Towards sustainable viticulture: key role of vineyard's precision monitoring

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1. INTRODUCTION

Nowadays, agriculture faces new challenges and threats, some of the most important being related to environmental and climate issues. In the specific case of viticulture, according to the International Organization of Vine and Wine, EU is the world leading producer and exporter of wine and still encompasses the largest vineyard area in the world (38%) representing 20% of total agricultural employment in the EU (being mainly composed of small producers). The critical environmental impacts of grape production come from the intense use of pesticides, from the very high variability of the amount of fertilizers and from energy consumption related to the application of fertilizers and pesticides and for irrigation, pruning and tillage which are normally done with diesel tractors. EU regulations highlight the strong need to reduce pesticides (e.g. the recent EU regulation of 13 December 2018 restricts the use of plant protection products containing copper pesticides in order to minimize the potential accumulation in soil and the exposure for not target organisms). The impact of global warming on wine growing European regions is increasing and vast portions of the Mediterranean basin may become completely inhospitable (warmer) to grape production by 2050. In particular, changes in temperatures and humidity may increase the presence of pest and diseases as their temperature limits move poleward. In this contest, vineyards can require lots of external inputs (water, pesticides and fertilizer) to reduce biotic and abiotic stressors and to ensure grape production Moreover, it is also important to note that the intense use of fertilizers significantly contributes to the production of ammonia and to the eutrophication phenomena. Most of EU vineyards are today based on traditional agronomy management and they have not been significantly driven by technology. The increased consumer awareness of environmental impact of viticulture and the importance of wine quality in relation to human health are encouraging the practice of alternative agronomic strategies, and the world of wine is heading towards a transformation enabling Precision Agriculture (PA) applied to viticulture. The objective is to gain in efficiency, in productivity and overall in quality of wine. New technologies can help winegrowers in the decision-making process in order to adapt their production mode in their vineyards using new devices (sensors, robots and drones) and digital techniques to monitor and optimize agriculture production processes. At the moment, a lot of progress has been made in PA development and the PA market is fully embraced by the sector and investors, but the full potential of PA has not yet been harnessed.

The aim of the study is to present some results of the project 'AgriDrone vision'. The main objectives of project were to assess the potential use of remote sensing platforms (aerial and/or terrestrial) to determine vines' physiological status (e.g. water stress) during the growing season thereby proving temporal and spatial vine performances by proximal (field) no-destructive measurements.

2. DETAILS EXPERIMENTAL

2.1. Materials and Procedures

Study area

The site investigation was located in the southern western area of Umbria region (Central Italy) denominated 'Valnerina' (Figure 1). The Valnerina landforms derived by the action of the one of the main Umbria's river: the Nera. In the upper site, the Nera cuts ravines in the mountains, while in lower it created a wide floodplain before flowing into the Tiber river.

This territory represents also an historical grape-wine growing area, where one of the first Umbria wine Designation of Origin, established in 1989, The PDO Amelia includes the municipalities of Attigliano, Giove, Penna in Teverina, Alviano, Amelia, Calvi dell'Umbria, Guardea, Lugnano in Teverina, Montecastrilli, Narni, Otricoli, Sangemini, Stroncone e Terni (Figure 1).

The wine-making suitability of Umbria region is known since 3000 years: here the Etruscans played a decisive role in the spread of the wine culture. Among grapevine landraces cropped in this area, the cv 'Ciliegiolo di Narni' from the 1200s nowadays it represents an Umbrian cv and wine excellence.

This geographic area is part of the Apennine Province, central Apennine Section, Umbria and Marche Apennine subsection (1C2a) (Blasi et al., 2017). The prevailing bioclimates are temperate semi- continental in main valleys of Umbria region. Annual precipitation ranges from 630 mm to over 2000 mm and presents a twofold maximum in autumn and winter, with increasing southward reduction of summer precipitation. Mean annual temperatures range between 10 °C and 15 °C under 1000 m a.s.l. and minimum temperatures in winter month are always below 3°C. (Blasi et al., 2017).

This area, has been classified as climate- vulnerable areas (Biasi et al., 2019). The annual mean temperature over the past two decades (1995–2015) increased over time in the study area (Figure 2). In particular, the average temperature in the second decade (2005–2015) it increased up to 14.7 °C. Simultaneously, area was characterized by an increase in the amount of precipitation and the average number of rainy days (precipitation > 1 mm) per year (Figure 3). Consequently, local climate regimes in the area changed from ‘warm–hot’ to ‘hot–very hot’ following a classification provided by Nesbitt et al., 2016.

Fig.1 Study area (above) the Umbria Region (central Italy) and in yellow the PDO Amelia where tested vineyard is placed (below).

According to Biasi et al., 2019 total phytosanitary treatments applied for the chemical control of powdery and downy mildew, exhibited exponential growth during the last 15 years, with significant differences observed during the growing season. In this contest climate characterization and permanent monitoring of phenological traits and berry biochemistry in accordance also to international protocols, are efficient tools to define strategic agronomic and canopy treatments to preserve berry health, yield and wine quality.

