

CORRELATION ANALYSIS BETWEEN VEGETATION INDEX (NDVI) AND CANOPY COVERAGE (TOC) BASED ON REMOTE SENSING BY USING UAV

Simone Pascuzzi, Francesco Santoro, Alexandros Sotirios Anifantis, Vincenzo Cimino

University of Bari Aldo Moro, Italy

simone.pascuzzi@uniba.it, francesco.santoro@uniba.it, alexandrossotirios.anifantis@uniba.it,

vincenzo.cimino3@gmail.com

Abstract. Remote sensing in precision agriculture that is achieved by using Unmanned Aerial Vehicles (UAV) allows us to measure both the plant vigour and the water stress effect on the vegetation. It is possible to survey wide areas in relatively short times (e.g., 5-10 min/ha) with a ground resolution of 40mm/pixel (GSD). Ground Instantaneous Field of View (GIFoV) areas are collected and rendered to prescription maps (tiling and 2D orthorectification): these show the overall condition of the crops and highlight the areas subjected to water or nutritional stress. Identification of the water stressed areas allows the technician/operator to assess the spatial variability of the crop (simple ratio) first, and then conducting field interventions/experiments, such as fertilization plans, weeding, parasite/pathogen management strategies and so on. The aim of this paper is to study the maize crop health condition by means of the remote sensing technique using UAV through the study of the relation between NDVI and TOC. Remote sensing performed at the time (18/06/2018) led to the acquisition of the basic photograms used for building prescription maps meaningful to the agronomic evaluation of the crop condition and progress. The canopy reflectance data (NDVI) of the maize crop were statistically analysed via the Student's t-test. Although the agronomic inputs were uniformly distributed, including the strict genetic basis of the hybrid used, we can infer that such spatial variability is ascribable to the physic-chemical characteristics of the soil, its texture and, possibly, a surfeit of carbonates that compromises the availability of nutrients.

Keywords: remote sensing, UAV, vegetation index, maize crop.

Introduction

Precision agriculture represents the set of the information systems and of the geospatial techniques mediated by sensors (GIS, remote sensing, GPS) useful for measuring and analysing spatial and temporal variability of soil and crop conditions [1-3] and could be useful also in solving some problems related to agricultural activities ranging from the operators' health and safety [4;5], and environment protection [6;7].

Application of corrective strategies allows attenuation of this variability and improvement of the production systems from a technical, environmental and economic point of view [8-10]. Using more controls on inputs and dynamically managing corrective actions during cultivation means improving the process efficiency, using fewer energy resources (fertilizers, plant protection products, irrigation volumes, and so on) [11;12]. There is a strong link between precision agriculture and the process sustainability as well as the reduction of environmental impact. As it is known, remote sensing in precision agriculture allows to obtain, at distance, data concerning the soil or vegetation, or both combined [13]. By adopting multispectral, hyperspectral or thermal optical sensors on drone platforms, it is possible to measure the reflectance and the emissivity of canopy in specific wavelengths and to extract vegetation indices [14-16]. The optical measurements obtained by remote sensing allow to estimate the agronomic variables of the cultivated species, describing the reciprocal relationships existing between solar radiation and vegetation [17]. There are many studies carried out to demonstrate the correlation between the vegetation indices and the experimentally measured agronomic variables [18-22]. The purpose of the vegetation indices is to compare the marked difference between the low reflectance in the in red and blue wavelength of the visible band caused by photosynthesis, and the high reflectance in the near infrared (NIR) due to the scattering processes within the foliar mesophyll. The Simple Ratio (SR) and the Normalized Difference Vegetation Index (NDVI) are the most used intrinsic indices that consider only the reflectance as variables. Considering the reflectance $\rho_{(NIR)}$ in NIR and $\rho_{(RED)}$ in the red wavelength, SR is given by $\rho_{(NIR)}/\rho_{(RED)}$, whereas NDVI is obtained through the expression $[\rho_{(NIR)} - \rho_{(RED)}]/[\rho_{(NIR)} + \rho_{(RED)}]$ [23-25]. The NDVI index is a simple indicator, which can be used to analyse the spectrum-radiometric data of any living plant species, compared to bare soil. Plants perceive PAR (Photosynthetically Active Radiation), absorbing in the visible spectrum the light energy useful for the photosynthetic process. Conversely, in NIR spectrum, solar radiation does not carry enough energy to allow the synthesis of organic molecules, therefore, the plants reflect it almost all. As a result, plant cells protect their photosynthetic systems

