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Diffuse reflectance spectroscopy for field-scale assessment of winter wheat yield

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The objective was to evaluate the ability of visible and near infrared spectroscopy to predict winter wheat grain yield, and to compare different prediction models according to the spatial variability. Research was conducted on experimental field in Western Pannonian subregion of Croatia. Reflectance measurements (350-1050 nm) were acquired from winter wheat flag leaves grown under nine mineral N fertilization treatments ranging from 0 to 300 kg N ha-1, during the stem extension stage of the year 2010. Linear statistical models (MLR - multiple linear regression, PLSR - partial least squares regression) and non-linear pattern analysis (ANN - artificial neural networks) were generated to estimate grain yield, based on the first derivative of reflectance in form of principal components (PC) and vegetation indices (VI). ANN models were the most efficient in capturing the complex link between yield and leaf reflectance spectra (train and test dataset with $r = 0.95$ and $r = 0.92$, RMSEC = 2.57 dt ha-1 and RMSEP = 4.41 dt ha-1, respectively) compared to corresponding VIs, MLR and PLSR models. Performance of the 8 factor PLSR model indicated the highest consistency due to the small difference between RMSEC (4.10 dt ha-1) and RMSEP (4.61 dt ha-1) besides high prediction ability (validation $R^2 = 0.84$). Correlations between measured and predicted data were found to be significantly very strong and complete with the highest correlation coefficient obtained for ANN model ($r = 0.94$, $p < 0.05$). This relationship was supported by very similar standard deviations of measured grain yield and ANN predicted data. T-test revealed there were no significant differences between the models. The spatial variability of the winter wheat yield was mapped using ordinary kriging for both measured and predicted values to explore within-field and intra-treatment differences in crop productivity needed for assessing good calibration model. Results indicated similarities between the maps generated from the equations and the one generated from field measurements, which is in agreement with high portion of yield variability explained by spectral data ($p < 0.05$). Disagreements mostly occurred on treatments with 250 kg ha-1 of nitrogen and added dolomite and phospho-gypsum due to the high variability in the yield data within the same treatments. Uncertainty of winter wheat yield spatial prediction was assessed by comparing the cross-validation statistics. All models achieved standardized mean nearest to 0 and the standardized RMSEP nearest to 1. Yield was in small portion over-estimated by NDVI and ANN model. Small under-estimation was found for RVI prediction. PLSR and ANN predictions were closest to measured winter wheat yield considering spatially comparable estimates and cross-validation statistics. Key spectral features and algorithms defined in this study should help to support site-specific and real-time yield forecasting in winter wheat production using hyperspectral remote sensing.
Key words: leaf reflectance, grain yield, nitrogen fertilization, principal component, vegetation indices, linear modelling, neural networks, ordinary kriging