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Advancements in Crop Water Modelling: Algorithmic Developments and Parameter Optimization Strategies for Sustainable Agriculture: A Review

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Abstract: This paper presents a review on algorithm development and crop water modelling with a focus on optimizing significant parameters related to crop factors, soil factors, and weather factors. The accurate representation and optimization of these parameters are crucial for reliable predictions and effective decision-making in agricultural practices. The objective of this review is to analyse the existing literature on algorithm development, parameter optimization techniques, and their application in crop water modelling, specifically emphasizing the importance of crop factors, soil factors, and weather factors. The review concludes with a discussion on the key findings and future directions in algorithm development and optimization for crop water modelling. It highlights potential research gaps and challenges that need to be addressed to improve the accuracy and efficiency of crop water modelling. The impact of optimized modelling approaches on sustainable agricultural practices and water management is also discussed. Overall, this comprehensive review provides valuable insights into the importance of algorithm development, optimization, and parameter selection in crop water modelling, specifically focusing on crop factors, soil factors, and weather factors.

Keywords: Algorithm development, Crop factor, Crop water modelling, Environment factor, Parameter optimization, Soil factor.

Introduction

Algorithm development and modelling played a crucial role in agricultural research by providing valuable tools to understand and optimize various processes. When it came to coconut water modelling, algorithms and models enabled researchers to simulate and predict the behaviour of coconut plants in response to different factors (Subeesh & Mehta, 2021). By accurately representing the complex interactions between crop factors, soil factors, and weather factors, these models contributed to more efficient water management and sustainable coconut cultivation practices (Thomas *et al.*, 2018).

Crop water modelling involved simulating the water requirements of crops to optimize irrigation practices. The optimization process aimed to determine the best values for significant parameters related to crop factors, soil factors, and weather factors. The optimization process in crop water modelling typically involved techniques such as genetic algorithms, particle swarm optimization, simulated annealing, fuzzy logic, or machine learning algorithms (Wu *et al.,* 2022). These approaches helped find the best values for significant parameters by minimizing the difference between simulated and observed data, maximizing crop yield, or optimizing water use efficiency as shown in fig. (1).

Optimizing parameters related to crop factors, soil factors, and weather factors was essential in coconut water modelling for several reasons. Firstly, accurate parameter values ensured that the model accurately reflected the real-world conditions, leading to reliable predictions. Secondly, optimization allowed researchers to determine the best values for these parameters, enabling more effective decision-making in terms of irrigation scheduling, nutrient management, and overall crop management strategies (Nti *et al.,* 2023).

By finding the optimal balance between these factors, coconut growers could achieve better yields, improved resource efficiency, and reduced environmental impact (Mohan Kumar & Kunhamu, 2022). Fig. (1a) showed the oil water balance components for evapotranspiration model, (b) Flowchart for Evapotranspiration and (c) FAO Penman-Monteith method.

The objective of this review was to comprehensively analyze the development of algorithms and models for coconut water modelling, with a particular emphasis on the optimization process to determine the best values for significant parameters related to crop factors, soil factors, and weather factors.

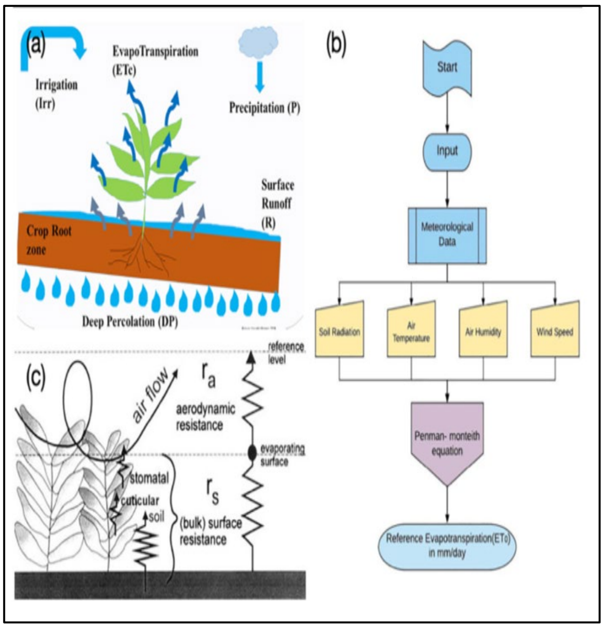

Fig. (1): (a) Soil water Balance components for evapotranspiration model (b) Flowchart for Evapotranspiration Reference (Jha *et al.,* 2019); (c) FAO Penman-Monteith method.