from oxidative phenomena, dissipating excess heat (extra-PAR). Plants, in short, reflect little in the visible spectrum, more in NIR [26-28].

Furthermore, starting from the aforesaid spectre-radiometric data, instruments exist, which by means of suitable filters can distinguish the pixels occupied by the vegetation from the remaining ones allowing to evaluate the amount of the foliar coverage of soil also known as Top-Of-Canopy (TOC).

The aim of this paper is to study the maize crop health condition by means of the remote sensing technique using Unmanned Aerial Vehicles (UAV) through the study of the relation between NDVI and TOC.

Materials and Methods

Field equipment

The research was carried out at a farm located in the Southern Italy (Lucera, Foggia) on a 4-hectare flat land cultivated with a maize crop for grains (P0937-hybrid corn crop) placed on, as shown in Fig. 1a (the yellow line marks the boundaries of the field test).

Management of the agronomic inputs was the same for the whole surface. The irrigation system, however, divided the cultivation into two sectors (north and south), each of 2 ha. This plant allowed to supply water in rescue of the vegetation for a total of 2400 m³ of water, with a 3-day turn. On average, therefore, for both sectors, the daily water volumes per hectare distributed below the canopy were equal to 400 m³ (40 mm), for a total of 10 supplies (Fig. 1b).

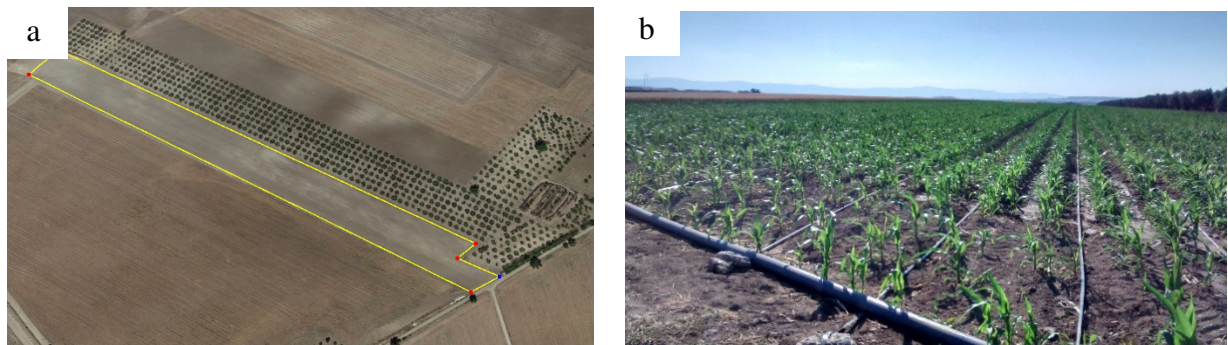


Fig. 1. **Field test:** a – Land cultivated with maize crop under test; b – Maize crop on 21 June 2018

UAV, digital cameras and software employed

Remote sensing was carried out using a quadcopter equipped with a vertical axis induction multirotor, belonging to the LASE category (Low Altitude Short Endurance). The UAV, with dimensions of 72x72x72 cm and mass around 7 kg, was manoeuvred in order to perform short-duration flight missions and with a high accuracy of the surveys, compared to similar studies conducted in precision agriculture (Ground Sampling Distance-GSD 4cm/px). The UAV, at the time of the overflight, was simultaneously equipped with the following cameras: i) digital optical RGB YI Action Camera (Shanghai, China) fitted with a 15Mpx image sensor; ii) multispectral optics ADC snap, which creates images with a resolution of 1280x1024 px (Tetracam Inc, Chatsworth, CA, USA); iii) thermal camera Flir Vue Pro R fitted with an uncooled micro-bolometer as the thermal imager that allows resolution of 640x512 px and a spectral band within 7.5-13.5 μm (Flir System Inc., Wilsonville, OR, USA).

