# CAN THE SATELLITE IMAGE RESOLUTION BE IMPROVED TO SUPPORT PRECISION AGRICULTURE IN THE VINEYARD THROUGH VEGETATION INDICES?

A. Bonfante[1]*, A. Brook[2], G. Battipaglia[3], A. Erbaggio[4], M. Buonanno[1], E. Monaco[1], C. Cirillo[5], V. De Micco[5]

[1]Institute for Mediterranean Agricultural and Forest Systems -CNR-ISAFOM, National Research Council, Ercolano-NA, Italy
[2]Spectroscopy & Remote Sensing Laboratory, Department of Geography and Environmental Studies, University of Haifa, Mount Carmel, Israel
[3]Department of Environmental, Biological and Pharmaceutical Sciences and Technologies, University of Campania "L. Vanvitelli", Caserta, Italy
[4]Freelance
[5]Department of Agricultural Sciences, University of Naples Federico II, Portici - NA, Italy

*Corresponding: antonello.bonfante@cnr.it

## Abstract

**Aim:** This study aims to show the application of a new methodological approach to improve the resolution of Sentinel-2A images and derived vegetation indices through the results from different vineyards.

**Methods and Results:** A multiscale fully-connected Convolutional Neural Network (CNN) was constructed and applied for the pan-sharpening of Sentinel-2A images by high resolution UAS-based orthophoto. The reconstructed data was validated by independent high resolution multispectral UAS-based imagery and *in-situ* spectral measurements. The reconstructed Sentinel-2A images provided a temporal evaluation of plant responses to environmental factors using selected vegetation indices. The proposed methodology has been applied on different vineyards in southern Italy. Here, the outputs of CNN were compared with morpho-physiological data, both collected *in-vivo* and reconstructed through the retrospective analysis of vine trunk wood (tree-rings). The functional anatomical traits and isotopic signals were measured and used to derive indices such as water use efficiency. The obtained results showed a valuable agreement between the vegetation indices derived from reconstructed Sentinel-2A data and plant hydraulic traits obtained from tree-ring based reconstruction of vine eco-physiological behavior.

**Conclusions:** The multiscale CNN architecture for remote sensing imagery pan-sharpening and reconstruction can overcome the constraints in use of satellite images in precision agriculture, by creating new fused data valid for applications that could not be supported by the original Sentinel multispectral or UVS data. The validation of such an approach on different and real vineyard systems, with data collected *in-vivo* and through retrospective analyses on tree-ring chronologies has shown great potential to extend the approach to other woody crop systems.

**Significance and Impact of the Study:** The integration between knowledge from different scientific domains represents a powerful approach to support the farmer in the field management and, at the same time, a valuable opportunity to study the plant adaptation to variable pedo-climatic conditions. This represents the base for understanding the vine adaptive capability and planning the actions for vineyard management under different climatic scenarios. Finally, emerging CNN methodologies can be implemented in DSS to support real-time monitoring of several parameters related to plant health status, to better follow plant growth in the field and evaluate its performance under changing environmental conditions.

**Keywords:** Precision agriculture, satellite image resolution, CNN, grapevine hydraulics, KTB group approach

## Introduction

Currently, the main goal of agriculture is to support the achievement of food security in a sustainable way through the improvement of use efficiency of farm resources, increasing crop yield and quality, under climate change conditions. Climate change is one of the major challenges for high incomes crops, such as vineyards for high-quality wines, since it is expected to drastically modify plant growth, with possible negative effects especially in arid and semi-arid regions of Europe.

In this context, the improvement of farm resources, as well as the reduction of negative environmental impacts of intensive agriculture (e.g. soil degradation), can be realized by means of high spatial and temporal resolution of field crop monitoring, aiming to manage the local spatial variability.

The monitoring of spatial behavior of plants during the growing season represents an opportunity to improve plant management, farmer income and to preserve environmental health, however, it represents an additional cost for the farmer. Then its diffusion is slowed down and with it the achievement of sustainable agriculture.

The most suitable platform for performing continuous land management and monitoring is satellite remote sensing. Due to its relatively coarse spatial resolution and limited observation by the pre-defined and fixed scale, multispectral satellite remote sensing imagery is applicable in large areas and imperfect in the non-fully closed canopy (e.g., soil and plant mixture) sites. The UAS-based imagery might provide detailed and accurate information across visible and near infrared spectral regions but this source is not reliable for temporal monitoring, (crucial for precision agriculture) with limitation in bands and then on vegetational indices provided. For these reasons, Convolutional Neural Network (CNN) approach can be constructed and applied to improve Sentinel-2A images resolution (pan-sharpening procedure) by high resolution UAS-based orthophoto.

