SYNERGY OF SENTINEL-2 SATELLITE DATA WITH AN UNMANNED AIRCRAFT SYSTEM (UAS) FOR PRECISION AGRICULTURE: A PILOT VINEYARD IN GREECE

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ABSTRACT

Site-specific agricultural analysis is performed for a pilot vineyard in regard to possible stress factors, irrigation issues, crop vigor, hydrological behavior etc., utilizing airborne and space-borne remote sensing (RS) techniques.

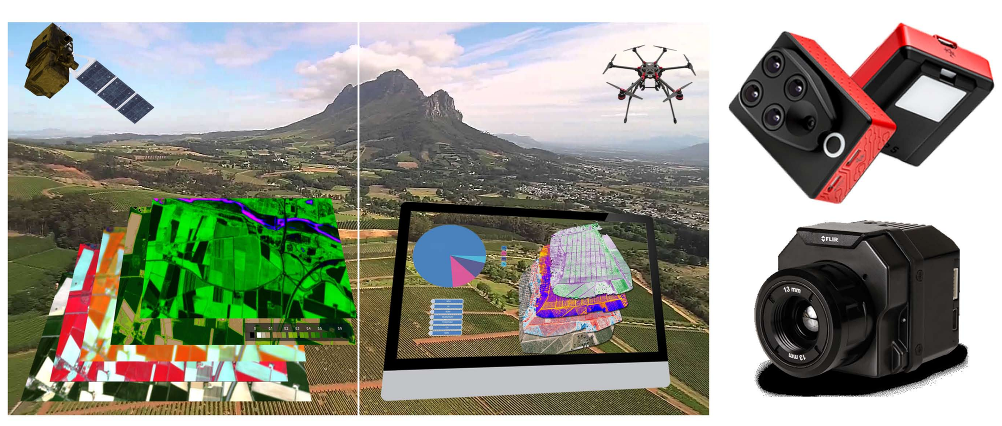
The pilot site was chosen because of its high internal variability in order to assess the sensors data and examine their potential.

The current study exercises precision agriculture for vineyards, otherwise called **precision viticulture**, employing a **hexacopter Unmanned Aerial Vehicle (UAV) with thermal and multispectral RS payloads:**

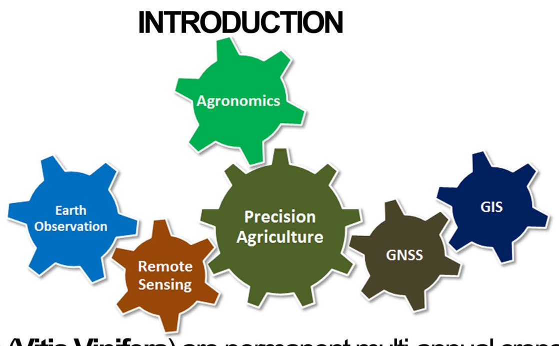
- the **Parrot SEQUOIA** four-band multispectral and panchromatic sensor array
- the **radiometric Flir Vue Pro R thermal camera**

The multispectral, panchromatic and thermal datasets were processed through a photogrammetric pipeline from Pix4D software in order to create **orthomosaics**. These orthomaps were employed to compute Vegetation Indices like the **Normalized Difference Vegetation Index (NDVI), the Red Edge Chlorophyll Index (CI-RedEdge)** and others, photointerpret and analyze them.

The pilot vineyard is also examined for the temporal variation of its several characteristics through the open **Sentinel-2 satellite images**, atmospherically corrected, in order to provide a consistent approach to the remotely sensed vineyards.



INTRODUCTION



Grapevines (**Vitis Vinifera**) are permanent multi-annual crops and precision agriculture (PA) for grapevines is called **Precision Viticulture (PV)**.

PV acknowledges that inherent variable production systems are existent within vineyards and the objective is to control and deliver decisions and expected outcomes managing those variabilities in multiple ways:

- vegetation condition: needs, stress and growth;
- irrigation/water management of the farming fields;
- better management of fertilizers, pesticides and other agrochemicals;
- macro- and micro- meteorological profiles of the area and the vines themselves;
- soil status, field structure and topography;
- crop forecasting and yield predictions;
- initial vineyard architecture for the rowing and spacing of the plants; various components like sentinel vines, trees etc.;
- cultivation practices like pruning and ploughing.

The PV zonal approach provides insight over vines'

- **structural properties** like the canopy Leaf Area Index (LAI), leaf layers, density;
- **biochemical properties** e.g. anthocyanins/carotenoids/phenolics content, pH;
- **other properties** like brix, biomass and berry weight correlated with the above.

