Drought stress in winter wheat - physiological responses and detection using remote and proximal sensing techniques

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Abstract
Wheat (Triticum aestivum, L.) is one of the world's most important crops and sources of calories and protein, making it a critical factor in food security. The stability of entire food systems is threatened by climate change, which is the main cause of abiotic stress in crops, such as salinity, waterlogging, heat, frost, nutrient deficiency, and drought as the most studied and damaging stress factor. Drought results from an insufficient amount of rainfall and water in the soil during the growing season and is the most limiting factor for wheat production worldwide. The effects of drought stress on wheat grain yield depend on the severity and duration of the stress, and the response varies depending on the phenophase of the crop. Drought stress affects leaf area expansion, dry matter distribution, photosynthetic rate, and root growth. It is most damaging just before anthesis and during the grain-filling stages, where it causes direct yield losses in the form of lower grain number and lower grain weight. Under drought conditions, CO_2 uptake is reduced due to stomatal closure, which affects respiration, photosynthesis, and overall plant development. As a result, production of cell components such as carbohydrates and proteins is reduced. Severe drought stress in wheat also significantly reduces chlorophyll content in leaves and thus photosynthesis. In addition, the water potential of wheat leaves may be reduced, leading to a decrease in turgor. Remote and proximal sensing of vegetation (RS and PRS) provides a non-destructive method suitable for rapid and accurate assessment of plant physiological responses to stress factors including drought. Hyperspectral measurements using different RS and PRS systems can be used to detect changes in plant reflectance caused by variations in leaf structure, pigments, and water content. The study of spectral reflectance (as a main element of the RS and PRS systems) of plant material has contributed to the definition of vegetation indices (VI), which can be used to quantify numerous agronomic variables by relating the values of different combinations of wavelengths of the electromagnetic spectrum to plant properties. Based on VI calculated from ratios and differences between reflectance values of plant material in the visible (VIS), near infrared (NIR), and shortwave infrared (SWIR) range, various agronomic plant traits related to drought can be estimated. Water content can be estimated remotely by using water absorption bands in the NIR to SWIR range where there are strong water absorbing features, e.g., at 970 nm, 1200 nm, 1450 nm, 1930 nm, and 2500 nm. To improve the extraction of spectral information on water metrics (such as leaf water potential) in vegetation, scientists have proposed several hyperspectral VI, including water index (WI), normalized difference vegetation index (NDVI), simple ratio (SR), photochemical reflectance index (PRI), normalized difference water index (NDWI), water band index (WBI), brown pigment index (BPI), normalized difference infrared index (NDII), simple ratio water index (SRWI), moisture stress index (MSI), deep water index (DWI), normalized difference vegetation index (Red-edge NDVI), etc. Together with irrigation management, rapid assessment of water content in wheat plants would enable effective screening and identification of resistant varieties in plant breeding programs. Based on numerous studies of water stress in wheat plants and applications of RS and PRS, there are a large number of accurate, reproducible methods that can be applied under a wide range of climatic, soil, and growing conditions.