Remote sensing validation with in-situ measurements for efficient crop irrigation management

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Abstract. The multi-spectral data acquired with either satellite imagery, UAV or tethered and stratospheric balloons can be used to calculate vegetation indices directly related to the well-being of the crops providing a quantitative information about its health and growth. The vegetation indices are calculated combining measurements from different parts of the electromagnetic spectrum, typically in the visible and near-infrared ranges. The aim of this work is to integrate the remote sensing data with in-situ collected measurements in order to validate remote observations for monitoring soybean water status and requirements. The study is conducted in Italy on a field of 160 x 40 m^2, divided into four plots of 40 x 40 m^2; two of them are irrigated at 100% of the CRW (Crop Water Requirement) and two irrigated at 70% of CWR. In each plot tensiometers and capacitive probes directly measure the soil moisture, along with a climate station used to monitor environmental parameters. The in-situ data are correlated with multi band satellite images by the PlanetScope constellation providing a ground resolution of 3 m. The use of UAV or balloons is needed to monitor the diurnal variation of the indices, as the satellite revisit time is once per day around 9:00 and 10:00 UTC on the site. The balloon payload is equipped with commercial cameras and dedicated filters to acquire images in the same spectral bands as satellites. The importance of this study lies in the possibility of managing the fields irrigation basing on the actual physiological need of the crop rather than relying on a predefined timetable, resulting in a more efficient and environmentally responsible irrigation. The article will present the methodology and the instruments applied, together with the results obtained.

Introduction

Soybean is one of the most important crops worldwide as it is used not only for livestock feed and human nutrition, but also assumes it has key role in the biofuel sector [1]. Moreover, the need to expand and increase irrigated agriculture appears to be extremely necessary in view of the increased demand for food in the coming decades [2].

For correct irrigation management, it is necessary to know the crop evapotranspiration index (ET_c) and the right value of the crop coefficient (K_c).

$$K_c = \frac{ET_c}{ET_0} \tag{1}$$

where ET_c is the evapotranspiration of the crop under optimal conditions and ET_0 is the potential evapotranspiration of the reference crop calculated with the Pennam-Withman equations.

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A linear relationship between K_c values and some vegetative indices, first of all NDVI, has been observed from several studies [3]. Agronomical indices can be obtained from remote-sensing images from cameras aboard instrumentation such as tethered balloon and satellites. Remote sensing can provide useful information with high accuracy regarding optimal irrigation management allowing to obtain information not only of the crop but also of the soil and environmental factors [4].

Study area

The study was conducted in Castelfranco Veneto (IT) on a field constituted of 4 plots of 40 x 40 m^2 each. Two different irrigation regimes were applied: full irrigation (application of 100% of the CWR) and regulated deficit irrigation (application of 70% of the CWR with 100% restoration between the beginning of flowering and the beginning of pod formation) as can be seen in *Figure 1*.

Figure 1: Field of study in Castelfranco veneto

Irrigation was managed by referring to probes capable of measuring soil moisture at three different depths (at 20, 40 and 60 cm) and with the data collected was calculated the water balance. Then consumption by evapotranspiration was obtained with the equation:

$$ET = I + P \pm \Delta S - R - D \tag{2}$$

Where ET is the evapotranspiration (in mm), I is the irrigation water (in mm), P is precipitation (in mm), ΔS is the change in soil water storage (in mm), R is surface runoff and D is deep percolation. Then with (1) was obtained K_c.

Satellite data and vegetation index calculation using multiband images

Images from Planetscope constellation have been used to calculate the indices. Planetscope is a constellation of 130+ Cubesat in sun-synchronous orbits which permits a revisit time of 24h on the field.

The satellites' camera operates in eight bands each one with a resolution of 3 m: Coastal Blue (431 - 452 nm), Blue (465 – 515 nm), Green I (513 - 549 nm), Green (547 – 583 nm), Yellow (600 - 620 nm), Red (650 – 680 nm), Red-Edge (RE) (697 – 713 nm), Near-Infrared (NIR) (845 – 885 nm).

