Optimal estimation of phenological crop model parameters for rice (*Oryza Sativa*)

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Introduction

Dynamic crop growth models are frequently used to study the response of crops to variation in environmental conditions, including climate change. Crop phenology affects simulated crop yield; thus, accurate modeling of development rates is critical.

Typically only a few parameters of phenology models are calibrated and default cardinal temperatures are used. This can lead to a temperature-dependent systematic phenology prediction error (systematic error). This systematic error is manifest in consistent over- or under-predictions of developmental rates as temperature changes.

- The objective of this study was to evaluate optimization approaches in the Oryza2000 and CERES-Rice phenology models to assess the importance of cardinal temperature optimization for model performance and systematic error.

Methods

- Oryza2000 and CERES-Rice phenology sub-models were used; thus, we only focused on the effect of temperature.
- Data on seven California rice cultivars were collected over three years (2102-14) at six locations (Table 1).
- Two optimization approaches were used to optimized all parameters (cardinal temperatures and developmental rate constants) in the model.
  - Single-stage (1Stg) from planting (PL) to heading (HD)
  - Three-stage (3Stg) from PL to panicle initiation (PI); PI to HD; and HD to physiological maturity (MT)
- We contrasted 3Stg and 1Stg to the "3Stg-Default" optimization approach in which cardinal temperatures were fixed using default values in Oryza2000 and CERES-Rice models.
  - These are 8, 30, and 42°C in Oryza2000 and 9, 33, and 42°C in CERES-Rice for base, optimum, and maximum temperature parameters, respectively.
- Systematic error was obtained by fitting a linear regression model of RMSE as a function of mean temperature during a given stage; thus a slope (β) closer to zero is preferred.
- Two optimization objectives were used: RMSE and RMSE-β. In RMSE, optimization was set to minimize the RMSE between predicted and observed duration to each stage. In RMSE-β, models optimized by minimizing β. However, he increase in RMSE was limited as the following: (RMSE-β < 1.5 × RMSE).

Table 1. Cultivars characteristics

Cultivar	Maturity	Grain type	Planting to panicle initiation (days)	Panicle initiation to heading (days)	Heading to physiological maturity (days)
CM101	Very Early	Short	46-56	25-36	13-23
L206	Very Early to Early	Long	46-58	27-39	7-21
M104	Very Early	Mediu	45-56	22-34	13-27
M202	Early	Mediu	47-58	31-45	14-29
M205	Early	Mediu	47-58	33-47	15-29
M206	Very Early to Early	Mediu	47-56	26-38	12-27
S102	Very Early	Short	46-56	24-35	14-26

