

Modelling response of wheat genotypes to combined nitrogen × water stress at critical growth stages in contrasting environments

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Introduction

- Rising temperatures already drive wheat yield decline in hot, dry regions
- Nitrogen shortage and water deficit at critical crop growth stages (CCGS) reduce yield
- Crop models predict yield poorly at booting and grain filling, constrained by source–sink capacity under $G \times E \times M$ interactions
- Few studies combine $N \times$ water stress with genotype-specific responses.

Hypothesis and objective

CERES-Wheat (v4.8.5) and APSIM-Wheat (v7.10) can reproduce genotype-specific responses to combined $N \times W$ stress at CCGS.

$G \times E \times M$ combinations that optimize yield and resource-use efficiency (Water and Nitrogen)

Materials and methods

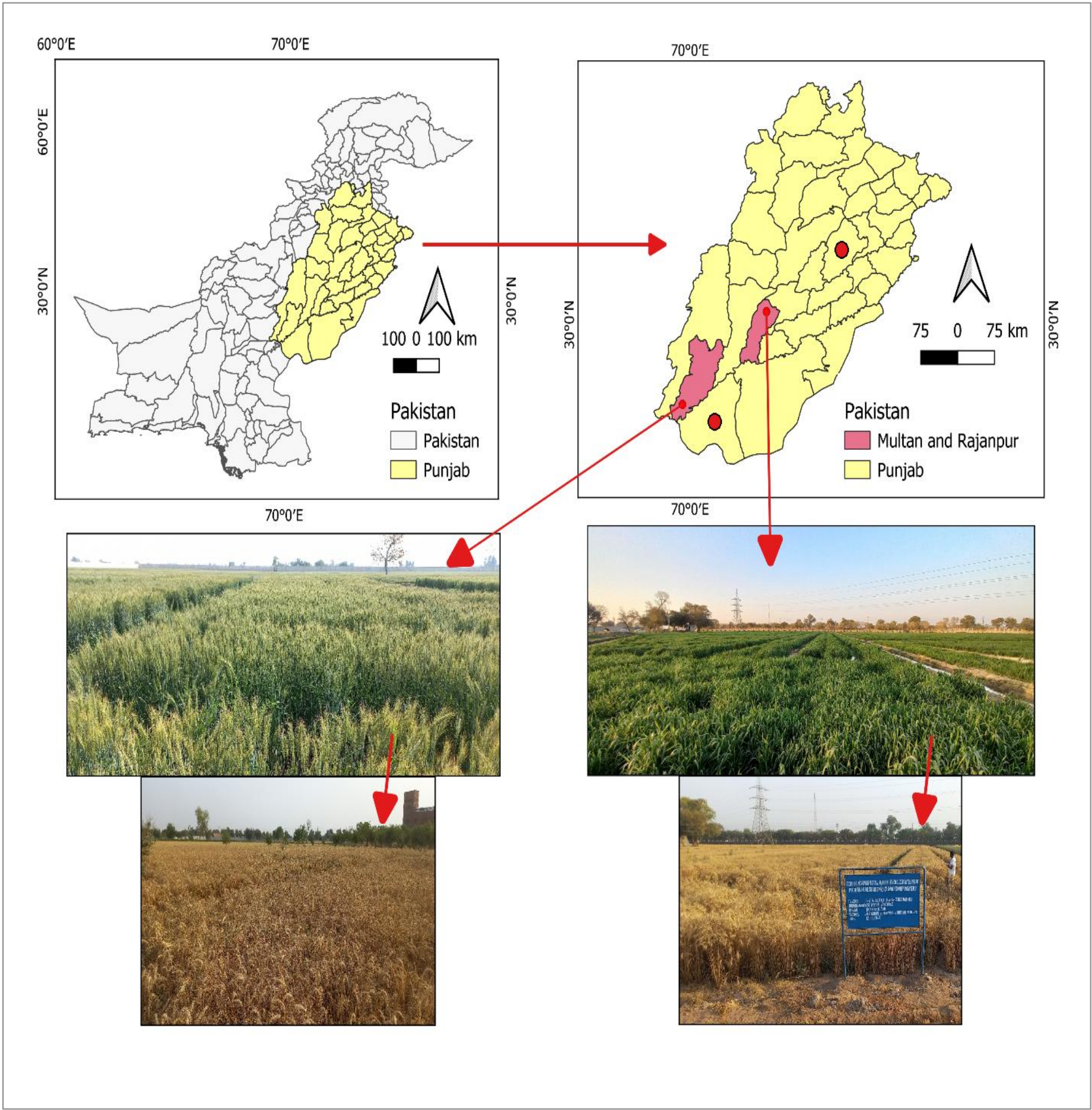


Fig. 1: Field experiments in the arid climate of Punjab, Pakistan. Photographs show the Multan and Rajanpur trials; red dots mark Faisalabad and Khanpur locations.

- Four locations, varied soils; seasons 2021–22 and 2022–23
- 4 irrigation regimes $\times$ 3 N rates (90, 140, 190 kg ha^{-1}) $\times$ 2 genotypes
- Genotypes: Akbar-2019 (new) and Faisalabad-2008 (older)
- Drought imposed at tillering, stem elongation, booting and grain formation (25, 35, 45, 65 BBCH)
- RCBD, split–split plot, four replicates