Data-driven algorithms in agriculture

The AquaCrop model's algorithms were comprehensively reviewed, detailing the calculation of reference evapotranspiration, crop water requirements, root zone water balance, crop growth stages, and yield formation. The incorporation of crop-specific parameters, like crop coefficients and stress response parameters, to capture variations among different crops and cultivars was discussed. The article emphasized AquaCrop user-friendly interface, input data requirements (including climate data, soil properties, and crop characteristics), and the calibration process using field observations to enhance accuracy. Limitations and uncertainties were also addressed, including the need for site-specific calibration, complexities in representing water stress-crop growth interactions, and model sensitivity to input parameters (Hsiao *et al*., 2009).

A thorough review of data-driven algorithms in agriculture categorized them into statistical models, machine learning, artificial intelligence, and optimization methods. The principles, advantages, and limitations of each category were explored, focusing on applications like crop yield prediction, disease detection, pest management, irrigation scheduling, and precision agriculture. Specific examples highlighted key findings and contributions in each area. The potential benefits included improved resource management, higher productivity, reduced environmental impact, and enhanced decision support systems. Interdisciplinary collaboration between agriculture and computer science was stressed for maximizing these approaches (Girsang, 2023).

Agricultural water scarcity was addressed by proposing a fuzzy-based irrigation algorithm for wheat crops. Deficit irrigation, supplying less water than the crop's full requirements, mitigated water scarcity. Determining suitable deficit irrigation levels involved complex considerations of crop and environmental factors. The innovative fuzzy-based algorithm, utilizing linguistic variables and membership functions, accommodated agricultural uncertainties. This approach incorporated soil moisture, crop water stress index, and weather factors (temperature and humidity) for irrigation decisions. Field experiments validated the algorithm's effectiveness, achieving water conservation while preserving crop yield. By considering dynamic interactions among soil, crop, and weather conditions, the algorithm provided nuanced, context-specific irrigation solutions (Bouman & Tuong, 2001).

The simulated annealing algorithm for crop water allocation was introduced, showcasing its effectiveness through a case study. The algorithm successfully balanced water availability and crop water needs, resulting in higher yields compared to traditional methods. Its systematic approach explored various solutions and converged toward the optimal one, addressing complexities efficiently. Notably, the algorithm handled constraints while maximizing crop yield, enhancing its applicability in agricultural water resource management. Economic considerations and water constraints were emphasized, guiding optimal crop water allocation decisions (Huang *et al.*, 2020).

An enhanced PSO algorithm tailored for crop irrigation scheduling was introduced. Modifications focused on improving convergence speed and accuracy, rendering it ideal for irrigation applications. Through a case study, the algorithm outperformed traditional methods, ensuring efficient irrigation and water conservation without compromising crop yield. Its adaptability to diverse factors like soil moisture and weather conditions showcased its effectiveness. The algorithm's ability to navigate complex optimization problems offered reliable irrigation schedules, promoting water efficiency and sustainability in agriculture (Peng *et al.*, 2019).

A novel approach to optimizing crop irrigation was tackled using an enhanced genetic algorithm (GA). This heuristic optimization technique, inspired by natural selection and genetic inheritance, evolved candidate solutions iteratively to find the optimal irrigation schedule. Factors like crop water needs, soil moisture, weather data, and irrigation constraints were considered. By minimizing water usage while ensuring optimal crop growth, the modified GA introduced new genetic operators like crossover and mutation, enhancing its diversity and exploration capabilities. This research presented a potent tool for optimizing irrigation schedules, crucial for agricultural water management and sustainability efforts (Teimoury *et al*., 2013).

