rye mulch in cabbage cultivation. Agric. Ecosyst. Environ. 2024;367:108951.
17. Doran JW. Soil health and global sustainability: Translating science into practice. Agric. Ecosyst. Environ. 2002;88(2):119-127.
18. Ellis RH, Hadley P, Roberts EH, Summerfield RJ. Quantitative relations between temperature and crop development and growth: Climatic change and plant genetic resources. Belhaven Press, Landon, UK. 1980;85-115.
19. Fahad S, Bajwa AA, Nazir U, Anjum SA, Farooq A, Zohaib A, Huang J. Crop production under drought and heat stress: Plant responses and management options. Front. Plant Sci. 2017;8:1147.
20. Ganesan M. Effect of poly-greenhouse on plant micro climate and fruit yield of tomato. Ka. J. Agric. Sci. 2002;15(4):750-752.
21. Harriman III LG, Plager D, Kosar D. Dehumidification and cooling loads from ventilation air. American Society of Heating, Refri. Air-Cond. Engi. 1997;39(11):6.
22. Hashimoto Y. Recent strategies of optimal growth regulation by the speaking plant concept. In International Symposium on Growth and Yield Control in Vegetable Production. 1989;260:115-122.
23. He F, Ma C. Modelling greenhouse air humidity by means of artificial neural network and principal component analysis.

Comput. Electron. Agric. 2010;71:S19-S23.
24. Hemming S. Use of natural and artificial light in horticulture-interaction of plant and technology. International Symposium on Light in Horticulture. 2009;6(907):25-35.
25. Ioslovich I, Gutman P, Linker R. Hamilton-Jacobi-Bellman formalism for optimal climate control of green-house crop. Automatica. 2009;45(5):1227-1231.
26. Ishii M, Sase S, Moriyama H, Okushima L, Ikeguchi A, Hayashi M, Giacomelli GA. Controlled environment agriculture for effective plant production systems in a semiarid greenhouse. Jpn Agr Res Q. 2016;50(2):101-113.
27. Jackson RD, Idso SB, Reginato RJ, Pinter PJ. Canopy temperature as crop water stress indicator. Water Resour. Res. 1981;17:1133-1138.
28. Jain N, Bhakar SR, Singhal. A review of greenhouse climate control application for cultivation of agriculture products. Int. J. Eng. Trends Technol. 2017;46:305-308.
29. Jensen MH. Controlled Environment agriculture in deserts, tropics and temperate regions- A World Review. In: International Symposium on Design and Environmental Control of Tropical and Subtropical Greenhouses, Acta Horti. 2001;578:19-25.
30. Joliet O. An improved static model for predicting the energy consumption of a greenhouse. Agric. For. Meteorol. 1991;55:265-294.
31. Kalbande SR, Gangde CN. Greenhouse Technology. Everyman’s Sci. 2013;10: 366.
32. Katsoulas N, Kittas C. Impact of greenhouse microclimate on plant growth and development with special reference to the Solanaceae. Eur. J. Plant Biotechnol. 2008;2:31-44.
33. Kittas C, Boulard T, Mermier M, Papadakis G. Wind induced air exchange rates in a greenhouse tunnel with continuous side openings. J. Agric. Eng. Res. 1996;65:37-49.
34. Kittas C, Karamanis M, Katsoulas N. Air temperature regime in a forced ventilated greenhouse with rose crop. Energy Build. 2005;37(8):807-812.
35. Kittas C, Katsoulas N, Bartzanas T. Greenhouse climate control in mediterranean greenhouses. Cuadernos de Estudios Agroalimentarios (CEA). 2012;3:89-114.
36. Kumar S, Bairwa DS, Kumar K, Yadav RK, Yadav LP. Climate regulation in protected structures: A review. J. agric. ecol. 2022;13:20-34.
37. Kumar S, Batra VK, Khajuria S, Kumar R. Poly-tunnel Technology: A Cost Effective and Affordable Method for Early Season Production of Bottle gourd. J. Comm. Mob. Sustain. Dev. 2017;12(1):107-110.
38. Kumar S, Batra VK, Partap PS, Narender K. Early season cultivation of bottle gourd: Effect of dates of sowing and growing conditions on different growth parameters. Int. J. Trop. Agric. 2015;33(2):1139-1143.