Modelling and analysis

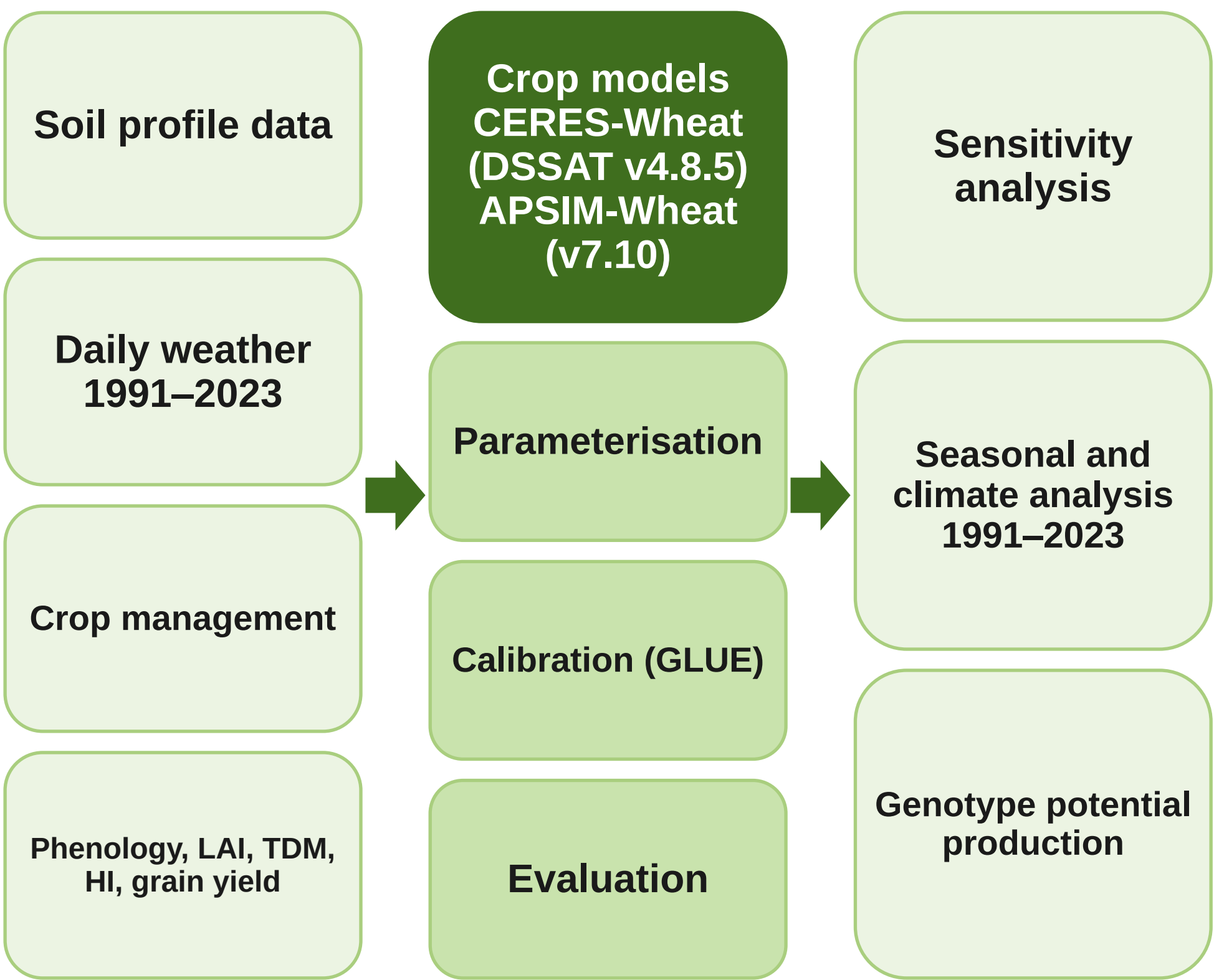


Fig. 2: Models parameterized for temperature functions, thermal time, base temperature and leaf senescence then calibrated per genotype with GLUE under non-limiting N and water, and evaluated on the remaining treatments and seasons.

