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# Calibration methodology of a remote PRI sensor for photosynthesis rate assessment in greenhouses†

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**Abstract:** Early detection of different types of crop stress under greenhouse cultivations is critical in order to optimize yield and resource use efficiency. Objective of the present work is to develop a system which, based on remote sensing, will recognize plant stress by combining microclimate and crop physiology data. The innovation of the platform is based on the integration of a remote PRI sensor that is used to correlate PRI measurements and photosynthesis rate (Ps). In this work, the methodology used for the PRI sensor calibration and acquisition is presented. The values recorded by means of the PRI sensor were correlated with the Ps rate obtained with handheld photosynthesis system. Data of PRI and Ps values were collected under different lighting, temperature and plant water status conditions of a greenhouse tomato crop. The basic statistical parameters of mean and standard deviation values are used to estimate spectral correlation at 530 nm and 570 nm on the interested leaf area. The determination coefficient ($R^2$) of the linear regression obtained between the PRI and Ps data was about 0.9. The obtained equation will be integrated in the sensing system and the data will be used to train a machine learning model to detect different type of crop stress under greenhouse conditions.

**Keywords:** Remote sensing; photosynthesis rate; multisensory platform; plant stress; plant water status

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## 1. Introduction

The double effect of the up-coming growth population and the need for more sustainable agriculture led to a call for higher yield production without expanding agricultural land use. Additionally, due to the COVID-19 pandemic, there are increasingly alarming reports about imminent threats on a global scale to economic sustainability and food security and quality. In this sense, the protected cultivation where the crops are cultivated in a controlled environment - especially soilless (growing a crop without soil) has become an important part of the agricultural industry [1].

In order to increase, however, the productivity in the existing greenhouse covered area, there is a need to redesign the operational control system among others to establish more demonstrative greenhouses. Till now, to maintain the desired indoor climate, a great variety of controllers are used supported by automated control models based on environmental data. However, to achieve satisfactory results given the overall objective, it is not enough to just control the greenhouse climate, but the crop must also be considered. Direct, and real-time monitoring of plant responses and processes under specific environmental and root conditions can help to improve climate and irrigation control and overall production over time and space [2]. Especially in commercial production systems, it is more advantageous to apply a real-time plant canopy health, growth, and quality monitoring system with multi-sensor platforms [3].

Up to now, it was not feasible to monitor crop physiological parameters in real-time without requiring plant contact or destructive sampling. Current computational intelligence techniques have allowed the development of a hyperspectral optic system that supplies information about crop physiology and morphology. Based on the current technology a series of reflectance indices such as Normalized Vegetation Index (NDVI) and Photochemical Reflectance Index (PRI) were significant correlated with crop green biomass and photosynthesis rate [3]. Hyperspectral camera, however, is a high-cost sensor, difficult to handle, and unable to be adjusted in a multi-sensor platform. The recent development of remote soft-sensors (i.e. mathematical models using real-time sensor data) allows the development of models that integrate plant-based indices/indicators.

In the current research, a remote Spectral Reflectance Sensor (SRS) that measures crop PRI in distance was used to estimate crop Ps remotely under greenhouse conditions. The aim was to study the sensor behavior and develop a regression that will estimate Ps through PRI values. To achieve this, tomato crop was cultivated in perlite slabs, while remote PRI values were evaluated with the Ps values recorded by a portable sensor in contact with the leaf.

## 2. Materials and Methods

The calibration procedure was performed in June of 2020 in a multi-tunnel greenhouse with a total ground area of 1500 $m^2$ (250 $m^2$ each compartment). The establishments were located at the facilities of the University of Thessaly, Velestino, Volos (Latitude 39º 22΄, longitude 22º 44΄ and altitude 85 m), in the continental area of eastern Greece. The greenhouse was covered by a transparent film and it is equipped with fans, a thermal screen, heating, and cooling system. Air temperature and relative humidity were automatically controlled using a climate control computer (SERCOM, Automation SL, Netherlands) to achieve optimal indoor climate conditions.