39. Laktionov I, Vovna O, Kabanets M. Information technology for comprehensive monitoring and control of the microclimate in industrial greenhouses based on fuzzy logic. J. Artif. Intell. 2023;13(1):19-35.
40. Lamnatou C, Chemisana D. Solar radiation manipulations and their role in greenhouse claddings: Fresnel lenses, NIR-and UV-blocking materials. Renew. Sustain. Energy Rev. 2013;18:271-287.
41. Lodhi AS, Kaushal A, Singh KG. Low tunnel technology for vegetable crops in India. In Best Management Practices for Drip Irrigated Crops. Apple Academic Press. 2015;45-52.
42. Lorenzo P, Maroto C, Castilla N. Carbon dioxide in plastic greenhouse in Almería (Spain). Acta Hortic. 1990;268:165-169.
43. Misra D, Ghosh S. Evaporative cooling technologies for greenhouses: A comprehensive review. Int. Agric. Eng. 2018;20(1):1-15.
44. Montero JI. Evaporative cooling in greenhouses: Effect on microclimate, water use efficiency and plant response. In: International Symposium on Greenhouse Cooling, Cabrils (Barcelona), Spain. 2006;719:373-384.
45. Moreno JC, Berenguel M, Rodríguez F, Baños A. Robust control of greenhouse climate exploiting measurable disturbances. IFAC world congress, Barcelona. 2002;35(1):271-276.
46. Mukazhanov Y, Kamshat Z, Assel O, Shayhmetov N, Alimbaev C. Microclimate control in greenhouses. International Multidisciplinary Scientific GeoConference: SGEM. 2017;17:699-703.
47. Nederhoff EM. Effects of carbon dioxide concentration on photosynthesis, transpiration and production of greenhouse fruit vegetable crops. Thesis. Wageningen, The Netherland. 1994;213.

48. Nemali K. History of Controlled Environment Horticulture: Greenhouses. Hortic. Sci. 2022;57(2):239-246.
49. Oren-Shamir M, Gussakovsky EE, Shpiegel E, Nissim-Levi A, Ratner K, Ovadia R, Giller Yu E, Shahak Y. Coloured shade nets can improve the yield and quality of green decorative branches of Pittosphorum variegatum. J. Hortic. Sci. Biotechnol. 2001;76:353-361.
50. Ould Khaoua SA, Bournet PE, Migeon C, Boulard T, Chasseriaux G. Analysis of green-house ventilation efficiency based on computational fluid dynamics (CFD). Biosyst. Eng. 2006;95(1):83-88.
51. Ozgener O, Hepbasli A. Experimental investigation of the performance of a solar-assisted ground-source heat pump system for greenhouse heating. Int. J. Energy Res. 2005;29(3):217-231.
52. Panwar NL, Kaushik SC, Kothari S. Solar greenhouse an option for renewable and sustainable farming. Renew. Sustain. Energy Rev. 2011;15(8):3934-3945.
53. Papadopoulos AP, Hao X. Effects of greenhouse covers on seedless cucumber growth, productivity and energy use. Sci. Hortic. 1997;68(1-4):113-123.
54. Paucek I, Pennisi G, Pistillo A, Appolloni E, Crepaldi A, Calegari B, Gianquinto G. Supplementary LED interlighting improves yield and precocity of greenhouse tomatoes in the Mediterranean. J. Agron. 2020;10(7):1002.
55. Pearson S, Hadley P, Wheldon AE. A model of the effect of day and night temperature on the height of chrysanthemum. Acta hortic. 1995;378:71-80.
56. Piñón SM, Camacho EF, Kuchen B. Constrained predictive control of a greenhouse. In: 15th IFAC World Congress, Barcelona, Spain; 2002.
57. Ponce P, Molina A, Cepeda P, Lugo E, MacCleery B. Greenhouse design and control Boca Raton, FL, USA, CRC Press. 2014;411.
58. Radojević N, Kostadinović D, Vlajković H, Veg E. Microclimate control in greenhouses. FME Trans. 2014;42(2):167-171.
59. Robledo FP, Martin LV. Aplicatión De Los Plásticosem La Agricultura. Mundi-Prensa, Madrid. 1981;552
60. Rodríguez F, Berenguel M, Arahal MR. Feed Forward Controllers for Greenhouse Climate Control Based on Physical Models. ECC01, Porto, Portugal; 2001.