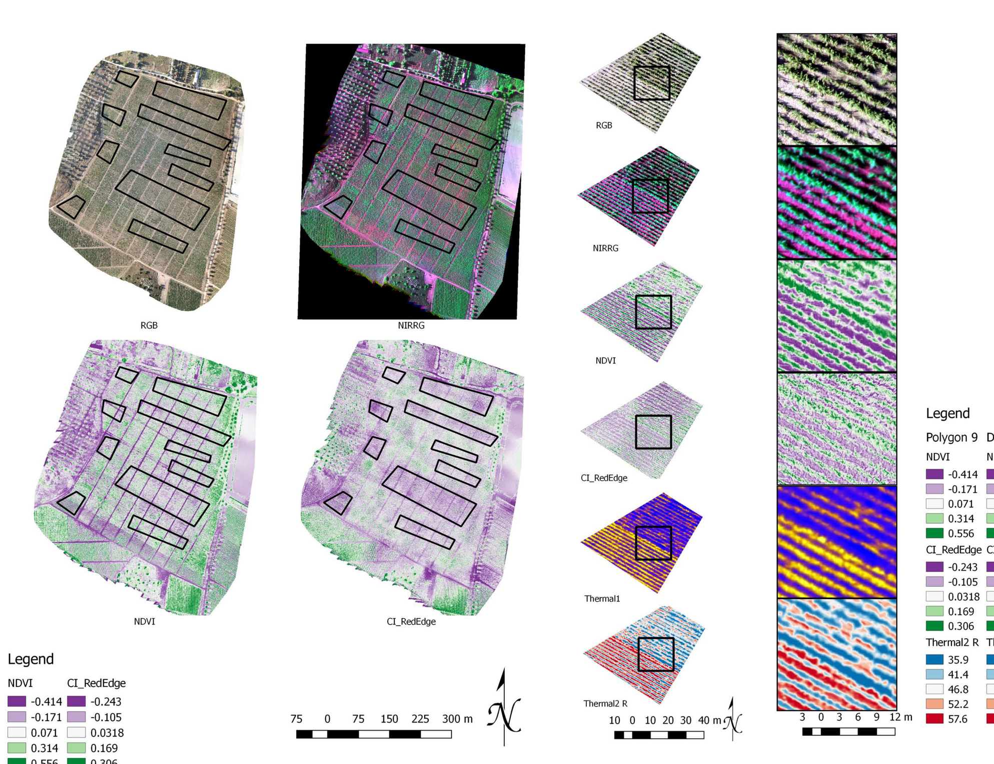


Figure 1: ROIs or zones of interest

OBJECTIVE

Vineyards through the PV perspective should be monitored

- **Spatially** in the context of the field they are planted in, determining **discrete regions and zones of spatial variability within (Figure 1)**;
- **Temporally**, through time series of observations and status monitoring. Copernicus satellite EO data provide this monitoring capacity (**Figures 8, 9**).

PV provides strategic advantages towards determining precautionary measures, diagnosis, treatment and optimization in quality and quantity.

In the traditional and empirical approach of vines cultivation and farming, these aspects are treated homogeneously, resulting in a series of disadvantageous and inefficient practices, a waste of resources, potential public health issues and lower quality products.

The pilot vineyard explored under the PV prism is located in **Attika, Greece**, engulfed in the unique characteristics of the **Mediterranean basin**.

METHODS

- **UAV** 100m survey flights of ~20ha were conducted. The panchromatic, multispectral and thermal sensor payloads image sets were geolocated by the autopilot along with their positioning in omega, phi and kappa properties;
- **Pix4D** software and a particular photogrammetric pipeline generated orthomosaics through aerotriangulation and orthorectification.
- The multispectral orthomaps were transformed into useful **Vegetation Indices** (VIs): NDVI, SAVI, Red Edge Chlorophyll Index, RENDVI, GNDVI, GRVI.
- Cloud and shadow free **Sentinel2** datasets clipped to the area under inspection were used during the critical time of grape berry growth at summertime in the same period as the UAV flights were conducted (June 2017).

