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Modeling Grain Yield Formation in Rice Based on Temperature and Water Management

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Abstract Rice yield formation is jointly influenced by temperature and water conditions; these two factors not only determine the progression of rice growth and development but also directly impact photosynthesis, dry matter accumulation, and grain-filling efficiency. With the intensification of global climate change and the increasingly prominent issue of agricultural water scarcity, the development of rice yield formation models-based on the management of temperature and water-holds significant importance for enhancing rice production efficiency and ensuring food security. This paper systematically reviews the physiological and ecological foundations of rice yield formation, with a particular focus on analyzing the mechanisms by which temperature, water, and their interactions influence rice growth and yield components. Furthermore, it compares and summarizes empirical statistical models, process-based mechanistic models, and AI-driven predictive models, while exploring the application of model parameterization, calibration, and validation methods in yield forecasting. Additionally, by incorporating typical management strategies-such as alternate wetting and drying (AWD) irrigation-the paper analyzes rice yield simulation results under various hydrothermal conditions and evaluates their practical value in agricultural applications. The findings indicate that rational temperature regulation and water management can significantly enhance water-use efficiency and yield stability, and that the fusion of multi-source data coupled with intelligent modeling will constitute a key direction for future research on rice yield modeling. This paper serves as a theoretical reference and provides technical support for precision agriculture, the optimal allocation of water resources, and the management of stable rice production within the context of climate change.
Keywords Rice yield model; Temperature regulation; Water management; Crop simulation; Precision agriculture

1 Introduction

Rice is a cornerstone of global food security, feeding more than half of the world's population and supplying a large share of calories in Asia and many low-income regions (Rezvi et al., 2022). However, climate change is already exerting measurable impacts on rice production through shifts in temperature regimes and altered water availability, contributing to observed yield declines in major producing and food-insecure areas (Algarni et al., 2025). Maintaining and increasing rice yields under these pressures requires a quantitative understanding of how grain yield is formed as a function of temperature and water dynamics across critical growth stages (Shrestha et al., 2022). Process-based modeling that links environmental drivers with physiological processes offers a way to anticipate risks, design adaptive management, and support policy decisions for sustainable rice systems (Farooq et al., 2023).

Rising temperatures threaten rice grain yield through both chronic warming and short, extreme events, especially around reproductive stages. High-temperature stress during booting and flowering increases spikelet sterility and alters yield components, with yield per plant declining sharply as heat degree days accumulate at these stages. Recent work also emphasizes that microclimate and organ temperature, rather than air temperature alone, determine sterility risk, indicating that accurate prediction requires modeling canopy and panicle temperature within the crop-water-atmosphere continuum. At the same time, irrigation water is becoming increasingly scarce, and meta-analyses show that water-saving irrigation strategies such as alternate wetting and drying can substantially reduce irrigation inputs and increase water productivity, although yield responses vary with climate and soil conditions. Integrating these temperature and water processes in yield formation models is therefore crucial for realistic projections under future climates.