Model performance

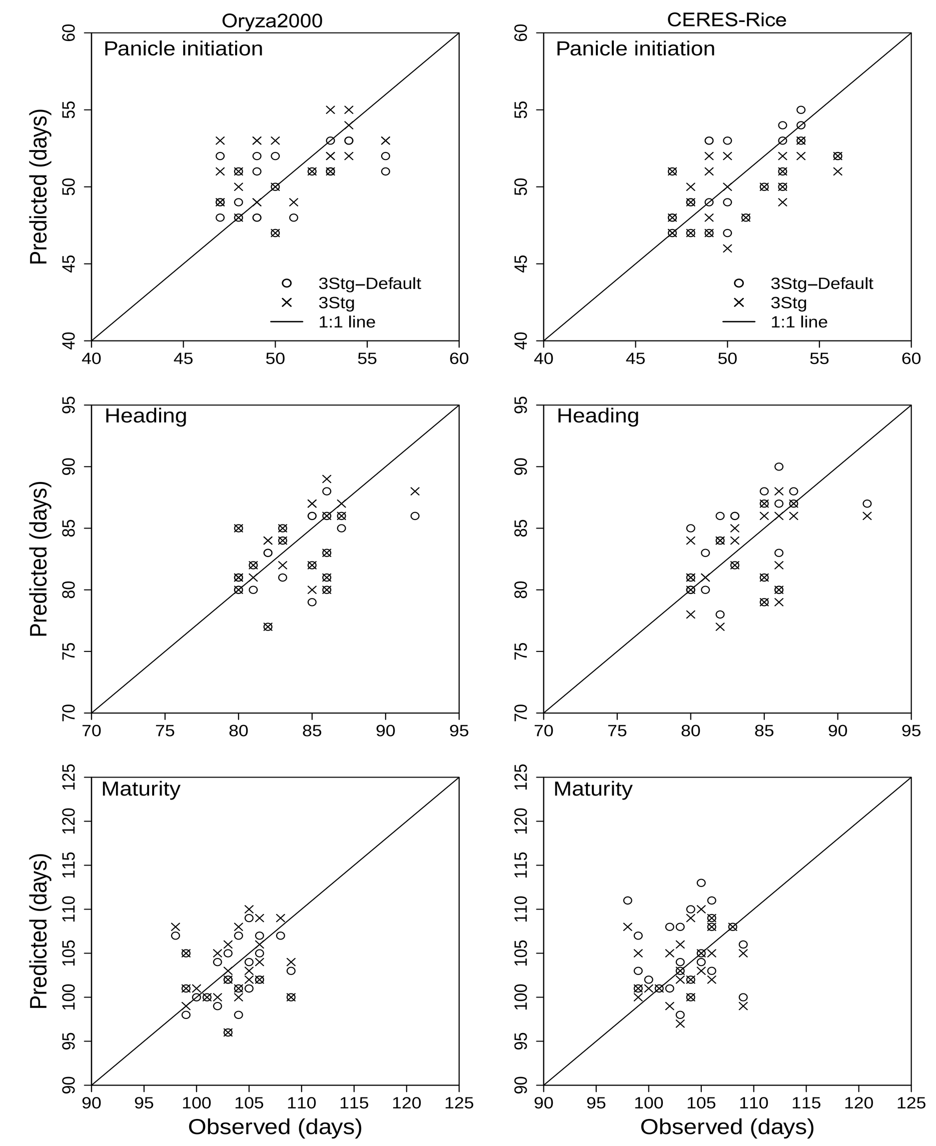

Fig1. For cultivar M206, observed and predicted duration (days) for panicle initiation, heading, and physiological maturity, with Oryza2000 and CERES-Rice three-stage default (3Stg-Default) and three-stage (3Stg) optimization approaches.