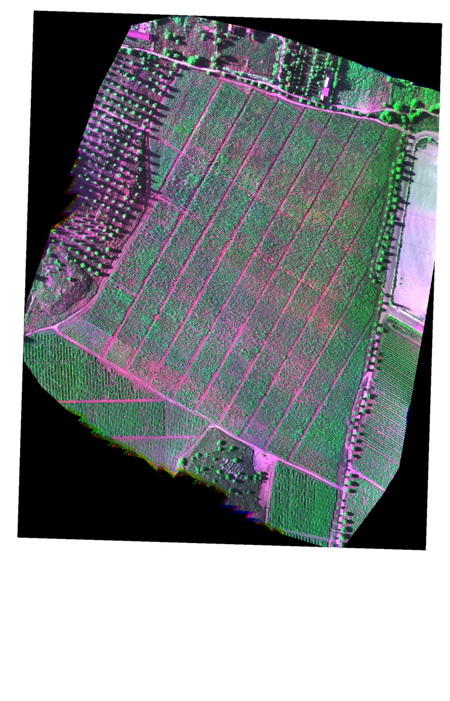


Figure 2: NIRRG false color composite

Figure 3: RGB composite

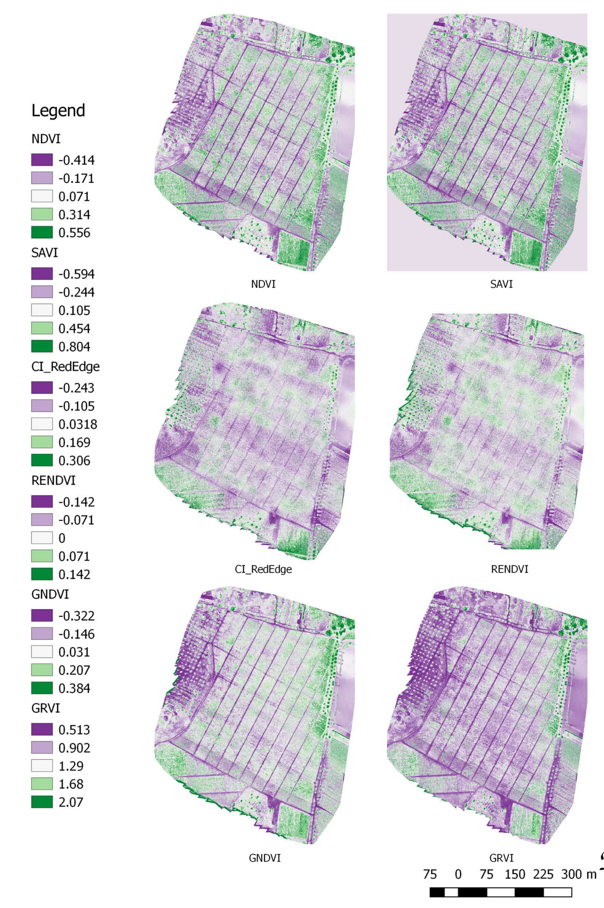


Figure 4: Vegetation Index maps

Vineyard survey orthomosaics:
RGB composite (Figure 3, pixel size: 2.7cm; orthomap size: 17068x22823 pixels);
NIR-Red-Green false color composite (Figure 2, pixel size: 10.6cm; orthomap size: 5000x6422 pixels);
Vegetation Index maps (Figure 4, pixel size: 10.6cm; orthomap size: 5000x6422 pixels).