Results

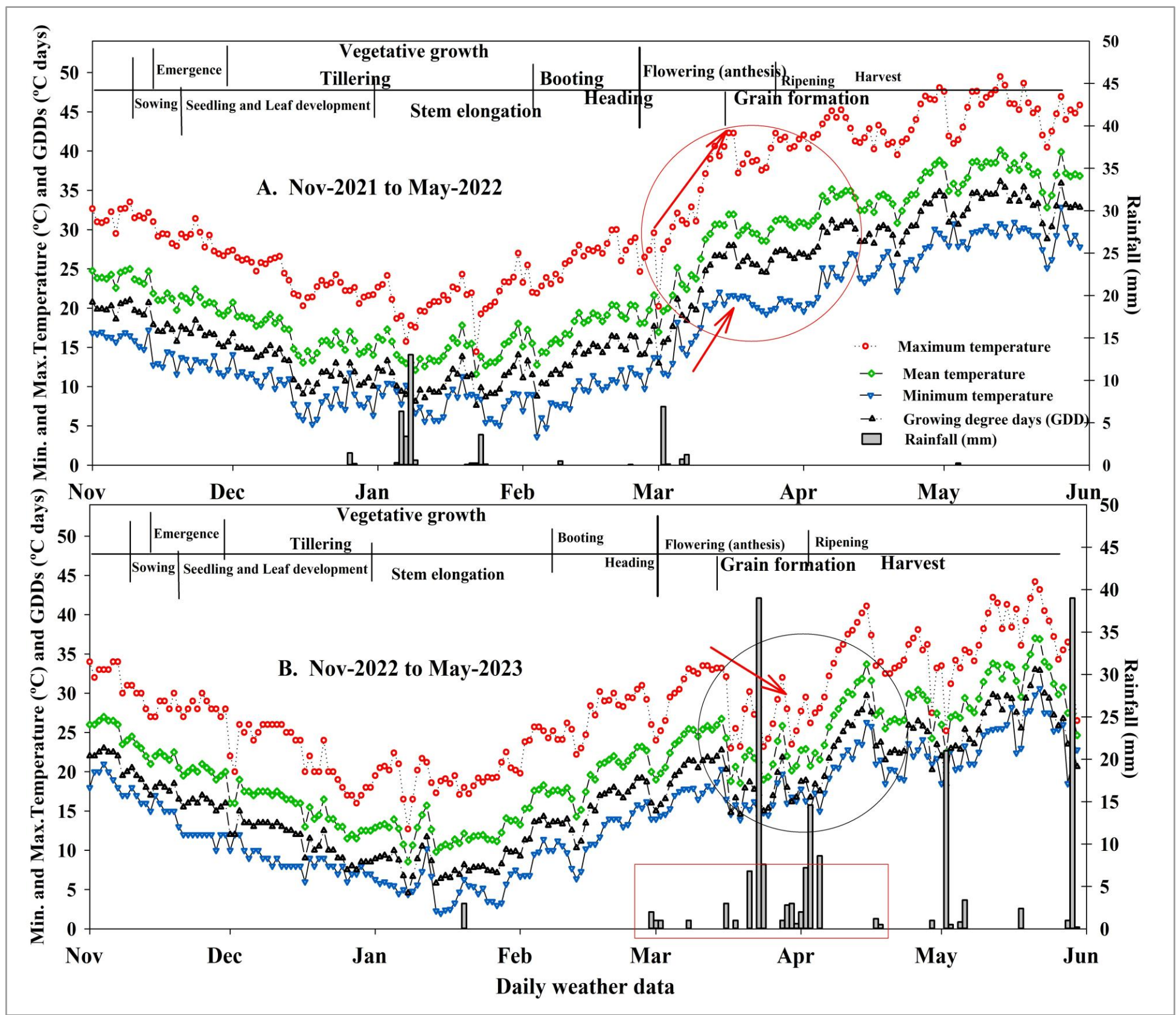


Fig. 3: Temperature, rainfall and growing degree days, (A) 2021–22 and (B) 2022–23. A heat wave in March–May 2022

