

Spectral reflectance indices as a phenotyping tool for assessing morpho-physiological traits of winter wheat (*Triticum aestivum* L.)

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Morpho-physiological traits of wheat such as a grain weight per plant, total leaf chlorophyll content, carotenoids, relative dry matter and nitrogen content are important traits *for the growth of winter* wheat genotypes. However, methods to estimate these traits are laborious and destructive. Spectral reflectance indices based on combination of visible and near-infrared wavelengths such as NDVI (Normalized Difference Vegetation Index), represent one of the most promising tools for application in field phenotyping with potential to provide complex information on different morpho-physiological traits of wheat. The aim of this study was to assess the utility of NDVI measurements of wheat canopy in identification of a specific growth stage in which remotely sensed data show the largest correlation with final grain yield, grain weight per plant, total leaf chlorophyll and carotenoid content, relative dry matter and nitrogen content in 29 winter wheat (*Triticum aestivum* L.) genotypes. The NDVI was measured using an active hand-held sensor GreenSeeker (NTech Industries Inc., Ukiah, California, USA) and hyperspectral camera (Ximea Corp., Lakewood, CO USA) at four growth stages of wheat: full flowering (BBCH 65), medium milk (BBCH 75), early dough (BBCH 83) and fully ripe stage (BBCH 89). Overall 66 different hyperspectral NDVIs were calculated from two-band combinations between red (600-700 nm) or far red (700-740 nm) and near-infrared (756-946 nm) regions. Pearson's correlation coefficient was used to explore the relationship among examined traits and NDVI measured at different growth stages of wheat. Obtained results indicate that most of observed NDVI indices showed negative correlation with the relative dry matter content at all observed growth stages. Significant positive correlations (higher than 0.6 and significant at $P < 0.05$) were found between the specific hyperspectral NDVIs measured at medium milk stage and grain weight per plant, total leaf chlorophyll, carotenoid and nitrogen content, as well as with final grain yield of wheat. The strong positive relationship between NDVI and examined traits found at medium milk stage suggests that this stage is the most appropriate for estimation of these traits of winter wheat in semiarid or similar wheat growing conditions. The overall results indicate that spectral reflectance tools based on combined visible and near-infrared wavelengths, such as NDVI, could be successfully applied to assess morpho-physiological traits of a large number of winter wheat genotypes in a rapid and non-destructive manner. Furthermore, although neither device appeared to have a sizeable advantage over the other, NDVI acquired by hyperspectral camera does appear to be more indicative than NDVI acquired by GreenSeeker sensor, suggesting that alternative spectral combinations can be used in assessing targeted traits of winter wheat genotypes.