The integration of genetic algorithm (GA) and simulated annealing (SA) for optimal irrigation scheduling was proposed. Both metaheuristic algorithms iteratively explored solution spaces for complex problems. The research delved into irrigation scheduling optimization, detailing parameters and mechanisms of GA and SA tailored to address scheduling complexities. Practical applications suggested implementation in decision support systems for effective irrigation management. This integration offered a robust solution, aiding farmers and water managers in optimizing schedules, ensuring sustainable water use, reduced consumption, and enhanced crop efficiency (UI Haq & Anwar*,* 2010).

An analysis of Iranian water management literature scrutinized academic papers, reports, and government documents. Prevailing practices, policies, and institutions were critiqued, spotlighting challenges like water scarcity, inefficient irrigation, unsustainable groundwater use, deficient infrastructure, and governance flaws. The study underscored these issues' sectoral impacts while stressing interdisciplinary collaboration among academia, government, and stakeholders. The findings emphasized the necessity of holistic research encompassing social, economic, and environmental dimensions (Santos *et al*., 2023).

The optimization of irrigation scheduling for cotton was explored, considering various factors such as soil moisture levels, evapotranspiration rates, and crop growth stages. A mathematical model was developed that integrated these factors and used genetic algorithms to search for the optimal irrigation schedule. The results demonstrated the effectiveness of genetic algorithms in optimizing irrigation scheduling, leading to improved crop yields and more efficient water use, contributing to sustainable agricultural practices (Nguyen *et al*., 2017).

The comparison of genetic algorithms with conventional methods like the FAO Penman-Monteith method and the CROPWAT model for irrigation scheduling was conducted. Factors such as climate data, crop needs, soil properties, and water resources were considered. Genetic algorithms minimized water use while maximizing crop yield. Results revealed their approach surpassed classical methods, enhancing water productivity and reducing consumption in the Zayandehrood River Basin (Al-Amin *et al*., 2022).

A novel approach based on PSO was proposed to address water scarcity and efficient water allocation in agricultural systems. Various factors influencing crop water allocation, including crop water requirements, soil properties, irrigation system characteristics, and available water resources, were considered. An optimization problem was formulated to maximize crop yield while minimizing water consumption and considering practical constraints (Abdel Magid & Mazumder, 2013).

The vital nexus of water and nitrogen management in crop production, particularly in water-scarce regions, was highlighted. Existing water-nitrogen coupling models were critically assessed, identifying limitations in representing the intricate interplay between water, nitrogen, and maize growth. An enhanced model integrated water and nitrogen factors, considering soil water content, soil nitrogen levels, crop phenology, and environmental factors. The improved model demonstrated superior predictive accuracy compared to existing ones, offering precise management insights (De La Rosa *et al.*, 2016).

The challenge of optimizing irrigation scheduling for efficient water use and crop productivity was addressed through the Harmony Search algorithm. This metaheuristic algorithm, inspired by musical improvisation, dynamically adjusted irrigation timing and amount. By maximizing crop yield and minimizing water use, it considered factors like soil moisture, crop water needs, and climate data. Field experiments compared Harmony Search with fixed schedules and threshold-based methods, illustrating its superiority in balancing crop water requirements and soil moisture availability (Huang *et al.*, 2015).

A fuzzy control algorithm for irrigation management, considering crop water needs, weather conditions, and soil moisture levels, was introduced. This approach provided adaptive irrigation management, allowing for adjustments based on real-time data. The fuzzy logic system integrated expert knowledge and dynamic inputs to optimize water application. Field tests demonstrated the algorithm's effectiveness in improving water use efficiency and crop yield compared to conventional methods (Rohilla *et al.*, 2016).