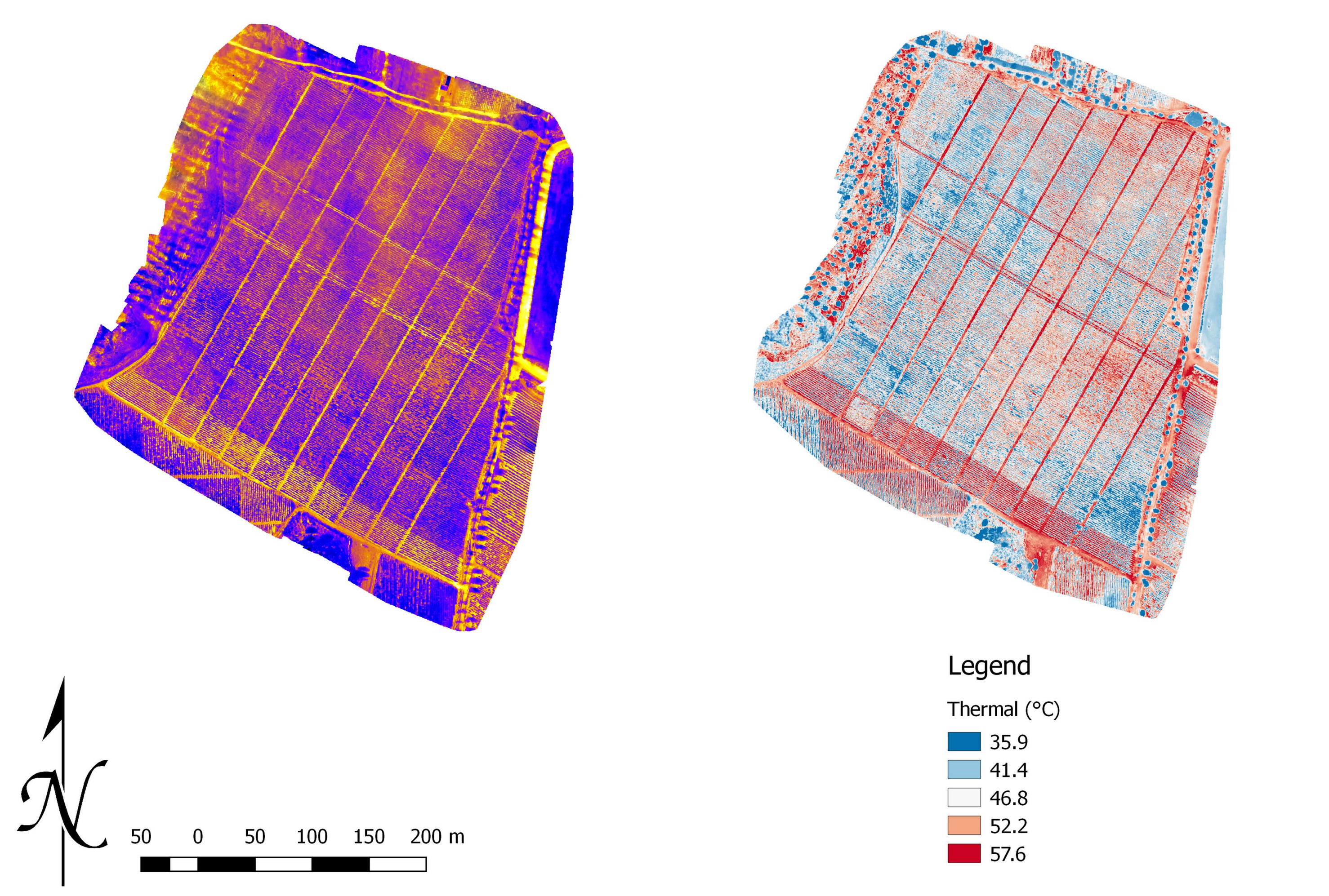


Figure 5: Thermal Infrared orthomaps

The two thermal orthomosaics generated in JPEG and TIFF format at different sun angles (shadowing effect assessment) from the thermal radiometric Flir Vue Pro R camera (Figure 5, pixel size: 13.3cm; orthomap size: 3741x4628 pixels).