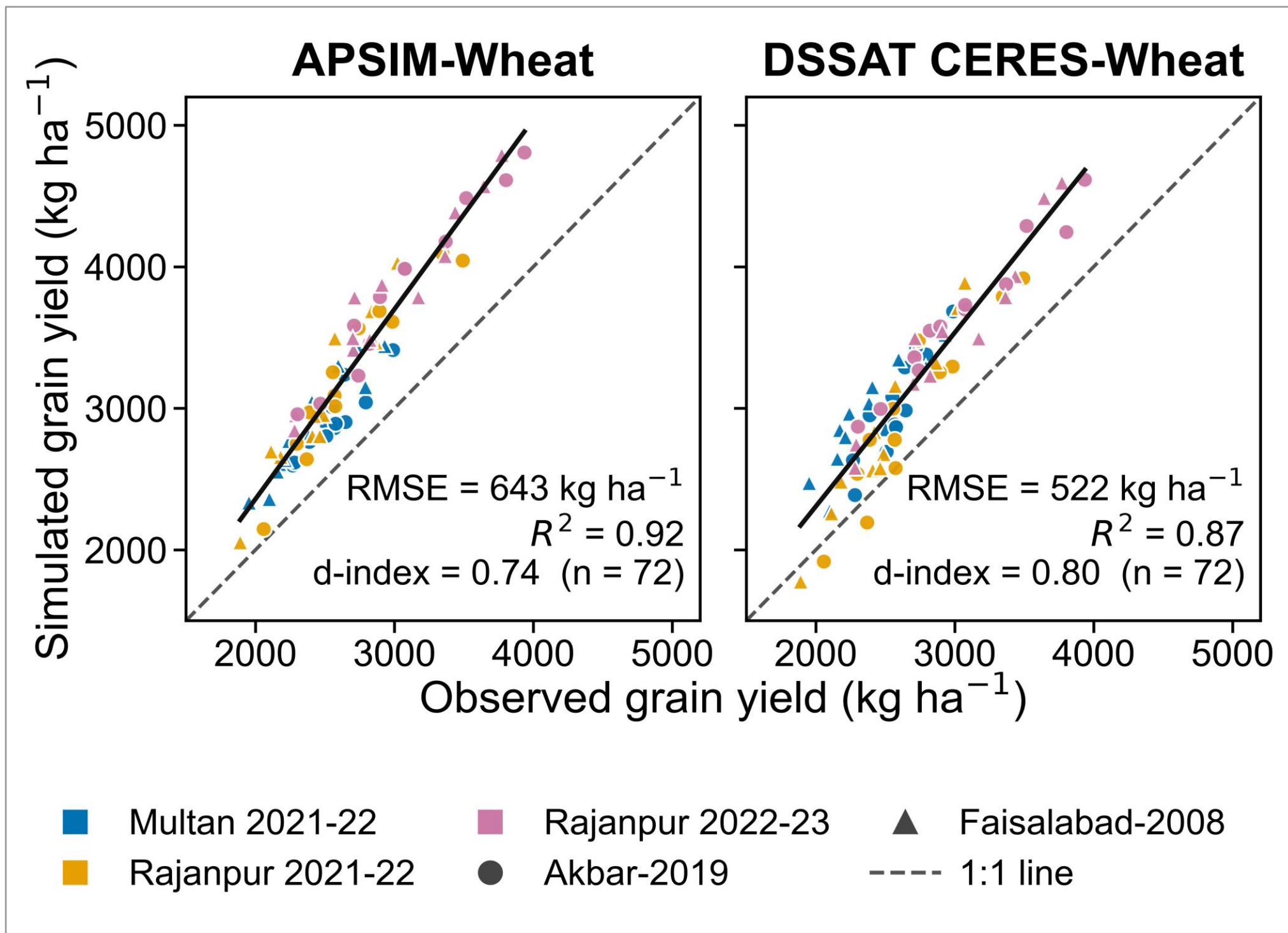


Fig. 4: Simulated vs. observed grain yield across all 24 treatments at three site-seasons, for both models. Colour = site-season, symbol = genotype. Dashed line 1:1, solid line regression.

Key findings

- Genotype Akbar-2019 yielded 14–21% more than Faisalabad-2008
- Long-term potential 7100–8300 vs 6300–7300 kg ha^{-1}
- NUE 15.2–30.4 $\text{kg grain kg}^{-1} \text{N}$; grain-WUE 5.9–14.1 $\text{kg ha}^{-1} \text{mm}^{-1}$