Crop factors

Crop factors include parameters that characterize the specific crop being grown, such as crop type, growth stage, and crop coefficient. Crop coefficient Kc (Table 1) represents the crop's water requirement relative to reference evapotranspiration (ETo) and is a key parameter in crop water modelling. Optimization techniques can be employed to estimate Kc values at different growth stages by considering factors such as leaf area index, canopy cover, and crop physiological processes. This optimization process helps in accurately estimating crop water needs and scheduling irrigation.

Table (1): Single (time-averaged) crop coefficients, K_c, and mean maximum plant heights for non-stressed, well-managed Tropical Fruits and Trees in subhumid climates (RH_{min} 45%, u_2 » 2 m.s^{-1}) for use with the FAO Penman-Monteith ET_o.

Crop	$K_{c\ ini}$	$K_{c\ mid}$	$K_{c\ end}$
(Banana) 1st year	0.50	1.10	1.00
(Banana) 2nd year	1.00	1.20	1.10
Cacoa	1.00	1.05	1.05
(Coffee) Bare ground cover	0.90	0.95	0.95
(Coffee) With weeds	1.05	1.10	1.10
Date palms	0.90	0.95	0.95
Palm trees	0.95	1.00	1.00

Source: (Allen *et al.,* 1998)

A comprehensive review of crop water use models and their applications in China aimed to summarize existing models for estimating crop water requirements and highlight their practical applications within the Chinese agricultural context. Challenges such as water scarcity, climate change, and increasing agricultural demands were emphasized, underscoring the need for reliable crop water use models. The paper provided a detailed overview of various models, including empirical, process-based, and remote sensing-based models, offering valuable insights into their effectiveness and applications (Qi *et al*., 2022).

A study on the calibration and validation of crop water balance models for deficit irrigation management at both field and irrigation system scales aimed to improve irrigation practices by accurately estimating crop water requirements and optimizing water use in water-limited environments. Results showed that the calibrated crop water balance models effectively predicted crop water requirements and optimized deficit irrigation management. These models proved to be accurate and useful for decision-making in water-limited environments, demonstrating their potential for achieving water savings while maintaining acceptable crop yields (Kanda *et al.,* 2021).

The significance of adopting participatory approaches and involving stakeholders in the decision-making process for sustainable water management in agriculture was highlighted. The paper emphasized the need for policy support, capacity building, and institutional reforms to promote effective water management practices. Successful water management strategies implemented in different regions were discussed, showcasing the practical applications and benefits of modern irrigation systems. Insights into potential water savings and productivity gains through improved water management practices were provided (Velasco Muñoz *et al*., 2022).

Implications for water management and decision-making were discussed, focusing on the potential of the CSM-CROPGRO-Cotton model to assist in optimizing irrigation scheduling, improving water use efficiency, and maximizing cotton yield in drip-irrigated systems. The study addressed the model's limitations and suggested areas for improvement, emphasizing the need for further validation and calibration with data from different locations and climatic conditions to enhance reliability and applicability (Li *et al*., 2020).

Various aspects of crop water management research, including irrigation techniques, water-saving strategies, and crop selection and management practices, were examined. The paper reviewed advancements in these areas and their implications for improving water use efficiency and agricultural productivity. Case studies and examples from research conducted in the semi-arid tropics highlighted successful crop water management practices and their impact on crop yields and water savings. The importance of participatory research and farmer involvement in adopting these practices was emphasized (Rojas-Valencia *et al*., 2011).

Methods and approaches for estimating crop water requirements, considering factors such as crop type, growth stage, climate, soil properties, and management practices, were discussed. The use of reference evapotranspiration (ET0) for determining crop water requirements was explored, along with the calculation and interpretation of crop coefficients (Kc) used to adjust ET0 for specific crop characteristics. Insights into variations in Kc values among different crops and growth stages were provided, highlighting the importance of accurate estimation for effective irrigation scheduling (Ramanathan *et al*., 2019).