Optimization approaches

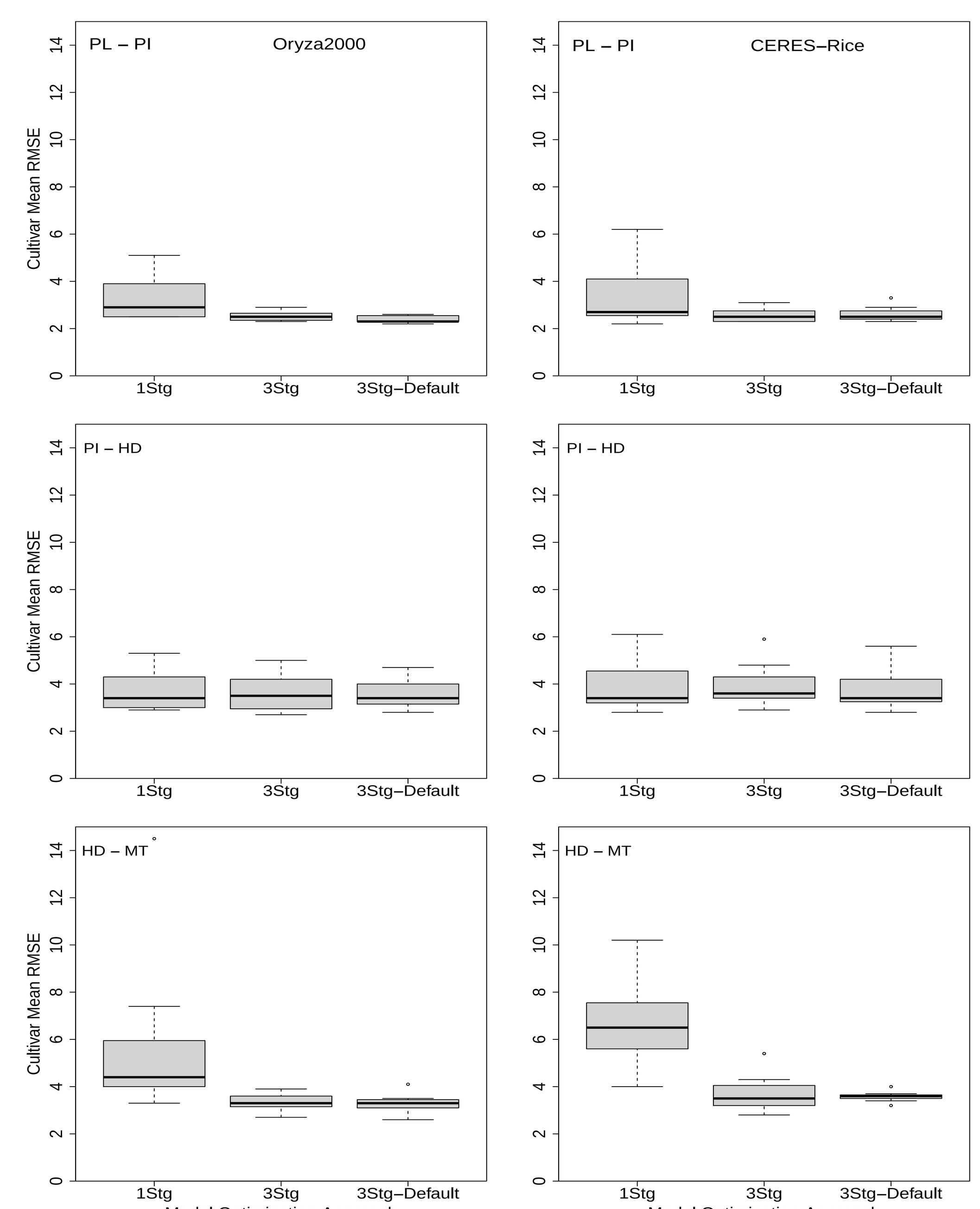

Fig. 2. Box and whisker plots of the cultivar mean RMSE for PL-PI, PI-HD, and HD-MT stages for Oryza2000 and CERES-Rice model optimization approaches. The RMSE objective used in model optimization. The horizontal line within the box indicates the median, boundaries of the box indicate the 25TH- and 75th -percentile, and the whiskers indicate the highest and lowest values of the results.

Systematic error

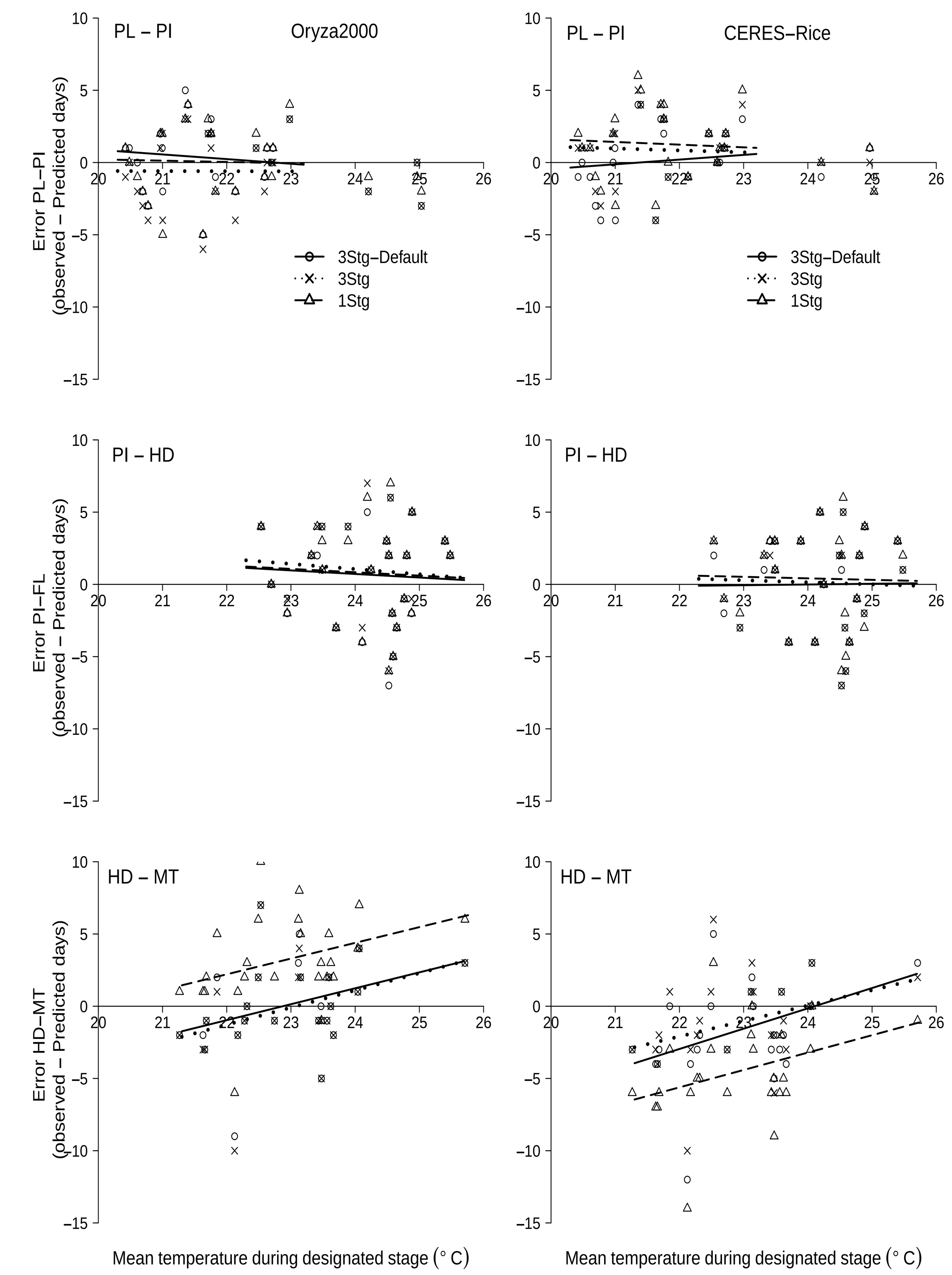

Fig. 3. Error in duration of planting to panicle initiation (PL-PI), panicle initiation to heading (PI-HD), planting to heading (PL-HD), and heading to physiological maturity (HD-MT), simulated with Oryza2000 and CERES-Rice default and optimized parameters for M206. 3Stg-Default is when default cardinal temperatures were used with 3Stg optimization approach. 3Stg is when all parameters (including cardinal temperatures) optimized using the three-stage optimization approach and 1Stg is the single-stage (from PL-HD). The RMSE objective used in optimization.