The tomato plants were cultivated rockwool slabs (Grodan Delta, NL 100x15x7.5 cm, 0.18 g cm-3, 90% water retention capacity). The plants were fertigated with fresh nutrient solution with set-points of electrical conductivity (EC) around 2 dS $m^{-1}$ and pH 5.8. The water used to prepare the NS had pH of 7.1 and an EC of 0.8 dS $m^{-1}$. The nutrient solution supplied to the crop was a standard nutrient solution for tomato grown in open hydroponic systems adapted to Mediterranean climatic conditions, with the following composition: 5.2 mM $L^{-1}$ $Ca^{2+}$, 2.9 mM $L^{-1}$ $Mg^{2+}$, 2.5 mM $L^{-1}$ $K^+$, 1.5 $Na^+$, 11mM $L^{-1}$ $NO^{3-}$, 0.8 mM $L^{-1}$ $H_2PO_4$-, 23.50 μmM $L^{-1}$ Fe, 5.00 μmM $L^{-1}$ Mn, 3.80 μmM $L^{-1}$ Zn. Moreover, micronutrients were added to NS: chelated with EDTA containing Fe 6%, Mn 13%, Zn 15%, B 21%, Cu 0.3%, Mo 0.2%.

PRI was measured through SRS sensor (SRS-PRI sensor; METER Group Inc., USA) (Figure 1). The remote PRI sensor is radiometrically calibrated by default to a NIST-traceable standard and it is centered at 532 nm and 570 nm with 10 nm FWHM. The corrected PRI was calculated as the ratio between reflected and incident radiation, measured using down-looking and up-looking sensors, respectively. Readings of both up and down-looking sensor are PRI outputs (Equation 1):

$$PRI = (R531 - R570)/(R531 + R570) \quad (1)$$

Where R is the reflectance in units of radiant flux density (W $m^{-2}$ $nm^{-1}$) in nanometers the PRI is calculated. In the reading outputs, the ratio between R531 and R570 is also adjusted. The up-looking SRS sensor was mounted above the canopy with an unobstructed view of the sky. The down-looking SRS sensor was placed in 2 m above the ground in 0.20 m from the crop at a constant angle of 45$^o$ from the vertical axis to view a leaf area of young and fully developed leaves. The surface area sensed was about 2000 $mm^2$. Additionally, a solar radiation sensor (Rn, W $m^{-2}$; SP-SS, Apogee Instruments, North Logan, USA) was used to measure the light intensity above the canopy. The microclimatic sensors installed in the greenhouse are connected to device-to-web data logger which feeds a respective database. Measurements were performed every 30 s and 5-min average was recorded.

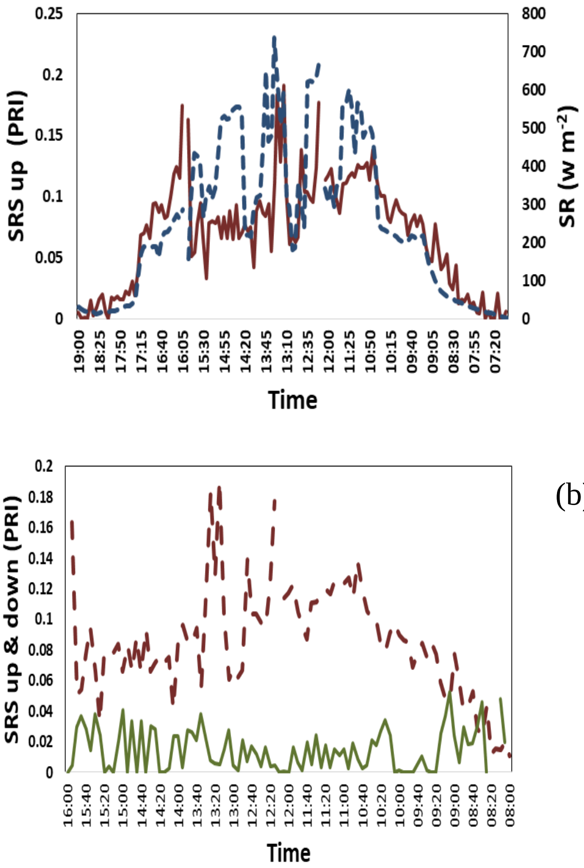
The mean PRI of the crop measured using remote sensing ($PRI_R$) was correlated by the mean of the PRI sensor ($PRI_L$) performing measurements in contact with the leaf (PlantPen PRI Meter, Alpha Omega-Electronics, Spain) for the same set of leaf and time period. Additionally, $PRI_R$ values were correlated with the photosynthesis rate ($A_s$, μmol $m^{-2}$ $s^{-1}$) obtained using a portable photosynthesis measurements system (LCpro, ADC Bioscientific Ltd., UK) for the same leaf set. The correlation was performed under different climatic conditions and light intensity.