The multispectral camera used is fitted with a rectangular lens and a “Global Shutter” sensor, which allows to record at the same time the entire Ground Instantaneous Field of View (GIFoV) area framed by the sensor without distortion effects (motion blur, and other). The images acquired in the multispectral band are in the native format RWS. The software GPS-Distiller (Tetracam INC), later, converted in RAW format, suitable for post-processing carried out by means the PW2 (PixelWrench2, Tetracam INC) and Pix4D Mapper (Pix4D S.A., Switzerland) software. The drone followed a path specified by several waypoints with a speed of 4.8 m·s⁻¹, acquiring images with a 70 % overlap from a constant altitude of 70 m. During the drone flight the average air temperature was 37 °C.

Image processing

PW2 was used to: i) set the colour matrix useful for identification of the “vegetation pixels” (colour-processing function); ii) to attribute to each layer of the image file (24 bit depth) the correct λ spectral band (NIR-790nm, Red-660nm, Green-550nm) and finally iii) convert RAW files to TIF format (Fig.2a). Using PW2 software were extracted data to evaluate the NDVI and TOC variables that, with a statistical analysis (Student’s *t*-test), allowed to detect areas with different vegetative growth.

Pix4D Mapper was then used for the construction of the DSM (Digital Surface Model) (Fig. 2b), resulted of the assembly of perfectly aligned mosaic units, which was used for computational calculation of the reflectance maps ρ (NIR-790nm, Red-660nm) and for extraction of the NDVI vegetation index.

Statistical analysis

The stitching model in the multispectral band clearly highlights an area with reduced vegetative growth in the upper half of the south sector of the field, despite the management of the agronomic inputs being equal for the entire surface, as well as for the whole sector. This spatial variability was analysed through the statistical comparison of the NDVI data averages compared to those detected in the entire south sector. The objective was to understand whether the spatial variability recorded in the NDVI data of the stress area was due to chance (H_0 = null hypothesis), or there was an external disturbance factor that caused the phenomenon (H_1 = alternative hypothesis) [29;30]. The agronomic inputs were applied equally on the entire surface (organic fertilization, mechanical processing, mineral fertilization, irrigation flow rate of $10 \text{ l}\cdot\text{s}^{-1}$ at 0.1 MPa, no verified anomaly of the irrigation plant), so, with the proper precautions, the different physical-chemical composition of the soil is accepted as an alternative thesis.

Results and discussion

Red and NIR reflectance map and scale

Data processing allowed to build two maps of reflectance of the analysed maize cultivation related, respectively, to the Red and NIR radiation (Fig.2a and 2b). Post-processing results in a graphic model, in which each pixel is assigned a number in a scale of values, are highlighted by colour variable gradation.