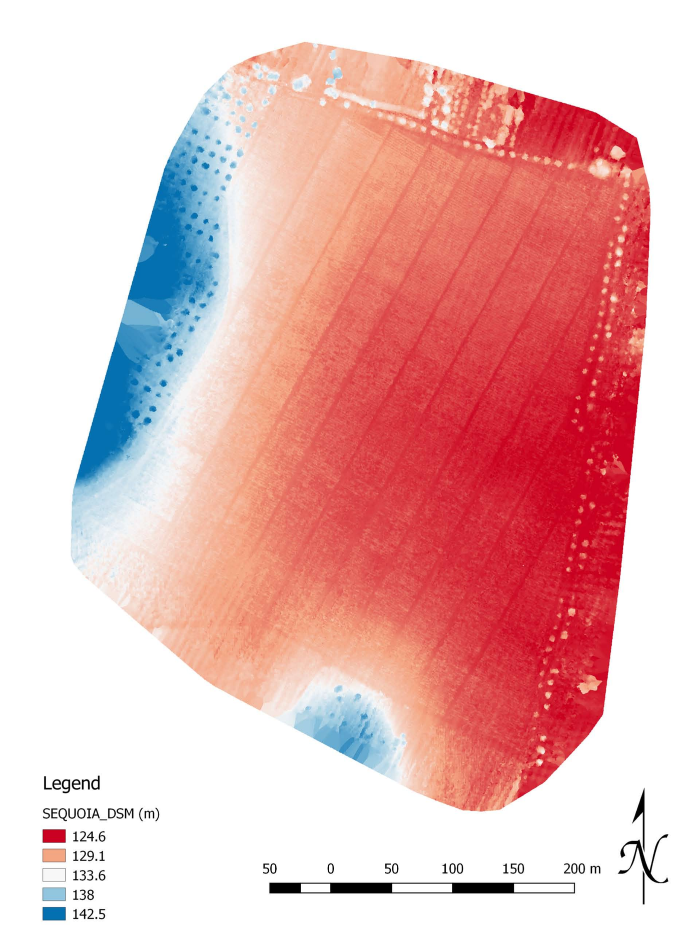


Figure 6: DSM

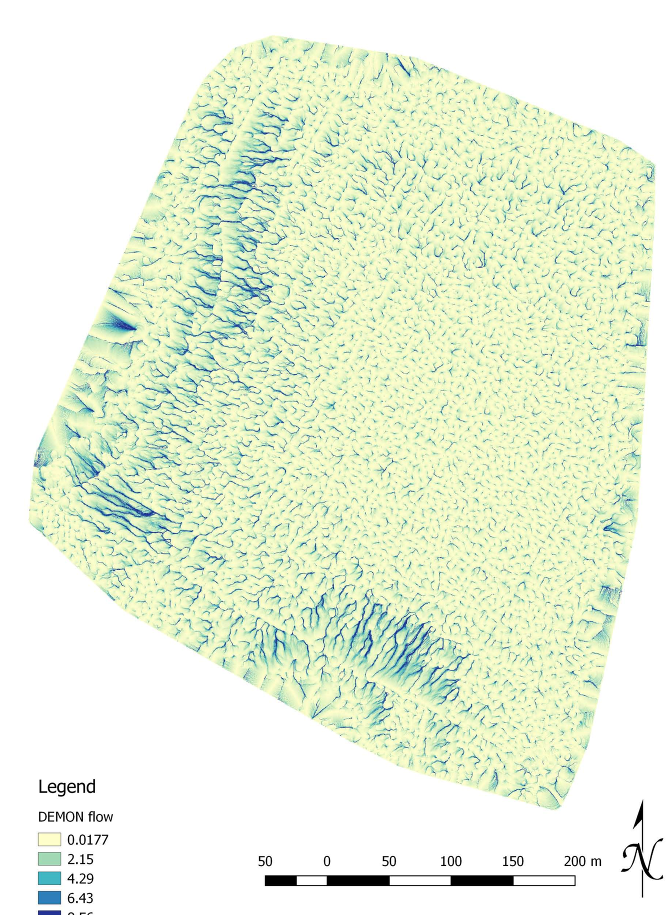


Figure 7: Hydrology map

The Digital Surface Model (Figure 6) and the hydrology map (Figure 7) generated using the DEMON algorithm