Strategies and approaches for coping with water scarcity, including demand management, water conservation, efficiency improvements, and technological advancements, were discussed. The concept of virtual water trade and its potential in addressing water scarcity issues was explored. Case studies from various regions showcased successful water scarcity coping strategies, highlighting the importance of integrated water resources management, stakeholder engagement, and policy interventions in promoting sustainable water use (Rastogi *et al*., 2024).

Estimation of crop water requirements in different agro-ecological zones of Pakistan using the CROPWAT model was the focus of the study. The aim was to provide insights into water needs for crop production in various regions, considering specific agro-ecological conditions. Results presented estimated crop water requirements for each agro-ecological zone, highlighting variations in water needs among different crops and regions and the significance of site-specific estimations (Solangi *et al*., 2022).

Estimating crop water requirements using an adaptive neuro-fuzzy inference system (ANFIS) was the focus of the study, aiming to create a precise model by considering diverse influencing factors. The paper detailed the ANFIS methodology, including necessary inputs like climate, soil, and crop data, and discussed training procedures and parameter optimization. Advantages of ANFIS, such as flexibility, adaptability, and handling of input uncertainties, were emphasized, with suggestions for integrating real-time and remote sensing data to enhance accuracy (Esmaili *et al*., 2021).

A comprehensive review of irrigation management strategies in water-scarce conditions addressed challenges related to water scarcity, including crop water requirements, distribution systems, scheduling, and modern technologies. Deficit irrigation and partial root-zone drying (PRD) were emphasized for their principles and advantages. Modern tools like remote sensing, GIS, and decision support systems were discussed for their role in efficient water allocation and decision-making, providing valuable insights into sustainable irrigation practices amidst water scarcity (Nikolaou *et al*., 2020).

A survey of ranging and imaging techniques used in precision agriculture phenotyping focused on applying these techniques to gather data and extract valuable information about crops and their characteristics. Various ranging techniques, such as Light Detection and Ranging (LiDAR), laser scanners, and ultrasonic sensors, were reviewed. These techniques enable measurements of plant height, canopy structure, and volumetric data, contributing to the advancement of precision agriculture by enhancing crop management practices and improving productivity (Yandun *et al*., 2017).

Soil factors

Soil factors play a crucial role in determining the water availability and retention capacity for crops. Parameters such as soil type, soil moisture characteristics, hydraulic conductivity, and soil water holding capacity influence the irrigation requirements. Optimization techniques can be used to determine the soil parameters through field measurements, laboratory analysis, or calibration with observed data (Pinheiro *et al.,* 2019). These optimized soil factors enable precise estimation of water infiltration, drainage, and soil moisture dynamics, leading to efficient irrigation management. Fig (2) shows the conceptual diagram of a soil profile illustrating the multiple flow paths through which water moves through soil.

The efficiency and adequacy of landscape irrigation scheduling using different control technologies were investigated. The study focused on optimizing water use in landscape irrigation, considering the increasing demand for water-efficient irrigation practices. Field experiments were conducted to evaluate the performance of various irrigation control technologies in terms of scheduling efficiency and adequacy. The research findings indicated that the use of advanced control technologies, such as sensor-based and evapotranspiration-based controllers, significantly improved irrigation scheduling efficiency and adequacy compared to traditional time-based controllers (McCready & Dukes, 2011).

Fig. (2): Conceptual diagram of a soil profile illustrating the multiple flow paths through which water moves through soil (O'Geen, 2013).

The fundamental role of soil moisture in plant physiology and crop productivity was emphasized. The paper discussed various ways in which soil moisture affected plant growth, including its influence on seed germination, root development, nutrient uptake, photosynthesis, and water use efficiency. It also highlighted the interactive effects of soil moisture with other environmental factors, such as temperature and light, on crop performance. The review explored the response of different crops to varying levels of soil moisture, ranging from water stress to optimal conditions, and discussed the physiological and morphological adaptations exhibited by plants under water-limited conditions (Bitew & Workie, 2017).

