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

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Abstract

Nitrogen shortage and water deficit at critical crop growth stages (CCGS) disrupt physiological processes and yield formation, consequently reducing wheat yield. Most crop growth models are not yet fit for accurately estimating yield during booting and grain-filling stages. This may partly be due to the fact that many models are constrained by source-sink capacities as influenced by G×E×M interactions. There are few studies investigating the interactions of N×W stress with genotype-specific responses. Here, we hypothesise that the simulation models CERES-Wheat (v4.8.2) and APSIM-Wheat (v7.10) can potentially reproduce genotype-specific responses to combined N×W stresses at CCGS in different environments.

Multi-year and multi-location field experiments were conducted in the arid climate of Punjab-Pakistan with varied soil conditions. The models were calibrated and evaluated under a diverse range of multi-factors (treatments: 4-irrigation regimes × 3-N rates (90, 140, 190 kg ha^{-1}) × 2 genotypes). Drought stress imposed at tillering, stem elongation, booting, and grain formation (25, 35, 45, and 65 BBCH). The models were parameterised with temperature functions, thermal time, base temperature, and leaf senescence functions adjusted before genotype-specific calibration. Systematic model sensitivity-analyses and seasonal-analysis were performed with historical climate (1991–2023) to test the genotype-specific yield potential for combined N×W stress at CCGS across different environments.

Overall, the models reproduced genotype responses to N×W stress interactions, showing acceptable statistical performance; for grain yield, RMSE= 486–717 kg ha^{-1} and d-index = 0.56–0.86, which are both satisfactory. LAI in CERES-Wheat was sensitive to SLAS, PHINT, and PARUE parameters, reflecting its use of a simple thermal-time threshold rather than APSIM-Wheat. Both models simulated TDM reasonably well (RMSE = 572–1395 kg ha^{-1}; d-index = 0.72–0.92), with CERES-Wheat closer to observed values than APSIM-Wheat. Genotype Akbar-2019 yielded 14–21 % more than FSD-2008 across treatments and locations. Multi-year climate interaction with G×N×W demonstrated that Akbar-2019 had a higher potential production than FSD-2008. In combination with four irrigations at CCGS, 140 kg N ha^{-1} significantly enhanced yield, and Akbar-2019 performed

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well, suggesting that it could be further cultivated even under combined stress conditions in this region. These results can also guide breeders in developing wheat ideotypes for high-yield production under multiple abiotic stress conditions.

Keywords: APSIM, climate analysis , DSSAT, genotype potential, G×E×M, model-sensitivity, N×W interactions