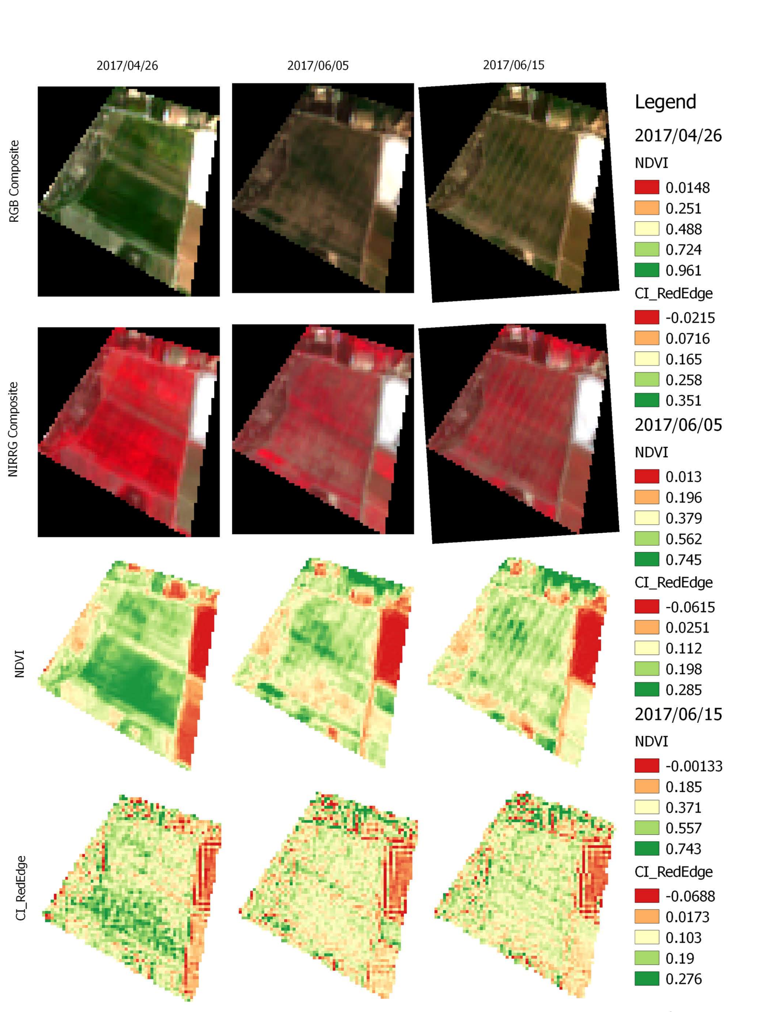


Figure 8: First set of Sentinel2 products

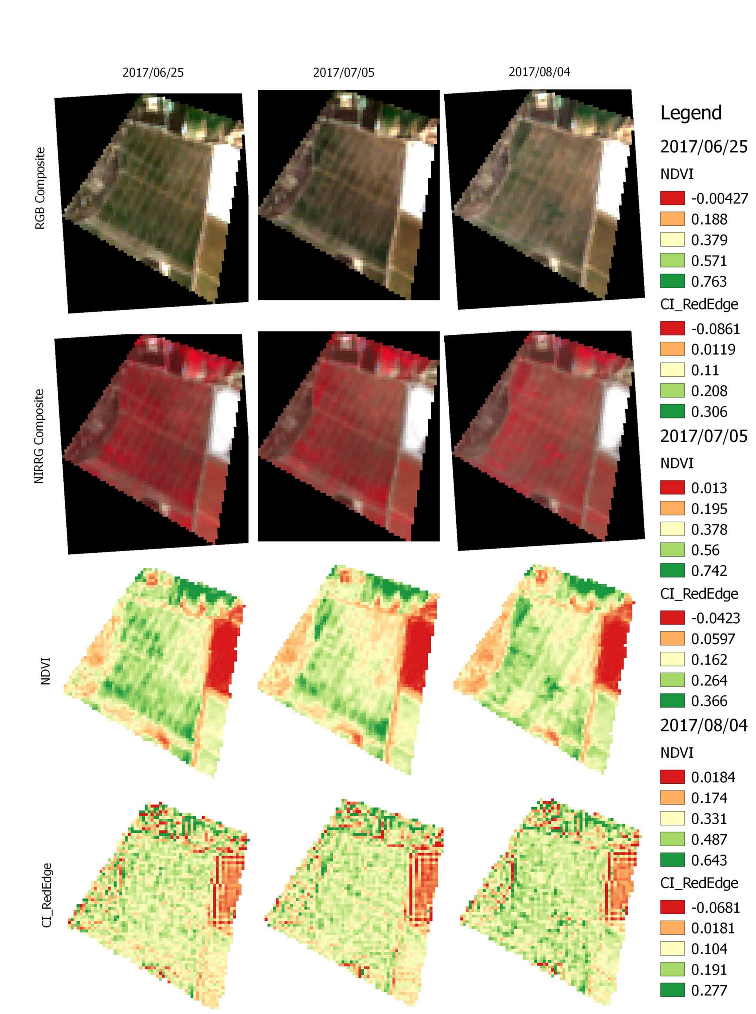


Figure 9: Second set of Sentinel2 products

The Sentinel2 datasets were atmospherically corrected and the bands used were the closest in central wavelength and bandwidth as the UAS multispectral Sequoia sensor. From the Red Edge bands, Band06 was used for the generation of the CI_RedEdge vegetation index.
RGB true color and NIR-Red-Green false color composites were also generated. (all products pixel size: 10m)

DISCUSSION

The ~15ha vineyard in the area monitored exhibits **very high internal variability** in multiple characteristics. This is the result of a very moderately cultivated vineyard mainly used for educational purposes, highlighted even more when compared with surrounding visible in the orthomaps professionally cultivated vineyards.

This enables the discrimination and very vivid presentation of the **zones** and the **variability factors** depicted in the generated VIs and orthomaps. In-situ analysis and validation is needed in order to assess the true nature of the variability factors, visible or non.

Those factors were observed to be:

- Missing vines;
- Lower vines growth rate or senescence due to watering, fertilization, infestation and other stress factors, as shown by the VIs and the photosynthetic activity/chlorophyll concentration;
- Higher soil vegetation under the vines and between the vineyard planted rows;
- Anthropogenic activities like ploughing;
- Irrigation and hydrological behavior;
- Plants and vegetation thermal conditions: Pathogen stressed plants (by e.g. fungi, foliar bacterial plant pathogens) may result in internal heat accumulation and a rise in canopy temperature. The plant's stomata are forced to close, ceasing to transpire, while pathogen ruptured epidermis is causing water loss. This translates into less CO2 diffusion, photosynthesis disruption and the deterioration of the plant's health and growth, interfering with protein and later chlorophyll synthesis.