The relationship between soil properties and crop productivity, with a specific emphasis on the wine industry, was the focus of discussion. The chapter explored the importance of soil texture, structure, and composition in relation to crop growth. It examined the impact of soil factors such as pH, organic matter content, cation exchange capacity, and nutrient availability on plant nutrition and overall crop performance. Additionally, it addressed the role of soil physical properties, including water infiltration, drainage, and aeration, in shaping plant growth and development. The concept of soil fertility and the role of essential nutrients in crop production were also explored, discussing the mechanisms by which different soil properties influenced nutrient availability and uptake by plants, and how nutrient deficiencies or imbalances could limit crop growth (Oliver *et al.,* 2013).

The detrimental effects of soil erosion on crop productivity were discussed, along with potential mitigation strategies. The study began by highlighting the importance of soil as a vital natural resource for sustainable agriculture and emphasized that soil erosion posed a significant threat to global food security and the long-term productivity of agricultural lands. The various processes and factors contributing to soil erosion, including water erosion, wind erosion, and human activities such as improper land management and deforestation, were explained (Kopittke *et al.,* 2019).

The influence of soil pH on plant growth and nutrient availability was examined. The chapter provided a comprehensive overview of the effects of soil pH on different nutrient elements, including macronutrients (such as nitrogen, phosphorus, and potassium) and micronutrients (such as iron, manganese, and zinc). It explored how soil pH affected the solubility, mobility, and availability of these nutrients, and consequently, their uptake and utilization by plants. The physiological and biochemical processes influenced by soil pH were discussed, including nutrient uptake mechanisms, nutrient transport within the plant, and nutrient utilization in various metabolic pathways. Interactions between soil pH and other soil properties, such as cation exchange capacity, organic matter content, and microbial activity, which collectively affected nutrient availability and plant growth, were also addressed (Ferrarezi *et al.,* 2022).

The effects of soil fertility on crop productivity and nutrient use efficiency in China were evaluated. The researchers aimed to understand the relationships between soil fertility, crop growth, and nutrient utilization, and to identify strategies for improving agricultural sustainability and productivity. The article provided an overview of the importance of soil fertility in supporting crop growth and development, discussing essential nutrients required by plants and their role in various physiological processes, such as photosynthesis, nutrient uptake, and metabolism. The need for a balanced and adequate supply of nutrients in the soil for optimal crop performance was emphasized (Shang *et al*., 2014).

The long-term effects of tillage, cropping systems, and nitrogen fertilization on soil organic carbon (SOC) and total nitrogen (TN) in semi-arid Montana, USA, were investigated. The researchers aimed to understand how different agricultural practices influenced soil fertility and nutrient dynamics in a region characterized by limited precipitation and fragile soil conditions. Results from a 16-year field experiment comparing different tillage systems (conventional tillage and no-till), cropping systems (continuous spring wheat and spring wheat-barley-fallow rotation), and nitrogen fertilization rates were presented, with measurements of SOC and TN levels in the topsoil and subsoil at various intervals to assess the impact of different treatments on soil nutrient status (Mazzoncini *et al*., 2011).

A comprehensive meta-analysis was conducted to investigate the effects of soil moisture on crop growth and water use efficiency (WUE). The researchers aimed to provide a quantitative synthesis of existing studies to better understand the relationship between soil moisture levels and crop performance, as well as the implications for water management in agriculture. The study involved systematically collecting and analyzing data from previous studies that investigated the effects of soil moisture on crop growth and WUE. Relevant studies were identified from various databases and publications, and data related to soil moisture levels, crop growth parameters, and WUE indicators were extracted (Wang *et al*., 2021).

Environment factors

Environment factors, including rainfall, temperature, humidity, solar radiation, and wind speed, significantly impacted crop water requirements. Optimization techniques were employed to analyze historical weather data and develop predictive models to estimate future weather patterns. These models considered the relationships between weather variables and crop water requirements to forecast irrigation demands accurately. Optimization also involved fine-tuning weather inputs to match observed data, resulting in improved crop water modelling accuracy (Li *et al*., 2009).