## 3. Results

### *3.1. $PRI_R$ indicator based on light signal*

Figure 1a presents the incident PRI recorded by the up-looking SRS sensor established above the canopy with an unobstructed view of the sky. The data follow the same trend with the incident radiation that was measured by the solar radiation sensor. As it was expected the maximum values were observed around noon. The differences observed between the SRSup and the conventional SR sensor were occurred due to the different position the sensors were placed and their effect of the neighborhood materials shadows to the measured area.

The daily progress of the down-looking sensor that restricts the field of view of the specific leaf target is presented in Figure 1b. The PRI intensity of the down-looking values contained high amounts of variability due to the environmental changes and observation conditions. The spurious data points occurred due to the low light intensity removed, since those data result in indeterminate or undefined calculations of PRI estimation. However, the daily sun moving during the sky did not affect the progress of the down-looking values, otherwise, a concave pattern should be noticed.




(a) (b)

**Figure 1.** The daily progress of: (**a**) Incident radiation and PRI recorded by SR and SRS up-looking sensor (dot line: SR values; solid line: SRS up values); (**b**) Incident and reflected PRI recorded by

SRS up-looking and down-looking sensor respectively (dot line: SRS up values; solid line: SRS down values).

### *3.2. Photosynthesis rate estimation based on remote PRI sensor*

The calculated $PRI_R$ that was estimated by the SRS sensor was correlated with the values recorded by the $PRI_L$ sensor in contact with the leaf (Figure 2). When plotting remote $PRI_R$ vs. contact $PRI_L$ values, a strong linear relationship was found while the determination coefficient ($R^2$) of the mentioned regression was found to be higher than 0.90 ($p<0.05$). The differences between canopy PRI and actual leaf PRI depends on atmospheric conditions.

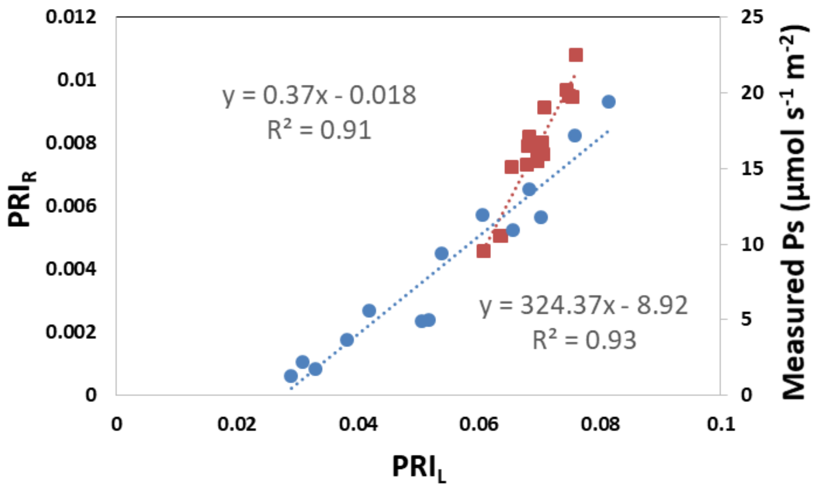



**Figure 2.** Relationship between $PRI_L$ with $PRI_R$ and Ps variation observed in young and fully developed leaves of tomato crop (dot: $PRI_L$ vs Ps; square: $PRI_L$ vs $PRI_R$).