The VIs generated were assessed on their overlapping information and specific purpose. The most potent ones for vineyards surveying purposes were chosen mainly by photointerpretation.
The well-known **NDVI and the CI_RedEdge were proven to be the most informative ones**, exploiting the most efficient for vegetation spectral reflectance characteristics at wavelengths from the **Red**, the **Near Infrared (NIR)** and the **Red Edge** parts of the electromagnetic spectrum (Figure 10).

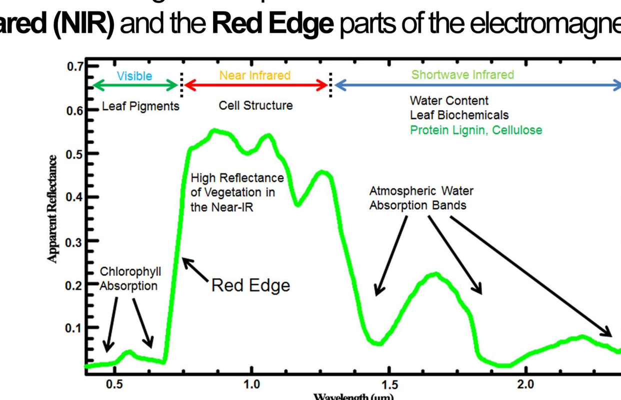


Figure 10: Vegetation reflectance spectrum (Source, modified: Mark Elowitz)

The indices values were mathematically compared between the overall values and the ROIs under specific inspection and **a shift to lower values was evident** both for the NDVI and the CI_RedEdge. Indicatively, Polygon09:

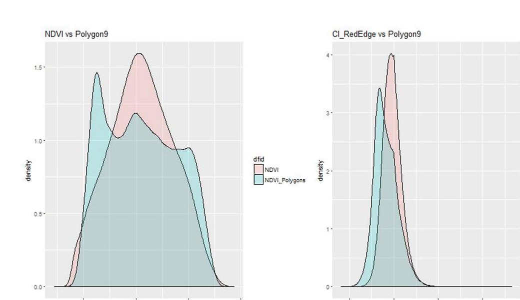


Figure 11: Polygon09 and ROIs index comparisons

The Sentinel-2 time series during the vineyard critical growth stage showed generic observations related to anthropogenic activities, the plants vigor and the zones potentially threatened by stress factors and irrigation possible issues.
Open and cost-free satellite imagery from Copernicus thus provides valuable information considering a relatively large vineyard.
Time consistent data can produce alerts for in-situ analysis and provide knowledge over expanding infestations, nutrient deficiencies etc.

CONCLUSIONS

The main purpose of the Precision Viticulture experiment is a showcase, an exhibition, a proof of concept and a preliminary analysis of the remotely sensed results with suitable scientific precision tools.
The results are highly satisfying in quality and richness, while demonstrating the potential of such a systematic monitoring formula.

In regard to the future perspective, it is well defined that remotely sensed data sets should be **validated and confirmed** in a detailed way through ground truth data and near-future observation and measurements.

Combining satellite imagery from Sentinel2 and UAV mosaics and analysis are the first **chain components of a holistic robust procedure** that integrates:

- **Space-borne**: Satellites with multispectral and hyperspectral optical payloads in high and very high resolutions, SAR instruments;
- **Airborne**: UASs, Aircraft campaigns with vegetation monitoring instrumentation like thermal, multispectral and hyperspectral optical sensors, Radars;
- **Ground in-situ measurements**: ICT sensor grids for the vineyards local meteorological monitoring, soil characteristics like humidity, salinity and temperature, PAR sensors, non-destructive hand held tools for e.g. LAI and chlorophyll content measurements, berry samples and biochemical analyses etc.;
- **Information Technology platforms** synthesizing the above data streams to automatically extract and transform the useful agronomical knowledge from all the available inputs.

Such an agronomical engineering multidisciplinary approach to vineyards cultivation would provide consistent and trustworthy knowledge to science, the farming community, government and other interested parties.
Those layers of information can be thus exploited throughout the scientific community and commercially through service oriented solutions.