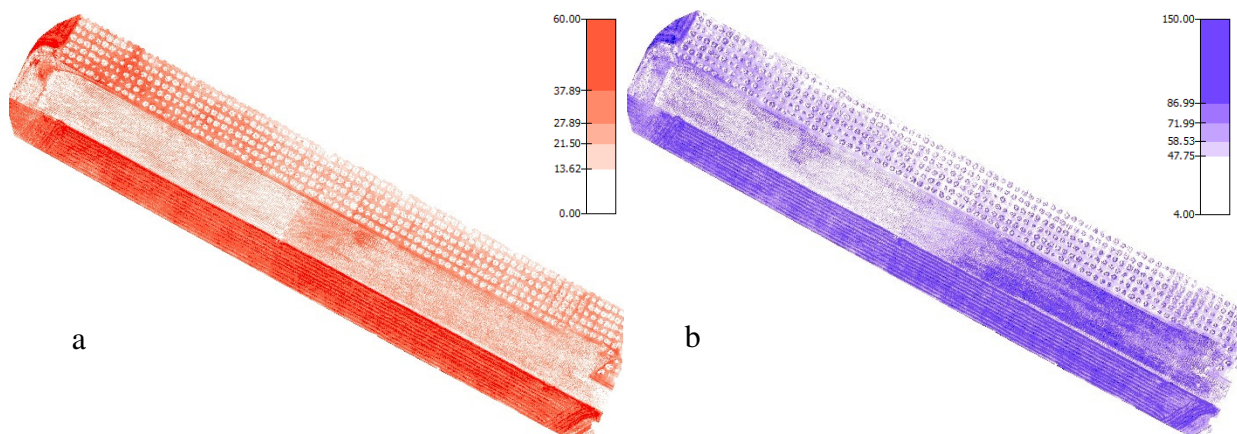


Fig. 2. **Reflectance map and scale:** a – Red; b – NIR

The red reflectance map, centred at the 660 nm band, shows reflectance gradients or inverting the reading scale of absorbance in the visible only relative to the south sector (Fig.2a). In this area, not completely homogeneous, the clearest pixels represent vegetation in good health and with a good level of development of the leaf apparatus compared to the soil (in red). This behaviour is due to the capacity of the plants to absorb almost completely the radiation in the Red, when they are in full vegetative activity, thus providing for the synthesis of organic molecules with photosynthesis. This consideration is realistic, because despite of the existence of a stressed area (central area), at the time

of the surveys the soil of the field related to the south sector was in the process of drying up the irrigation water (Fig. 2a).

Conversely, the north sector was irrigated at the time of the overflight and seems able to absorb almost all the radiation in the Red (light pixels) even more uniformly than in the south sector. It must be said, however, that the conditions of hydration of the soil due to the presence of rainwater and/or irrigation, with the relative emission of steam, may affect the results of remote sensing, altering the optical readings and thus providing false data about the real conditions of vegetation.

Therefore, the result related to the north sector of the field is probably unrealistic, also because an inspection carried out on the location showed a more stunted growth of plants and a small number of leaves issued by plants. In this regard, the scientific works showed that the greater the absorbance of plants in the Red spectrum, the more limited their development relative to the ability to produce biomass. Therefore, the influence of several combined factors, such as the soil moisture, evaporation of free waters produced by irrigation, the high air temperatures (temperature of 37 °C, at the altitude of 70 m), makes complex the evaluation of the physiological state of watered culture.

The reflectance map in the NIR radiation is the result of the data processing produced by the multispectral sensor, calibrated at the 790 nm band (Fig. 2b). The model shows densely blue coloured areas, while other ones have almost completely lacking colour. It is possible to hypothesize that the coloured areas of the cultivation are affected by an intense activity of biosynthesis, such that at the achievement of luminous saturation in the leaves there is an equally intense reflection for NIR.

We can conclude that the plants concerning the north sector, at the beginning of the irrigation time, have average high absorbance values in the Red radiation (corresponding to the minimum levels of reflectance), and low in the NIR radiation, due to the vegetative standstill caused by the high temperatures of the air and water stress. Conversely, there are medium-high levels of reflectance in NIR at the end of the irrigation period in the south sector, probably due to the growth metabolism, to the increase of refractive light phenomena inside the aerial spaces of the foliar parenchyma, as a consequence of the greater cellular turgidity and gaseous exchanges with the outside.

The reflectance maps in the Red and in the NIR radiation allowed to calculate for each pixel the NDVI vegetation index formula attaining to the definitive DSM of the NDVI index of the cultivation.