Climate change posed significant challenges to global food security by altering temperature patterns, precipitation regimes, and increasing the frequency of extreme weather events. These changes directly impacted crop growth, development, and yield. The key climatic factors affecting crop production, including temperature, rainfall, and carbon dioxide (CO2) levels, were examined, and their complex interactions were discussed. The paper reviewed empirical studies and modelling approaches to assess the effects of climate change on major crops such as wheat, rice, maize, and soybeans. It was highlighted that crop responses to climate change were crop-specific and depended on various factors including the crop's sensitivity to temperature and water stress, phenological stages, and the availability of genetic resources for adaptation (Lobel & Gourdji 2012).

The influence of temperature on crop growth, development, and productivity was comprehensively reviewed. The impact of both high and low temperatures on crop performance was discussed. Extreme temperatures were explained to lead to physiological stress, disrupt metabolic activities, and affect photosynthesis, respiration, transpiration, and nutrient uptake in plants (Waraich *et al.,* 2012). The potential for heat stress and cold stress to cause cellular damage, reduce crop growth rates, and impact crop quality and yield was also addressed. Additionally, the concept of crop-specific temperature requirements and optimal temperature ranges for different stages of crop development, including growing degree days and the importance of accumulated heat units in determining crop phenology and maturity, was explored (Hatfield, 2015).

The effects of light intensity on photosynthesis, chlorophyll fluorescence, and reactive oxygen species (ROS) production in cucumber leaves were investigated. The researchers aimed to understand how varying light conditions affected the physiological processes and oxidative stress response of cucumber plants (Ashrostaghi *et al.,* 2022). The experiment involved subjecting cucumber plants to different light intensities and measuring various parameters related to photosynthesis and ROS production. Results showed that changes in light intensity significantly influenced the photosynthetic performance of cucumber leaves. Higher light intensities led to increased photosynthetic rates, indicating enhanced carbon assimilation and energy production (Liu *et al.*, 2019).

The effects of temperature stress on crops were explored, providing an in-depth analysis of the physiological, biochemical, and molecular responses of plants to both high and low temperature conditions. The review discussed how temperature stress influenced various physiological processes in plants, including photosynthesis, respiration, transpiration, and nutrient uptake. Mechanisms by which temperature stress affected these processes, leading to alterations in plant growth and development, were explained. The complex interplay between temperature stress and plant hormones, signalling pathways, and gene expression was also examined (Moore *et al.*, 2021).

The effects of temperature on plant growth and development were investigated. The authors reviewed existing literature to provide an overview of the complex relationships between temperature and various physiological processes in plants. The study focused on how temperature affected key aspects of plant growth and development, including germination, seedling establishment, vegetative growth, flowering, and fruit development. It explored optimal temperature ranges for these processes in different plant species and highlighted deviations from these ranges that could lead to adverse effects on plant growth (Bernal-Vicente *et al.*, 2018).

The effects of temperature on crop photosynthesis and metabolism were studied. The researchers focused on understanding the physiological and biochemical responses of crops to different temperature regimes and how these responses impacted their photosynthetic efficiency and overall metabolism. The article reviewed current literature and presented an overview of the complex interactions between temperature and photosynthesis in various crop species. The role of temperature in regulating the rates of key photosynthetic processes, including light absorption, electron transport, carbon fixation, and assimilate partitioning, was discussed (Song *et al*., 2014).

Conclusions

In this review, the study delved into the crucial area of algorithm development and crop water modelling, focusing on optimizing key parameters related to crop, soil, and weather factors within coconut cultivation. Algorithm development and modelling techniques were pivotal, offering invaluable insights into the intricate interplay between these factors. These insights enabled the precision required for accurate and efficient water management decisions. The selection and optimization of parameters such as plant physiology, soil moisture content, and weather elements demanded meticulous attention, underscoring the need for precise representation for effective decision-making and resource allocation.

