7.2 Model construction and simulation results

Case-study modeling of AWD typically couples a calibrated crop growth module with an explicit water-balance representation of ponded depth, soil water status, and irrigation triggers. In a DSSAT-CERES-Rice application for central China, cultivar coefficients were first calibrated under observed AWD and non-AWD regimes, achieving normalized RMSE of 3%-10% for yield, biomass, evapotranspiration, irrigation, and leaf area index, indicating reliable capture of growth and water use across treatments. The calibrated model was then driven with historical climate sequences and AWD rules defined by reflooding thresholds, allowing simulation of grain yield and water productivity under contrasting hydrological years and irrigation strategies (Gao et al., 2023).

To better represent AWD hydrology, an improved ORYZA2000 framework integrated a new water-balance simulation tailored to intermittent flooding and drying, along with dynamic root-length growth and revised water-stress algorithms. Applied to paddy fields under CF and AWD in two Chinese regions, the enhanced model substantially improved the simulation of ponded water depth, irrigation and drainage volumes, evapotranspiration, and percolation, with Nash-Sutcliffe efficiencies for ponded depth of 0.82-0.94 and relative errors for total irrigation and drainage mostly within ±10%. Yield prediction remained comparable to or slightly better than the original version, demonstrating that explicit AWD parameterization can capture both water balance and yield formation with good accuracy.

7.3 Implications for sustainable rice production

Model-supported analyses clarify under which conditions AWD can save water without compromising yield, informing sustainable irrigation guidelines. Meta-analysis of 528 AWD-CF comparisons showed that, overall, AWD reduced yields by 5.4%, but mild AWD regimes did not significantly decrease yield, whereas severe AWD caused average losses of 22.6%, particularly in higher-pH and low-carbon soils. A broader synthesis of 3194 observations from 200 studies confirmed that AWD increased water-use efficiency by about 31% but imposed an average 6% yield penalty, and identified optimal thresholds (soil water potential > -15 kPa, water depth < 18.5 cm) and favorable soil conditions under which AWD can actually raise yields by up to 4-7% when combined with appropriate nitrogen, straw, or biochar management.

Process-based simulations extend these insights to long-term climate variability and regional planning. CERES-Rice modeling over 60 historical weather years showed that AWD often produced the highest yields among several water-saving schemes across wet, normal, and dry years, though other controlled irrigation-drainage strategies sometimes achieved greater irrigation and rainwater-use efficiency, suggesting context-specific trade-offs between yield maximization and water conservation (Gao et al., 2023). Global analyses indicate that implementing soil-water-potential-based AWD on suitable irrigated rice areas can increase water productivity over large fractions of Asia, particularly in India, Bangladesh, and central China, demonstrating that AWD-informed models can underpin strategies for sustainable intensification that jointly address food security and freshwater scarcity (Bo et al., 2024).

8 Challenges, Future Perspectives, and Conclusions

Despite substantial advances, rice yield projections under future climate remain highly uncertain. A meta-analysis of 111 studies showed large variability in simulated yield responses to changes in temperature, precipitation, radiation, and CO_2, reflecting differences in climate models, emission scenarios, and, critically, crop model structure and parameterization. Similarly, a multi-model intercomparison of 13 rice models found that spread among crop models exceeded that from 16 global climate models, and that individual models did not consistently reproduce yields across very cool and very warm sites, indicating structural weaknesses in representing temperature and CO_2 responses. Key physiological processes are still imperfectly captured. Sensitivity analysis of the 13-model ensemble identified biomass formation and harvest index responses to warming and elevated CO_2 as major sources of error, while most simulations assumed ideal water and nutrient management and ignored pests, diseases, and sub-optimal farmer practices. Meta-regression work further demonstrated that yield responses aggregate multiple interacting drivers (temperature, precipitation, CO_2, management), and that the choice of study sites, climate scenarios, and adaptation assumptions introduces additional unexplained variation into projected yield changes.