61. Runkle ES, Heins RD. Manipulating the light environment to control flowering and morphogenesis of herbaceous plants. International Symposium on Artificial Lighting in Horticulture. 2005;(5)711: 51-60.
62. Sabir N, Singh B. Protected cultivation of vegetables in global arena: A review. Indian J. Agric. Sci. 2013;83(2):123-135.
63. Sanchez-Guerrero MC, Lorenzo P, Medrano E, Castilla N, Soriano T, Baille A. Effect of variable Carbon dioxide enrichment on greenhouse production in mild winter climates. Agric. For. Meteorol. 2005;132:244-252.
64. Santosh DT, Tiwari KN, Singh VK, Reddy RG. Micro Climate Control in Greenhouse. Int. J. Curr. Microbiol. Appl. Sci. 2017;6(3):1730-1742.
65. Sassenrath GF, Heilman P, Luschei E, Bennett GL, Fitzgerald G, Klesius P, Zimba PV. Technology, complexity and change in agricultural production systems. J. Agric. Food Syst. 2008;23(4):285-295.
66. Shahak Y, Lahav T, Spiegel E, Philosophadas S. Growing aralia and monstera under coloured shade nets. Olam Poreah. 2002;13:60-62.
67. Shamshiri R, Ismail WIW. A review of greenhouse climate control and automation systems in tropical regions. J. Agric. Sci. 2013;2(3):176-183.
68. Shelly MP, Lloyd GM, Park GR. A review of the mechanisms and methods of humidification of inspired gases. Intensive Care Med. 1988;14(1):1-9.
69. Sigrimis N, Rerras N. A linear model for greenhouse control. Trans ASAE. 1996;39(1):253-261.
70. Silva RS, Kumar L, Shabani F, Picanço MC. Assessing the impact of global warming on worldwide open field tomato cultivation through CSIRO-Mk3· 0 global climate model. J. Agric. Sci. 2017;155(3):407-420.
71. Singh MC, Singh JP, Singh KG. Development of a microclimate model for prediction of temperatures inside a naturally ventilated greenhouse under cucumber crop in soilless media. Comput. Electron. Agric. 2018;154:227-238.
72. Singh MC, Yousuf A, Singh JP. Greenhouse microclimate modeling under cropped conditions-A review. Res. Environ. Life Sci. 2016;9:1552-1557.

73. Soussi M, Chaibi MT, Buchholz M, Saghrouni Z. Comprehensive Review on Climate Control and Cooling Systems in Greenhouses under Hot and Arid Conditions. J. Agron. 2022;12(3):626.
74. Tap F, Van willigenburg LG, Van straten G. Receding horizon optimal control of greenhouse climate based on the lazy man weather prediction. 13th IFAC World Congress, San Francisco, USA. 1996;387-392.
75. Vadiee A, Martin V. Energy management in horticultural applications through the closed greenhouse concept, state of the art. Renew. Sustain. Energy Rev. 2012;16(7):5087-5100.
76. Von Elsner B, Briassoulis D, Waaijenberg D, Mistriotis A, Von Zabeltitz C, Gratraud J, Suay-Cortes R. Review of structural and functional characteristics of greenhouses in European Union countries: Part I, design requirement. J. Agric. Eng. Res. 2000;75(1):1-16.
77. Walker JN. Predicting temperature in ventilated greenhouses. *Trans.* ASABE. 1965;8(3):445-448.
78. Wittwer SH, Castilla N. Protected cultivation of horticultural crops worldwide. Horttechnology. 1995;5(1):6-23.
79. Zhang C, Zhang W, Yan H, Ni Y, Akhlaq M, Zhou J, Xue R. Effect of micro–spray on plant growth and chlorophyll fluorescence parameter of tomato under high temperature condition in a greenhouse. Sci. Hortic. 2022;306:111441.
80. Zhang S, Mahrer Y, Margolin M. Predicting the microclimate inside a greenhouse: an application of a one-dimensional numerical model in an unheated greenhouse. Agric. For. Meteorol. 1997;86:291-297.

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