This contribution reports the recent achievements in multiscale full-connected convolutional neural network (CNN) application for pan-sharpening of Sentinel-2A images by UAV images in vineyard. The study has requested synergic efforts of a multidisciplinary research group.

The reconstructed data was validated by independent multispectral UAV images and *in-situ* spectral measurements, providing a multitemporal evaluation of plant responses through a set of selected vegetation indices. The proposed methodology has been tested on morpho-physiological data gained from *in-vivo* analyses on vines and from the retrospective reconstruction of the eco-physiological vine behavior, by the evaluation of water conductivity and water use efficiency indices from anatomical and isotopic traits recorded in vine stem wood (tree rings). Details on the procedure are reported in Brook *et al*. (2020).

## Materials and Methods

The study area is located in a hilly environment of southern Italy (Paternopoli, Avellino, Campania region: Lat 40.961426°, Lon 15.062929°, 401 m a.s.l.), in the Fonzone-Caccese farm which is oriented to the production of high-quality wines (about 20 ha). The vineyard studied was an Aglianico cultivar (controlled designation of origin – DOC/AOC), planted in the 2006 with E-W row orientation and 2.2 × 1 m spacing (≈ 4545 vines/ha) and placed along a slope of 120 m length, with a 9% gradient. Vines are trained to cordon spur system.

The drone-based data was collected between July and September 2018 by a DJI Phantom 4 pro quadcopter and its standard camera, and RedEdge -MX Micasense camera (5 bands data) equipped on Matrice 600 DJI (flight altitude ~30m from the ground with a pixel size of 2 cm). The acquisition of both UAV and satellite imagery was nearly simultaneous, taking place at the same day in July 2018, but slightly different hours. The image was obtained from Copernicus Sci Hub as a Level 2A product. Atmospheric correction was performed by using the sen2cor (v. 2.4.0) software provided by ESA (Main-Knorn *et al.,* 2017). The ground spectra of the validation targets were measured with the portable field spectrometer OceanOptics USB4000 and NIR-FLAME which consists of hundreds of wavelengths ranging between 350 and 1800 nm, with bandwidths of 0.5 nm in the VNIR region (350-1100 nm) and 10 nm in SWIR region (950-1800 nm), and wavelength accuracy of ±1 nm/±5 nm.

Past eco-physiological behavior of vines was reconstructed by analyzing tree-ring series. Common dendro-ecological techniques to build tree-ring chronologies are applied. Core sampling was carried out by means of an increment borer (diameter 5 mm) at a 30 cm height. Wood cores were seasoned in a fresh-air dry store and sanded with different grain size paper. Semi-thin (15-20 $\mu$m) cross sections from each core were obtained through the sliding microtome and observed under an epi-fluorescence microscope (BX51 Olympus, Germany) with settings to detect the autofluorescence of lignified cell walls. Digital images of the sections were collected with a digital camera (EP50, Olympus) and the microphotographs were analyzed with software programs to quantify wood anatomical traits. Measured parameters included: ring width, vessel lumen area, hydraulic diameter (Hd) and potential hydraulic conductivity (Kh). The C stable isotope composition was also measured by continuous-flow isotope ratio mass spectrometry to calculate the intrinsic water use efficiency (WUEi) per each ring or pools of rings.

A multiscale fully-connected Convolutional Neural Network (CNN) was constructed and applied for pan-sharpening of Sentinel-2A images by UAV images across VIS-NIR-SWIR bands. Among numerous spectral vegetation indices (VIs), the following were calculated: NDVI (normalized difference vegetation index), GNDVI (green NDVI), RENDVI (red-edge NDVI), and NDII (normalized difference infrared index).

**Result and Discussion**

The Sentinel-2A data has been widely used for production management in large and homogeneous areas (e.g. Zarco-Tejada et al., 2019). However, site-specific variability, oriented to a precision agriculture management, cannot be reflected in these data. Figure 1 shows Sentinel-2A image from Fonzone site collected on May 2017 paired with the NDVI map, versus the results obtained by the suggested multiscale CNN approach and its NDVI map. Prior to applying VIs and crop analysis, the performance of the network with fixed settings was tested and confirmed.

