International Conference on Sustainable Water Management: Science, Policy and Practice, 29 September-2 October 2026, Diyarbakır, Turkiye,

(ICOSUWAM-2026)

Procedings of International Conference on Sustainable Water Management: Science, Policy and Practice, 29 September-2 October 2026, Diyarbakır, Turkiye, (ICOSUWAM-2026)

02.11.2026

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Comparative Evaluation of Meteorological, Agronomic, and Sensor-Based Variables for Winter Wheat Yield Prediction Using Machine Learning

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Abstract

This study aimed to determine the contributions of plant and meteorological variables to wheat grain yield prediction across different growing seasons and to compare Partial Least Squares Regression (PLSR) models developed using different groups of predictor variables. The study was conducted over five growing seasons, from 2017–2018 to 2021–2022, at the research area of the Faculty of Agriculture, Dicle University. Three bread wheat genotypes, Ceyhan-99, Dinç, and Empire, were evaluated in a randomized complete block design with four replications, resulting in 60 plot observations. Plant-based variables included days to heading, normalized difference vegetation index (NDVI), SPAD chlorophyll readings, leaf area index (LAI), plant height, thousand-grain weight, grain protein, and wet gluten, whereas environmental variables included growing degree days (GDD) to heading, temperature, precipitation, and relative humidity. Relationships among variables were assessed using Spearman correlation analysis. Four PLSR models were developed based on plant traits, meteorological variables, all predictors combined, and variables with a variable importance in projection (VIP) value >0.8. Model performance was evaluated using leave-one-out cross-validation, R^2, RMPRESS, RMSE, and MAE. Grain yield showed a very strong positive correlation with NDVI ($r=0.94$), as well as strong positive correlations with LAI ($r=0.78$) and thousand-grain weight ($r=0.75$), while negative associations were observed with protein content ($r=-0.89$) and wet gluten ($r=-0.68$) ($p<0.01$). The strong correlation between NDVI and LAI ($r=0.90$) indicated substantial shared information among plant-based predictors. Among the PLSR models, Model 3, which combined plant and meteorological variables, explained the highest proportion of grain-yield variation (88.467%) and achieved $R^2=0.885$, RMSE=53.560, and MAE=39.651. However, the lowest RMPRESS value was obtained with the meteorological model (Model 2; 0.427). The VIP-based variable selection approach produced a more compact model but did not reduce cross-validation error relative to Models 2 and 3. The results demonstrate that integrating plant developmental traits with meteorological variables can substantially improve the explanation of wheat grain-yield variability. The contrasting results obtained from explained variance and cross-validation error also highlight the importance of evaluating both model fit and predictive performance when selecting yield-prediction models.

Keywords: Wheat, grain yield, NDVI, LAI, meteorological variables, PLSR, yield prediction