MAJOR REFERENCES

Arno, J., Mart?nez Casasnovas, J.A., Ribes Dasi, M., Rosell, J.R., 2009. Review. Precision viticulture. Research topics, challenges and opportunities in site-specific vineyard management. Spanish Journal of Agricultural Research 7, 779. doi:10.5424/sjar/2009074-1092
Bannari, A., Morin, D., Bonn, F., Huete, A.R., 1995. A review of vegetation indices. Remote Sensing Reviews 13, 95–120. doi:10.1080/02757259509532298
Bramley, R.G.V., 2005. Understanding variability in winegrape production systems 2. Within vineyard variation in quality over several vintages. Australian Journal of Grape and Wine Research 11, 33–42. doi:10.1111/j.1755-0238.2005.tb00277.x
Chen, C., 2015. Determining the Leaf Emissivity of Three Crops by Infrared Thermometry. Sensors 15, 11387–11401.
Clevers, J.G.P.W., Gitelson, A.A., 2013. Remote estimation of crop and grass chlorophyll and nitrogen content using red-edge bands on Sentinel-2 and -3. International Journal of Applied Earth Observation and Geoinformation 23, 344–351. doi:10.1016/j.jag.2012.10.008
Delegido, J., Verrelst, J., Alonso, L., Moreno, J., 2011. Evaluation of sentinel-2 red-edge bands for empirical estimation of green LAI and chlorophyll content. Sensors 11, 7063–7081.
Fuchs, M., Tanner, C.B., 1966. Infrared thermometry of vegetation. Agronomy Journal 58, 597–601.
Gitelson, A.A., Kaufman, Y.J., Stark, R., Rundquist, D., 2002. Novel algorithms for remote estimation of vegetation fraction. Remote sensing of Environment 80, 76–87.
Gitelson, A.A., Merzlyak, M.N., 1997. Remote estimation of chlorophyll content in higher plant leaves. International Journal of Remote Sensing 18, 2691–2697. doi:10.1080/014311697217558
Gudesblat, G.E., Torres, P.S., Vojnov, A.A., 2009. Stomata and pathogens. Plant Signal Behav 4, 1114–1116.
Hall, A., Lamb, D.W., Holzapfel, B., Louis, J., 2002. Optical remote sensing applications in viticulture - a review. Australian Journal of Grape and Wine Research 8, 36–47. doi:10.1111/j.1755-0238.2002.tb00209.x
Huete, A.R., Post, D.F., Jackson, R.D., 1984. Soil spectral effects on 4-space vegetation discrimination. Remote sensing of environment 15, 155–165.
Lamb, D.W., 2000. The use of qualitative airborne multispectral imaging for managing agricultural crops - a case study in south-eastern Australia. Australian Journal of Experimental Agriculture 40, 725. doi:10.1071/EA99086
Landgrebe, D., 1999. Information extraction principles and methods for multispectral and hyperspectral image data. Information processing for remote sensing 82, 3–38.
Moran, M., 1997. Combining multifrequency microwave and optical data for crop management. Remote Sensing of Environment 61, 96–109. doi:10.1016/S0034-4257(96)00243-X
Poni, S., Intrieri, C., Silvestroni, O., 1994. Interactions of leaf age, fruiting, and exogenous cytokinins in Sangiovese grapevines under non-irrigated conditions. I. Gas exchange. American Journal of Enology and Viticulture 45, 71–78.
Reddy, K.R., Zhao, D., 2005. Interactive effects of elevated CO2 and potassium deficiency on photosynthesis, growth, and biomass partitioning of cotton. Field Crops Research 94, 201—213. doi:10.1016/j.fcr.2005.01.004
Rouse, J.W., Haas, R.H., Schell, J.A., Deering, D.W., n.d. Monitoring Vegetation Systems in the Great Plains with ERTS
Rubio, E., Caselles, V., Badenas, C., 1997. Emissivity measurements of several soils and vegetation types in the 8–14, μm Wave band: Analysis of two field methods. Remote Sensing of Environment 59, 490–521.
Schellberg, J., Hill, M.J., Gerhards, R., Rothmund, M., Braun, M., 2008. Precision agriculture on grassland: Applications, perspectives and constraints. European Journal of Agronomy 29, 59–71. doi:10.1016/j.eja.2008.05.005
Steele, M., Gitelson, A.A., Rundquist, D., 2008. Nondestructive estimation of leaf chlorophyll content in grapes. American Journal of Enology and Viticulture 59, 299–305.
Trishchenko, A.P., Cihlar, J., Li, Z., 2002. Effects of spectral response function on surface reflectance and NDVI measured with moderate resolution satellite sensors. Remote Sensing of Environment 81, 1–18. doi:10.1016/S0034-4257(01)00328-5
Zhang, N., Wang, M., Wang, N., 2002. Precision agriculture - a worldwide overview. Computers and Electronics in Agriculture 36, 113–132. doi:10.1016/S0168-1699(02)00096-0

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