Figure 2 presents also the correlation between the $PRI_L$ and the Ps values recorded by portable equipment that measures the $A_s$ in contact with the leaf. When plotting $PRI_L$ *vs*. contact Ps values, a strong linear relationship was found while the $R^2$ of the mentioned regression was found to be higher than 0.92 ($p<0.05$). Similar progress followed the correlation between the $PRI_R$ and the actual Ps values.

Figure 3 presents the daily evolution of $PRI_R$ and the calculated Ps values during the time period in which the light intensity was higher than 100 W $m^{-2}$. According to the calculated data, the daily mean Ps was about 18 μmol $m^{-2}$ $s^{-1}$. The maximum values of photosynthesis rate mentioned after noon while minimum values around 7.4 were observed occasionally during the day.

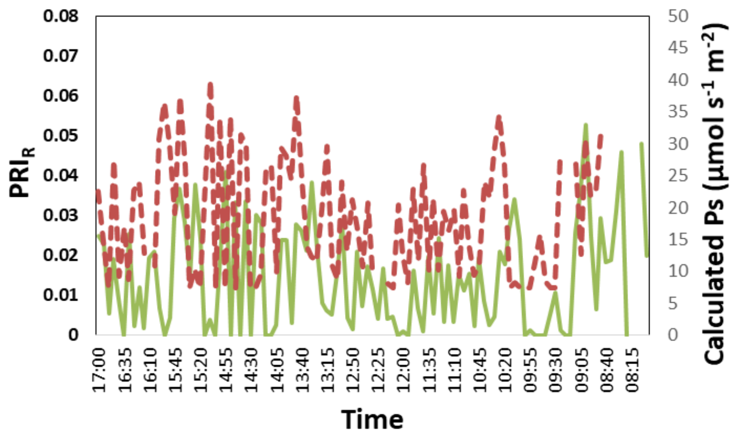


**Figure 3.** Corrected PRI data collected remotely at five minute intervals and the calculated photosynthesis rate values occurred from a tomato canopy under greenhouse conditions (dot line: Calculated Ps; solid line: $PRI_R$).

## 4. Discussion

The fraction of photosynthetically active radiation absorbed by the canopy can be estimated by remotely sensed vegetation indices. The PRI for instance, derived from narrow-band spectro-radiometers is a spectral index increasingly being used as indicator of photosynthetic efficiency [4].

Gammon et al. [5] were among the first who presented a correlation between the physiological reflectance index and the depoxidation state of the xanthophylls cycle pigments. Thenot et al. [6] carried out experiments under greenhouse conditions to connect PRI with correlate Photosynthetic Active Radiation-PAR level of 1800 mmol $m^{-2}$ $s^{-1}$ in Chenopodium quinoa with significant results. Sarlikioti et al. [7] used a handheld sensor to measure PRI in tomato crop under greenhouse conditions. According to their data, a good correlation was observed ($R^2$>0.6) between PRI and relative water content, $CO_2$ assimilation, stomatal conductance, operating efficiency of PSII (Photosystem II) and NPQ. However, the resulted correlation was significant only when light intensity was higher than 700 mmol $m^{-2}$ $s^{-1}$. In the current research, the index was measured remotely and the correlation between PRI and Ps variation was observed when the light intensity within the greenhouse was at least 100 W $m^{-2}$ $s^{-1}$.