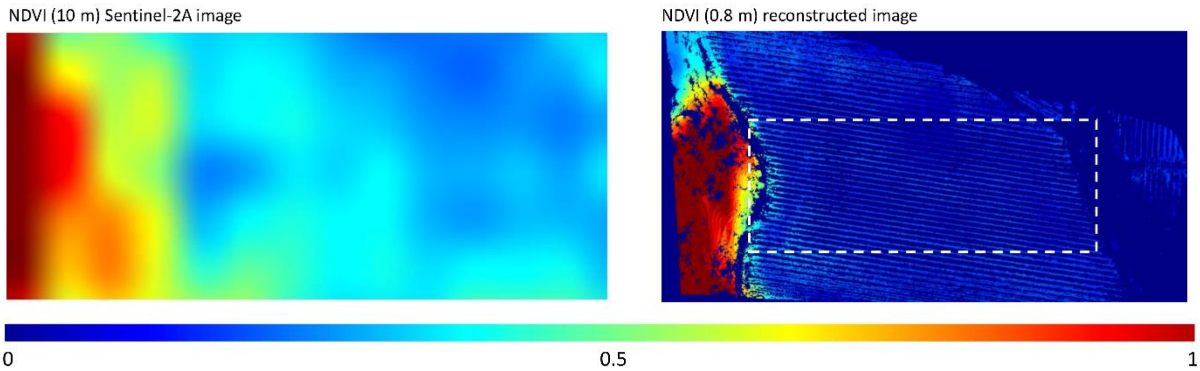


**Figure 1:** Example of NDVI maps scaled from 0 to 1 for the original Sentinel-2A data (10 m), and the reconstructed image via multiscale CNN (0.8 m) in Fonzone vineyard in the middle of May 2017.

Due to the low spatial resolution of the Sentinel data, it is impossible to separate the effects of the soil from the effects of the crops prior to calculating any vegetation index for any given pixel in the vineyard (Fig. 1), where effective canopy covers is only 25% of the total surface area for vertical images (Brook *et al.,* 2020).

The applied methodology is able to use the high temporal and spectral resolution of satellite data (Sentinel-2A pass every 2-3 days) improving the spatial resolution (combining the pro and cons of space-borne and UAVs data), and then providing a tool useful to better manage the variability of plant responses in the vineyard.
To evaluate the reliability of the approach, the model has been applied to analyze the period from 2015 to 2018, and the obtained results compared with plant measurements. In particular, in agreement with the farmer, the effectiveness of the method was tested in two sub-zones of the vineyard where vines showed different growth behavior and response to environmental constraints in the year 2015.

The obtained results showed a good agreement between the vegetation indices obtained from reconstructed Sentinel-2A data and plant measurements obtained from tree-ring based retrospective reconstruction of vines eco-physiological behavior. The correctness of the reconstruction was confirmed by both the data about the morphological development and production recorded *in-vivo* in the year 2015 and by anatomical and isotopic data in tree rings from 2015 to 2018.

**Conclusion**

The integration between knowledge from different scientific domains represents a powerful approach to support the farmer in field management and, at the same time, a valuable opportunity to study the plant adaptation to variable pedo-climatic conditions. This represents the base for understanding the vine adaptive capability and planning the actions for vineyard management under different climatic scenarios.

The multiscale CNN architecture for remote sensing imagery pan-sharpening and reconstruction can overcome constraints in satellite and UAV data application in precision agriculture, by creating new fused data valid for applications that could not be supported by the original Sentinel multispectral or UVS data.

The assessment of plant hydraulic behavior from 2015 to 2018 through anatomical and isotopic traits in tree-ring series proved to be useful to validate the output of the CNN image reconstruction methodology. The latter was able not only to reconstruct, at a very fine spatial resolution (i.e. the sub-plot), the indexes related to plant growth, canopy evolution throughout the growing season and plant water status, but also to differentiate plant behavior at the inter-annual scale. This validation approach shows a great potential to extend the CNN approach to other woody crop systems and forests. Moreover, emerging CNN methodologies can be implemented in DSS to support real-time monitoring of several parameters related to plant health status to better follow plant growth in the field and evaluate its performance under changing environmental conditions.

Finally, we can conclude that, in general, the integration between knowledge from different scientific ambits (remote and proximal sensing, botany, ecophysiology and pedology) represents a powerful approach. In particular, in vineyard, such a multi-scale, multi-temporal and multi-disciplinary approach can be considered a good opportunity to support the farmer in field management and at same time a valuable mean to study the plant adaptation to pedo-climatic conditions. The latter represents the base to understand the vine adaptive capability and plan the actions for vineyard management under different climatic scenarios. Indeed, emerging CNN methodologies would support a real-time monitoring of several parameters related to plant health to better follow plant growth in the field and evaluate its performance depending on changing environmental conditions. This would provide real-time evaluation of plant performance to design precision agriculture and forestry management.

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