Genotype potential

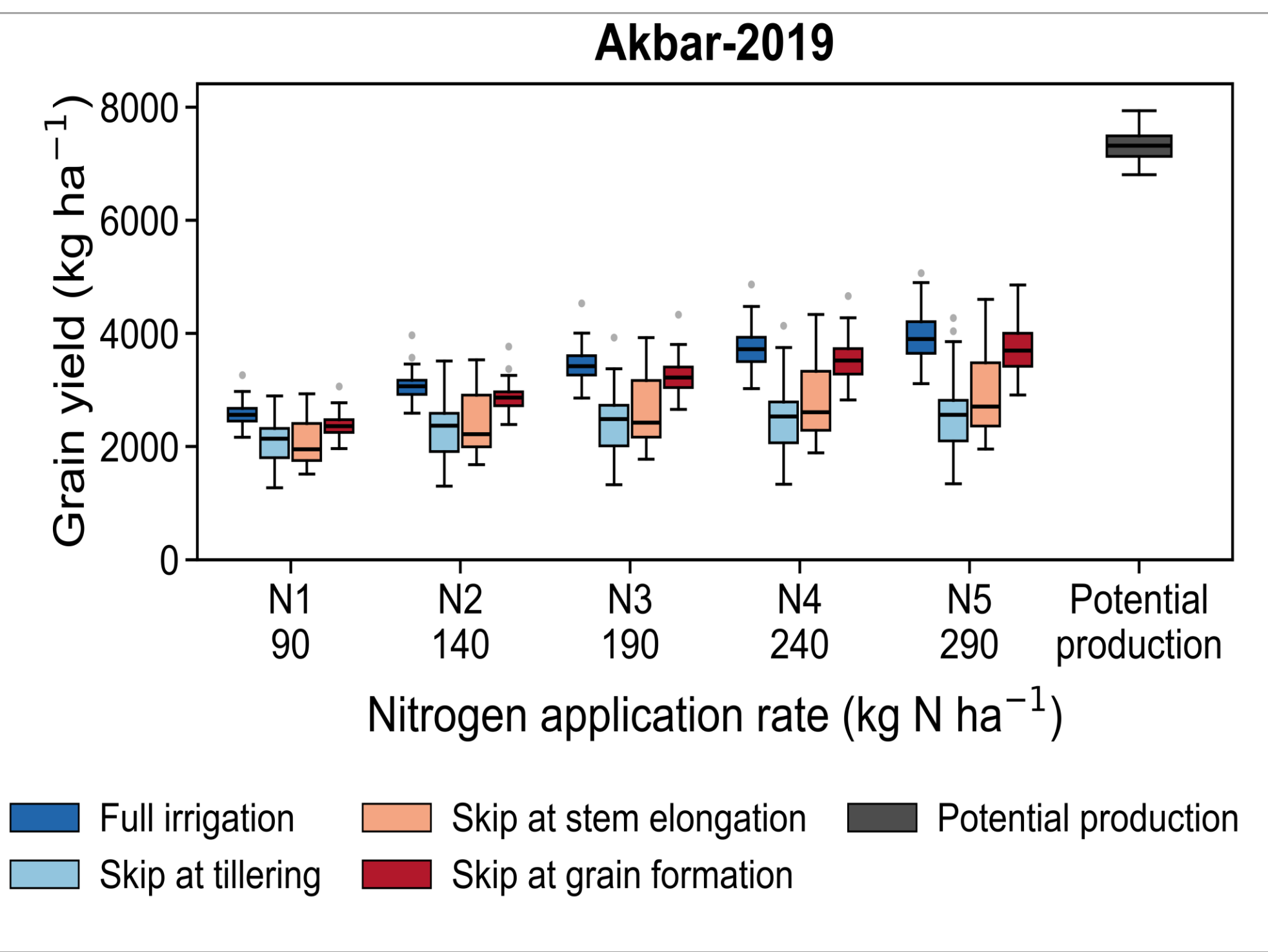


Fig. 5: Seasonal analysis with historical climate 1992–2023 (APSIM-Wheat, Rajanpur), genotype Akbar-2019. Grain yield across five nitrogen rates and four irrigation regimes, with the potential-production treatment for reference.

