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Review

Crop reflectance monitoring as a tool for water stress detection in greenhouses: A review

Nikolaos Katsoulas [a,b,*], Angeliki Elvanidi [a], Konstantinos P. Ferentinos [b], Murat Kacira [c], Thomas Bartzanas [b], Constantinos Kittas [a,b]

[a] Department of Agriculture, Crop Production & Rural Environment, University of Thessaly, Volos, Greece
[b] Institute for Research & Technology – Thessaly, Centre for Research and Technology – Hellas, Volos, Greece
[c] Department of Agricultural and Biosystems Engineering, The University of Arizona, Tucson, AZ, United States

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Multisensory platforms for remote sensing measurements offer the possibility to monitor in real-time the crop health status without affecting the crop and environmental conditions. The concept of the speaking plant approach, and plant response based sensing in general, could be valuable providing a better understanding of the interactions between the microclimate and the physical conditions of the plants. Early detection of plant stress is critical, especially in intensive production systems, in order to minimise both acute and chronic loss of productivity. Non-contact and non-destructive sensing techniques can continuously monitor plants and enable automated sensing and control capabilities. This paper reviews past research and recent advances regarding the sensors and approaches used for crop reflectance measurements and the indices used for crop water and nutrient status detection. The most practical and effective indices are those based on ground reflectance sensors data which are evaluated in terms of their efficiency in detecting plant water status under greenhouse conditions. Some possible applications of this approach are summarised. Although crop reflectance measurements have been widely used under open field conditions, there are several factors that limit the application of reflectance measurements under greenhouse conditions. The most promising type of sensors and indices for early stress detection in greenhouse crops are presented and discussed. Future research should focus on real time data analysis and detection of plant water stress using advanced data analysis techniques and to the development of indices that may not be affected by plant microclimate.

1. Introduction

1.1. Background

Plant stress is caused by biotic or abiotic factors that adversely affect plant growth and significantly reduces productivity. Plant stress is expressed in the plant canopy in many types of symptoms. Water stress, for example, closes stomata and impedes photosynthesis and transpiration, resulting in changes in leaf colour and temperature (Nilsson, 1995, p. 146) but other symptoms of water stress include morphological changes such as leaf curling or wilting due to loss of cell turgidity. Early detection of plant stress is very critical

* *Corresponding author*. Department of Agriculture Crop Production & Rural Environment, University of Thessaly, Volos, Greece.
E-mail address: nkatsoul@uth.gr (N. Katsoulas).
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Nomenclature

ARVI	Atmospherically resistant vegetation index
AVI	Average vegetation index
C	Sensors that measure plant reflectance in contact with the leaf
ChF	Chlorophyll fluorescence
Chl	Chlorophyll content
CO_2	Carbon dioxide
CWSI	Crop water stress index
DVI	Difference vegetation index
ETc	Crop evapotranspiration
EVI	Enhanced vegetation index
eNDVI	Enhanced normalised difference vegetation index
F	Fluorescence
FOV	Field of view
FR	Fluorescence ratio
Fwbi	Floating position water band index
GNDV	Green normalised difference vegetation
GNDVI	Normalised difference vegetation index on greenness
g_s	Stomatal conductivity
GVI	Green vegetation index
LAI	Leaf area index
LED	Light emitting diode
MIR	Middle infrared region
mNDVI	Modified normalised difference vegetation index
MNDVI8	Modified normalised difference vegetation index
Macc01	Maccioni index
D	Derivative Reflectance at D690
DD	Datt Derivative
mrNDVI	Modified red edge normalised difference vegetation index
mrSRI	Modified red edge simple ratio index
MSI	Moisture stress index
MTCI	Merris terrestrial chlorophyll index
N	Nitrogen
ND	Normalised difference
NDII	Normalised difference infrared index
NDVI	Normalised difference vegetation index
NDWI	Normalised difference vegetation index
NIR	Near infrared region
NPh	Non phosphorylated thylakoids
NPQI	Normalised phaeophytinization index
NPQ	Non photochemical quenching
NWI	Normalised water index
OSAVI	Optimization soil adjusted vegetation
PAR	Photosynthetic active radiation
PRI	Photochemical reflectance index
PSII	Photosystem II
PSRI	Plant senescence reflectance index
PWC	Plant water content
RI	Reflectance index
rNDVI	Red edge normalised difference vegetation index
rNDVI	Red normalised difference vegetation index
RS/CAM	Remote sensing based on imaging systems
RS/FOV	Remote sensing based on spectroradiometer that measures in specific field of view of the target
RS	Remote sensing
RVI	Red vegetation index
RWC	Relative water content
SAVI	Soil adjusted vegetation index
SB	Single band
SIPI	Structure independent pigment index
SIWSI	Shortwave infrared water stress index
sNDVI	Similar normalised difference vegetation index
Sp	Spectroradiometer in laboratory
sPRI	Similar photochemical reflectance index
SR	Simple ratio
SR	Simple ratio
SWC	Soil water content
Tc	Canopy temperature
TCARI	Transformed chlorophyll absorption in reflectance index
VI	Vegetation index
VIS	Visible spectrum
VOG REI	Vogelman red edge index
VPD	Vapour pressure deficit
WI	Water index
Y	Yield
ΔPRI	Delta photochemical reflectance index

especially in intensive production systems in order to minimise both acute and chronic loss of productivity.

Plant water stress may be the result of a single parameter or a combination of environmental conditions (e.g. air temperature, relative humidity, solar radiation intensity, air velocity) root conditions (e.g. available water in the root, electrical conductivity in the root zone), the microclimate and plant genetic traits. Methods such as substrate water content (for soilless crops) or soil water tension, leaf water potential and sap flow, among others, have been widely used to help describe plant water status. However, soil or substrate water content indicates the availability of water in the root zone and that is not always directly correlated with the water status of the plant. In addition, although leaf water potential and sap flow measurements provide direct information about plant water status, they require plant contact or destructive sampling which is difficult to realise in commercial scale. Non-contact and non-destructive sensing techniques can continuously monitor plants and enable automated sensing and control capabilities (Ling, Giacomelli, & Russell, 1996).

The dynamic response of plants to the changes of their environment is often called 'speaking plant' (Takakura, Kozai, Tachibana, & Jordan, 1974). The concept of the speaking plant approach and plant response – based sensing is valuable to have a better understanding of the interactions between the microclimate and the physical conditions of the plants (Kacira, Sasae, Okushima, & Ling, 2005). Thus, in this approach, the physical responses of the plants to the environmental changes are monitored and the information is utilised to identify conditions which put plants under stress