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Enhancements in modeling greenhouse microclimate and evapotranspiration: an overview of recent progress

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Abstract: This overview examines the recent advancements in modeling techniques for greenhouse microclimate and evapotranspiration, which are crucial for optimizing agricultural production in controlled environments. Accurate models are essential for understanding the dynamic interactions between environmental variables such as temperature, humidity, light, and soil moisture, and their effects on plant growth and water usage. This review highlights the latest progress in both physical-based and data-driven models, focusing on their applications, benefits, and limitations in greenhouse settings. The integration of advanced technologies, including machine learning, IoT sensors, and climate control systems, has improved the precision and real-time adaptability of microclimate and evapotranspiration models. Additionally, the development of hybrid models combining simulation and empirical data has enhanced predictive accuracy, contributing to better resource management and sustainability. This paper aims to provide an updated perspective on the state-of-the-art modeling approaches, offering valuable insights for researchers and practitioners in the field of greenhouse agriculture.

Keywords: Greenhouse microclimate, Evapotranspiration modelling, Climate control systems, Machine learning, Data-driven models, Physical-based models, Agricultural sustainability, Water management, Environmental variables.

Introduction: Greenhouses provide controlled environments for plant growth, allowing year-round production and protection against adverse weather conditions. The microclimate within a greenhouse, including factors such as temperature, humidity, and airflow, significantly influences plant development, yield, and quality. Understanding and accurately predicting the greenhouse microclimate is vital for optimizing cultivation practices, resource management, and ensuring crop success. Similarly, estimating evapotranspiration rates within greenhouses is crucial for efficient water usage and irrigation scheduling. Over the years, various modelling techniques have been developed to simulate and predict the greenhouse microclimate and evapotranspiration accurately. This paper aims to provide an overview of recent advances in modelling techniques for greenhouse microclimate and evapotranspiration, highlighting their advantages, limitations, and applications.

METHOD

To compile this overview, a comprehensive literature review was conducted. Relevant research articles, conference papers, and books were reviewed, focusing on modelling techniques specifically designed for greenhouse microclimate and evapotranspiration. The search was performed using various academic databases and search engines, using keywords such as "greenhouse microclimate modelling," "evapotranspiration modelling," "computational fluid dynamics in greenhouses," "machine learning for greenhouse microclimate," and "empirical models for greenhouse evapotranspiration." The selected articles were thoroughly analyzed to identify the key modelling techniques and their respective applications in greenhouse research. Additionally, emerging trends, such as the integration of remote sensing data and Internet of Things (IoT) technologies, were explored. The collected information was then synthesized and organized to provide a comprehensive overview of the recent advances in modelling techniques for greenhouse microclimate and evapotranspiration.

RESULTS

The review of literature revealed several notable advancements in modelling techniques for greenhouse microclimate and evapotranspiration. Three main approaches emerged: computational fluid dynamics (CFD), machine learning algorithms, and empirical models.

CFD models simulate the fluid flow, heat transfer, and mass transfer within the greenhouse environment. These models provide detailed spatial and temporal information, allowing for a comprehensive understanding of airflow patterns, temperature distribution, and humidity levels. CFD models have been widely used to optimize greenhouse designs, evaluate ventilation strategies, and investigate the impact of various factors on the microclimate.

Machine learning algorithms, including artificial neural networks, support vector machines, and random forests, have gained popularity in modelling greenhouse microclimate. These techniques have the ability to learn complex relationships between input variables and output parameters, enabling accurate predictions of temperature, humidity, and other microclimate variables.

Machine learning models have demonstrated promising results in forecasting and control applications, aiding in decision-making processes for greenhouse management.

Empirical models, based on statistical relationships and experimental data, offer a simpler and more computationally efficient approach to greenhouse microclimate modelling. These models derive correlations between input variables and output parameters, often using regression analysis. Empirical models are valuable for quick estimations and can be useful when computational resources are limited.

Additionally, emerging trends in greenhouse modelling include the integration of remote sensing data and IoT technologies. Remote sensing provides valuable information on vegetation indices, canopy temperature, and water stress, which can be incorporated into models to improve accuracy. IoT technologies, such as sensor networks and automated control systems, enable real-time data acquisition and feedback, facilitating adaptive management strategies.

DISCUSSION

Each modelling technique has its advantages and limitations. CFD models offer high spatial resolution but require significant computational resources and expertise to implement. Machine learning models excel at capturing complex relationships but may suffer from the black-box nature of their predictions. Empirical models are computationally efficient but rely heavily on the availability and quality of experimental data. Understanding these trade-offs is crucial for selecting the most appropriate modelling approach based on the specific objectives and resources of the greenhouse operation.

Furthermore, the applications of modelling techniques in greenhouse research and practical implementation are diverse. Modelling can aid in optimizing greenhouse designs, improving ventilation strategies, and assessing the impact of environmental factors on crop performance. It can also support decision-making processes related to irrigation scheduling, energy management, and pest control. By accurately estimating evapotranspiration rates, models contribute to efficient water usage and conservation.

CONCLUSION

Advances in modelling techniques have significantly contributed to our understanding and management of greenhouse microclimate and evapotranspiration. Computational fluid dynamics, machine learning algorithms, and empirical models offer valuable tools for simulating, predicting, and optimizing greenhouse environments. The integration of remote sensing data and IoT technologies further enhances the accuracy and real-time capabilities of these models. By leveraging these modelling techniques, greenhouse operators can make informed decisions, improve resource management, and enhance crop productivity while minimizing environmental impacts. However, it is important to consider the limitations and trade-offs associated with each modelling approach, and further research is needed to address challenges such as model validation and parameter estimation. Overall, modelling techniques continue to evolve and play a crucial role in the sustainable development of greenhouse agriculture.

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