Statistical analysis

The Student's t-test applied in the analysis of the averages of a sample in deficit with the ones concerning a regular development highlights a significant value of t both unilateral ($\alpha = 0.05$) and bilateral ($\alpha = 0.10$). Therefore, based on the statistical data obtained and the wide margin of reliability of the Student's t-test, the validity of the thesis in the object H_1 is confirmed, that is the phenomenon is caused by an external disturbance factor. Concerning this, it is believed that in areas subject to physiological stress, excess in active limestone causes a localized increase in pH, which makes the nutritional elements supplied with mineral fertilization unavailable. Furthermore, the combination with the clayey component of the soil, in some limited areas, would also cause an increase in the water requirement, unlike the remaining cultivated areas. Therefore, there is a spatial variability of the soil with a different fertility gradient in the various areas, which can significantly affect the production, reducing the profitability of the crop.

Correlation NDVI-TOC

The interpolation of the NDVI and TOC data is reported in Fig. 3. The function is logarithmic with a positive correlation coefficient $r = 0.9345$ and linear regression $R^2 = 0.8732$.

This trend line, in describing the behaviour of the two variables, shows a more than proportional variation of the NDVI index in conditions of low canopy density; conversely, it is not very proportional (tending to asymptote) with higher coverage density.

The NDVI index seems to be able to provide more detailed information about the canopy structure only when this last one is vigorous. Therefore, according to this statement, probably it is appropriate to carry out surveys aimed at evaluation of the NDVI before the end of the vegetative stage of the crops, limit beyond which the saturation occurs.

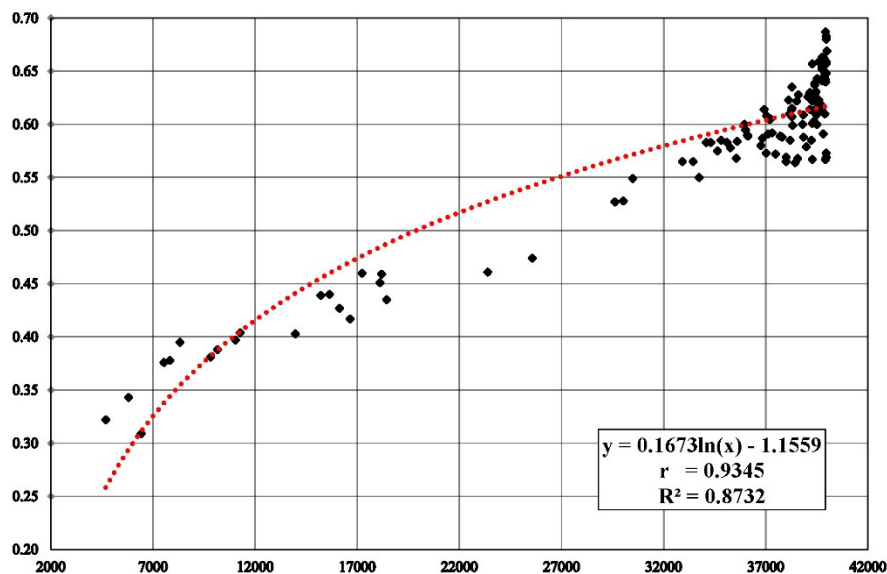


Fig. 3. NDVI – TOC correlation

Conclusions

1. Images were acquired by means of multi-spectral sensors arranged on a drone, which flew over the maize crop extending for 4.0 ha, which was divided into two sectors (north and south). Data processing allowed to analyse the reflectance of the cultivation related, respectively, to the Red and NIR radiation.
2. The plants concerning the north sector, at the beginning of the irrigation time, had average high absorbance values in the Red radiation (corresponding to the minimum levels of reflectance), and low in the NIR radiation, due to the vegetative standstill caused by the high temperatures of the air and water stress. Conversely, there are medium-high levels of reflectance in NIR at the end of the irrigation period in the south sector, probably due to the growth metabolism.
3. The statistical data analysis of NDVI and TOC highlighted that the zones with reduced vegetative growth could be due to an excess in active limestone that locally increasing in pH makes the nutritional elements supplied with mineral fertilization unavailable.
4. Analysing the correlation between NDVI and TOC seems that the NDVI index can provide more details about the canopy structure only when this last one is vigorous.

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The authors equally contributed to the present study.

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