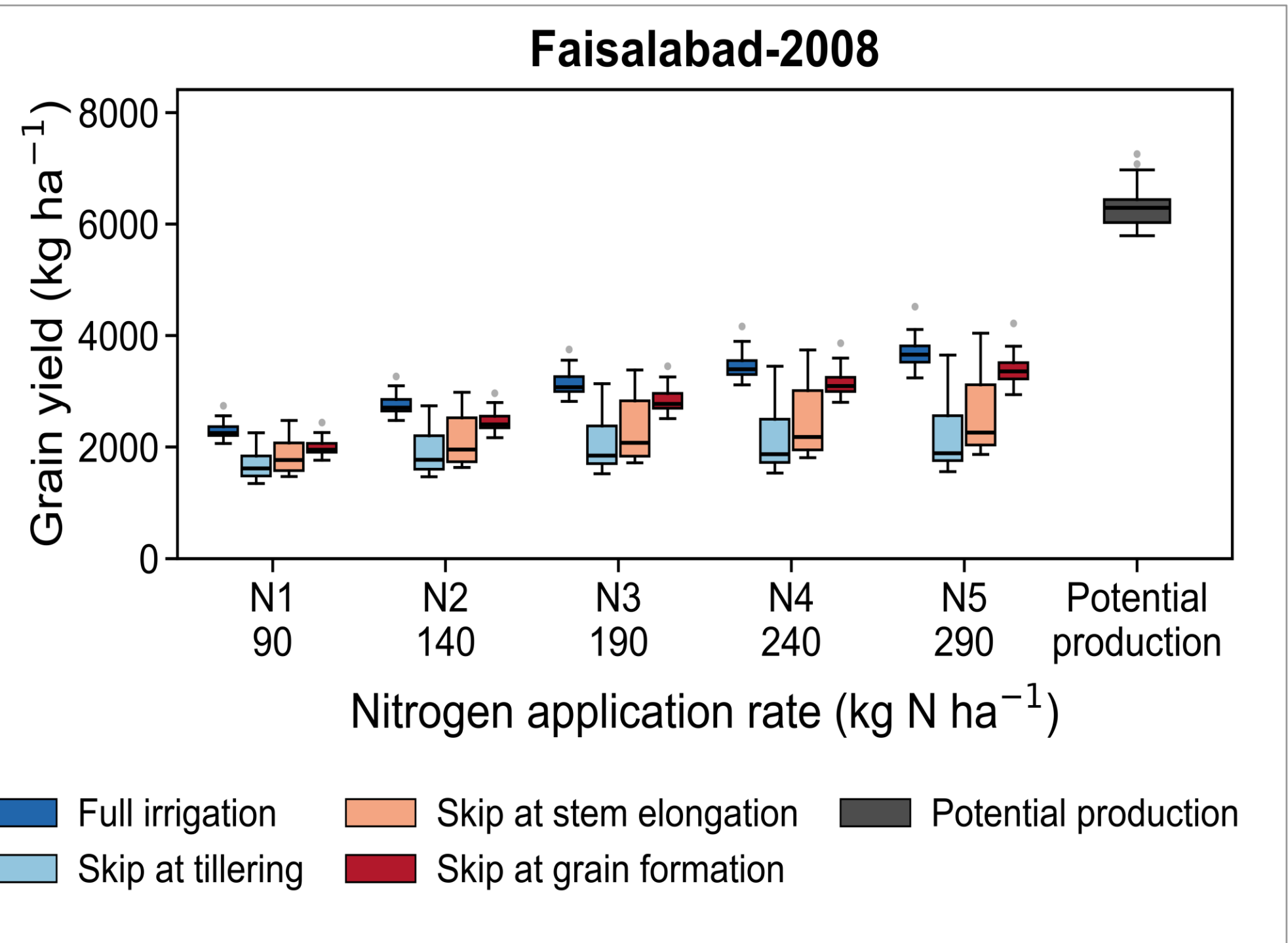


Fig. 6: The same analysis for Faisalabad-2008, on identical axes. It yields less at every nitrogen rate and its potential production stays about 1000 kg ha^{-1} below Akbar-2019.

Model performance

- Grain yield: RMSE 486–717 kg ha^{-1} , d-index 0.56–0.86
- Total dry matter: RMSE 572–1395 kg ha^{-1} , d-index 0.72–0.92
- CERES-Wheat closer to observed than APSIM-Wheat
- LAI in CERES-Wheat sensitive to SLAS, PHINT and PARUE

Conclusions

- Both models reproduced genotype responses to combined $N \times$ water stress at CCGS.
- With four irrigations at CCGS, 140 kg N ha^{-1} significantly enhanced yield.
- Under water stress, 190–240 kg N ha^{-1} was an effective adaptation.
- Akbar-2019 performed best and suits cultivation under combined stress.
- Results can guide breeders towards water- and nitrogen-efficient wheat ideotypes development to tackle climate change.

Acknowledgements

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