Various algorithms and optimization techniques were employed in coconut water modelling, each with distinct strengths and limitations. To enhance accuracy, efficiency, and applicability across diverse agro-climatic conditions, future research should concentrate on exploring advanced algorithms and optimization approaches. Recommendations from this review advocated for the development of integrated models that comprehensively considered the interactions between crop, soil, and weather factors. Such models would provide holistic insights into coconut water requirements, paving the way for precise predictions and optimized water management practices. Additionally, efforts should be directed toward improving parameter estimation methods, leveraging advanced sensing technologies, and employing machine learning techniques to enhance accuracy and reduce uncertainties in coconut water modelling.

Validation of these models with extensive field data from varied coconut-growing regions was deemed imperative to assess accuracy and reliability, allowing for the identification and rectification of shortcomings. Furthermore, considering the potential impacts of climate change on coconut cultivation, integrating climate change scenarios into modelling became crucial. This integration would facilitate the assessment of future water requirements, identification of risks, and formulation of adaptive water management strategies for sustainable coconut cultivation.

Encouraging interdisciplinary collaboration between agricultural scientists, hydrologists, computer scientists, and related disciplines was highlighted as vital. Such collaboration fosters innovation, knowledge exchange, and the development of robust and practical modelling frameworks for coconut water management. Addressing these recommendations stands to significantly enhance the understanding and optimization of key parameters in coconut water modelling, ultimately leading to improved water management practices, sustainable coconut cultivation, and enhanced resource efficiency.

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Contributions of authors

ASS: Corresponding author, first author, and responsible for writing the manuscript.

AW: PhD supervisor, project leader, conceptualized the paper, and served as a reviewer.

SAA: PhD co-supervisor, conducted data analysis, reviewed the manuscript, and contributed to the methodology concept.

WMY: Main project leader, PhD co-supervisor, responsible for project administration, and served as a reviewer.

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Conflicts of interest

The authors declare no conflict of interest.

Ethical approval

This study was conducted following the ethical guidelines and standards set by the Universiti Putra Malaysia (UPM) Ethics Committee. All procedures performed in the study involving human participants or animals were in accordance with the ethical standards of UPM.

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التطورات في نمذجة مياه المحاصيل: تطوير الخوارزميات واستراتيجيات تحسين الخصائص للزراعة المستدامة: مراجعة

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المستخلص: تقدم هذه الورقة مراجعة حول تطوير الخوارزميات ونمذجة المياه الزراعية مع التركيز على تحسين المعلمات الهامة المتعلقة بعوامل المحاصيل، وعوامل التربة، وعوامل الطقس. إن التمثيل الدقيق وتحسين هذه المعلمات أمران حاسمان للتنبؤات الموثوقة واتخاذ القرارات الفعالة في الممارسات الزراعية. هدف هذه المراجعة هو تحليل الأدبيات الحالية حول تطوير الخوارزميات، وتقنيات تحسين المعلمات، وتطبيقاتها في نمذجة المياه الزراعية، مع التأكيد بشكل خاص على أهمية عوامل المحاصيل، وعوامل التربة، وعوامل الطقس. تختتم المراجعة بمناقشة النتائج الرئيسية والاتجاهات المستقبلية في تطوير الخوارزميات وتحسينها لنمذجة المياه الزراعية .تبرز المراجعة الفجوات والتحديات البحثية المحتملة التي تحتاج إلى معالجة لتحسين دقة وكفاءة نمذجة المياه الزراعية .كما يتم مناقشة تأثير الأساليب المُحسّنة على الممارسات الزراعية المستدامة وإدارة المياه. بشكل عام، توفر هذه المراجعة الشاملة رؤى قيمة حول أهمية تطوير الخوارزميات، وتحسينها، واختيار المعلمات في نمذجة المياه الزراعية، مع التركيز بشكل خاص على عوامل المحاصيل، وعوامل التربة، وعوامل الطقس.

الكلمات المفتاحية: تطوير الخوارزميات، عامل المحصول، نمذجة مياه المحاصيل، العوامل البيئية، تحسين المعلمات، عامل التربة.