Ground-based remote sensing is well established as a tool for assessing crop ecophysiological variables and has garnered wide interest from agricultural practitioners to track crop performance with higher temporal and spatial resolution than the handheld sensors [8]. The mechanistic basis for PRI index is changed from leaf scale to canopy and larger scales [9, 4]. In the current calibration process, a difference between canopy PRI and actual leaf PRI performed due to atmospheric conditions was occurred. The resulted values, however, are strongly influenced by the canopy shading caused by sun angle as a result the $PRI_R$ recorded signal to be less intense than the $PRI_L$ shignal. Magney et al. [10] used spectral remote sensor to evaluate PRI under different environmental conditions. Their results showed that the use of smoothing algorithm eliminated the data variation due to the ambient conditions.

## 5. Concussion

In the current research, a spectral remote sensor that measures PRI was used to estimate photosynthesis rate on a real and timescale. In this sense, the $PRI_R$ values were correlated with Ps values (μmol $m^{-2}$ $s^{-1}$) obtained with a handheld photosynthesis system for the same set of leaves. The set occurred under different light conditions within the greenhouse. The resulted linear regression between the set of data was significant and their determination coefficient was estimated higher than 0.9. To record crop photosynthesis rate remotely at five-minute intervals forms an innovation that leads to the development of more autonomous and sustainable greenhouse control systems.

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## References

1. Elvanidi, A.; Benitez Reascos, C.M.; Gourzoulidou, E.; Kunze A.; Max, J.F.J.; Katsoulas, N. Implementation of the circular economy concept in greenhouse hydroponics for ultimate use of water and nutrients. *Hort.* **2020**, *6(4)*, 83.
2. Elvanidi, A.; Katsoulas, N.; Bartzanas, T.; Ferentinos, K.P.; Kittas, C. Crop water status assessment in controlled environment using crop reflectance and temperature measurements. *Precis. Agric.*, **2017**, *18*, 332–349.
3. Katsoulas, N.; Elvanidi, A.; Ferentinos, K.P.; Kacira, M.; Bartzanas, T.; Kittas, C. Crop reflectance monitoring as a tool for water stress detection in greenhouses: A review. *Biosyst. Eng.*, **2016**, *151*, 374–398.
4. Garbulsky, M.F.; Pe nuelas, J.; Gamon, J.A.; Inoue, Y.; Filella, I. The photochemical reflectance index (PRI) and the remote sensing of leaf, canopy and ecosystem radiation use efficiencies: a review and meta-analysis. *Rem. Sens. Environ.*, **2011**, *115*, 281–297.
5. Gammon, J.A.; Penuelas, J.; Field, C.B. A narrow-wave band spectral index that track diurnal changes in photosynthetic efficiency. *Rem. Sens. of Env.*, **1992**, *41*, 35-44.
6. Thenot, F.; Methy, M.; Winkel, T. The photochemical reflectance index (PRI) as water stress index. *Intern. Journ. of Rem. Sens.*, **2002**, *23(23)*, 5135-5139.
7. Sarlikioti, V.; Driever, S.M.; Marcellis, L.F.M. Photochemical reflectance index as a mean of monitoring early water stress. *An. of App. Biol.*, **2010**, *157(1)*, 81-89.
8. Mulla, D.J. Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. *Biosyst. Eng,* **2013**, *114*, 358–371.
9. Inoue, S.; Kinoshita, T.; Matsumoto, M.; Nakayama, K.I.; Doi, M.; Shimazaki, K. Blue light-induced autophosphorylation of phototropin is a primary step for signaling. *Proc Natl Acad Sci*, **2008**, *105*, 5626-5631.
10. Magney, T.S.; Eitel, J.U.; Huggins, D.R.; Vierling, L.A. Proximal NDVI derived phenology improves in-season predictions of wheat quantity and quality. *Agric. For. Meteorol.*, **2016**, *217*, 46–60.