RMSE and systematic error trade-off

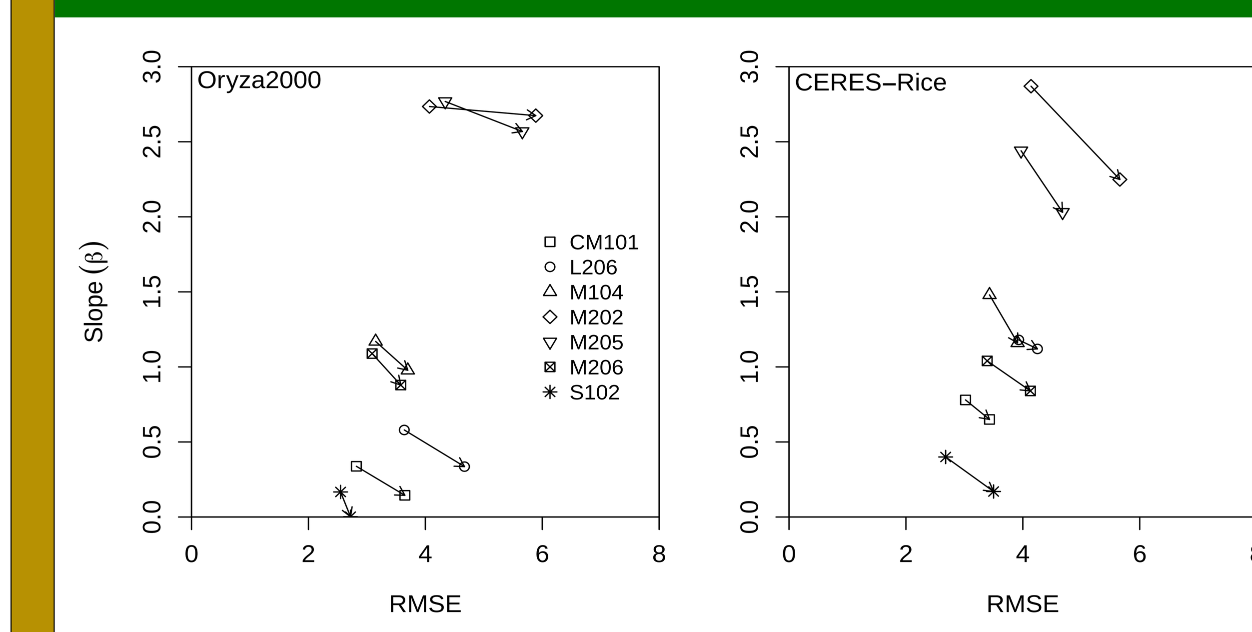

Fig. 4. For all cultivars, model results for RMSE and slope parameter β when model objective was set to minimize RMSE or RMSE-β with 1Stg optimization approach (from planting to heading). The direction of the arrow (➔) shows model output (RMSE and slope parameter (β)) when minimizing for RMSE to RMSE-β.

Results

- In the temperature ranges of this study (20-26 °C), optimizing cardinal temperatures resulted only in small changes relative to the default values in both models and thus did not improve model accuracy or reduced systematic error (Fig.1).
- A unique aspect of this study was that we compared the typical approach of optimizing phenology parameters from planting to heading (1Stg approach which then uses these parameters for the whole season) with a 3Stg approach. Results show that the 3Stg was superior to the 1Stg in both models for predicting phenological stages, especially the HD-MT stage (Fig. 2).
- Systematic error was generally small for all cultivars and stages (systematic error < 2.2 days) (Fig. 3).
- We found a trade-off between RMSE and systematic error when optimization objective was set to minimize systematic error. It is important to find the limits within which the trade-offs between RMSE and systematic error are acceptable, especially in climate change studies where extrapolation beyond observed conditions may otherwise lead to erroneous results (Fig. 4).

Conclusion

- Temperature-dependent systematic prediction error was evaluated for two rice models
- Three-stage optimization increased model accuracy, especially for maturity stage
- Optimization to minimize systematic error reduced bias when RMSE was constrained
- Relatively small systematic error was found for all phenological stages
- In the temperature range of this study, cardinal temperature optimization had no effect on systematic error reduction

Acknowledgments

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