The bands given by the camera allow to calculate numerous indices, each of these utilizes specific combination of spectral bands to capture different aspects of the crop health and vigour:

- Normalized Difference Vegetation Index (NDVI): used to assess the health and vitality of plants, allowing the recognition of areas with development issues. [5]

$$NDVI = \frac{NIR - Red}{NIR + Red} \tag{3}$$

- Green Normalized Difference Vegetation Index (GNDVI): GNDVI is a variant of NDVI that uses reflectance in the green band instead of the red band. This index is more sensitive to chlorophyll concentration and is used to determine the presence of water and humidity. [5]

$$GNDVI = \frac{NIR - Green}{NIR + Green} \tag{4}$$

- Normalized Difference Red Edge (NDRE): NDRE is an index combines reflectance in the Red Edge band with reflectance in the NIR band. This index is particularly sensitive to the presence of chlorophyll and is useful for assessing crop health and detecting water stress. [5]

$$NDRE = \frac{NIR - RE}{NIR + RE} \tag{5}$$

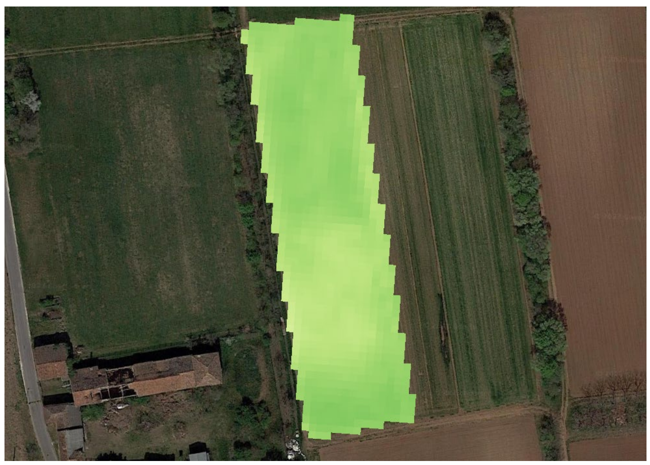

Figure 2: NDVI index of 15 July 2022

The purpose was to identify which index exhibited the strongest correlation with Kc.

The correlations aimed to determine which index could provide the most accurate estimation of K_c to study and compare the health of the two subplot.

Correlation of satellite based vegetation indexes and in situ based

The linear correlation was performed by considering the pixel mean value calculated for each of the two plots and the K_c data obtained from the water balance for each day when satellite data was available. The correlation coefficients were very close to each other, as can be seen in *Table 1*, so further analysis need to be conducted. In the meantime, this study helped defining the payload for the tethered balloon which will fly the next months to collect data on the variation of the indices over one day.

Table 1: Correlation coefficients between K_c and NDVI, GNDVI, NDRE for the two subplot

	70%CWR	**100%CWR**
NDVI	0,231445	0,23948
GNDVI	0,251871	0,23865
NDRE	0,272279	0,24143

Integration of balloon based multispectral images

The tethered balloon will fly over the field approximately once a month throughout the crop development phase. It will acquire data for at least one day at a height of 50 meters, providing a field of view of about 100 x 100 m^2, it will be positioned at the center of the field, acquiring with half of his Field Of View the field at 70% CWR and with the other half the field at 100% CWR.

It is equipped with a thermal camera, to measure the temperature of the crop and of the soil, and with two other cameras: a monochrome camera with a Red-Edge filter and a colored camera with a triple band filter in the bands of Blue, Green and NIR, to obtain data on the bands respectively of 735 nm, 475 nm, 550 nm and 850 nm.

In this way, the bands will be acquired to measure GNDVI, NDRE, and ENDVI (Enhanced Normalized Difference Vegetation Index) as substitutes for NDVI.

$$ENDVI = \frac{((NIR + GREEN) - 2BLUE}{((NIR + GREEN) + 2BLUE} \tag{6}$$

Conclusions

In conclusion, after acquiring data from the balloon and conducting a more detailed analysis of the correlations, it will be possible to effectively utilize the indices to assess the health status of the crop and optimize irrigation practices. This is especially crucial during a time when water resources are more critical than ever. By leveraging the information provided by the indices, farmers and irrigation can make informed decisions to ensure efficient water usage and maximize crop productivity while considering the limited water availability.

Acknowledgments

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