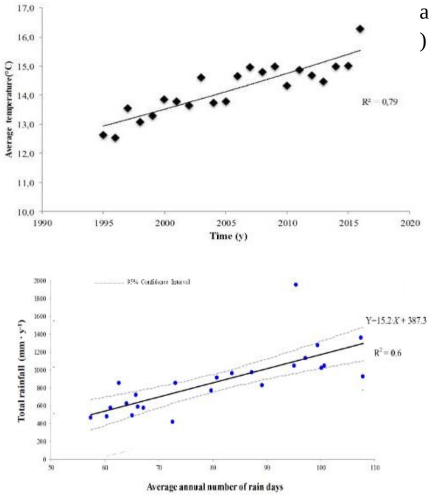

Fig.2 (a & b). Annual average temperature (°C) and linear relationship between total precipitation per year and annual number of rainy days (rain > 1mm/day) (1995 – 2015) in one traditional grape-wine growing area of Umbria region (Biasi et al., 2019).

Experimental design

The vineyard was divided in four units related to integrated canopy managements: e.g. foliar nutrition, leaf removal. For each unit, a block of 25 vines for a total of 20 m has been considered as sampled area for real time feedback of vines performances (vigour, leaf chlorophyll content and photosynthetic performance), health and berry quality, monitored during the growing season by field measurement, GRover’s platform and airborne campaigns (UAV).

Vegetation indices (Vis) based on leaf/canopy reflectance has been used as an indicator of plant function because green vegetation absorbs a greater portion of the light reflected and depend directly on a leaf’s pigment composition (e.g. chlorophylls), which can be correlated with the plants’ physiological status.

Description of airborne campaigns.

Data acquisition over the vineyard consisted of flight- lines acquired in sunny weather at midday. The flight mission was planned by GS Pro (Ground Station Pro) designed to control and plan automatic flights. In this study the flight mission was conducted at 20 m altitude and 4 m/s ground speed. Ortho-rectification was carried out using the Agisoft Metashape software and a high quality orthomosaic was generated. Next, ECognition Developer (Trimble Geospatial), a software enables to classify vines successfully separating vines from shaded, soil, etc. and integrate remotely sensed images (Benz et al,

2004) were used for segmentation and classification. Finally, the QGIS (geographic information system) software was used for calculating vegetation indices (VIs).

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3. RESULTS AND DISCUSSION

3.1. Testing of data and platform robustness

Preliminary measurements were encouraging and showed that field, GRover’s platform and UAV-based data collection were able to effectively and non- destructively capture detailed vegetative data for integrated canopy managements applied in vineyards. The provision of an adequate and well- exposed leaf surface to solar radiation affects the amount of photosynthesis and, therefore, the final synthesis and accumulation of compounds affecting grape quality (Hidalgo 2006).

3.2. Canopy characterization

Leaf area index (LAI) by using mobile terrestrial and aerial scanners was related to plant vigour and foliar development, an important parameter for many agricultural practices, pest and disease development. Of the various indexes related to the characteristics of grapevine foliage, LAI is probably the most widely used in viticulture and in according to Johnson et al. (2003) it showed a significant correlation ($R^2 = 0.72$) between the estimated leaf area per vine based some Vis, e.g normalized difference vegetation index (NDVI) or green leaf index (GLI – figure 3) based on RGB images and leaf area per vine obtained by field measurements.

At harvest time the proximal (field) and remote sensing monitoring of eco-physiological indices of leaves, such as chlorophyll concentration (μg · m^2) showed significant difference among canopy integrated treatments. In particular the integration of leaf removal to foliar nutrition (N) concurred to increase the photosynthetic pigments content (figure 4).

Fig.3. RGB GRover’s platform images, vegetational index (Green leaf index -GLI),bunch rot disease development during berry growth under standard canopy management and leaf removal treatment.

3.3. Berry quality and health status

Integrated canopy management could also concur to modify cluster architecture. The greatest changes to berry number per cluster, cluster weight, and yield per vine resulted from the application of leaf removal treatment. In particular, it’s used to regulate yield as a means to increase the quality of the grapes and decreasing cluster compactness on tight-clustered varieties for controlling cluster rot disease. In fact, during the season 2018 (very wet season) health quality of berry was safeguard only where this treatment was done (Figure 4), while under standard canopy management and under foliar nutrition treatment berries at harvest were affected by rot disease.

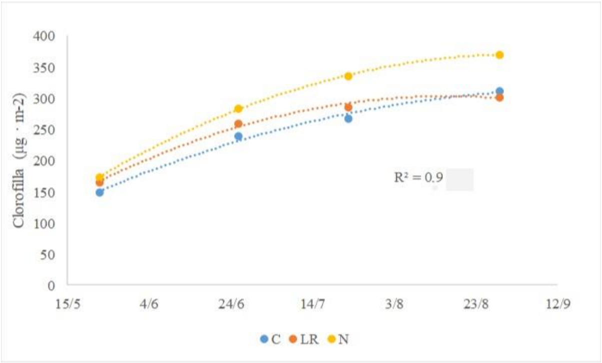


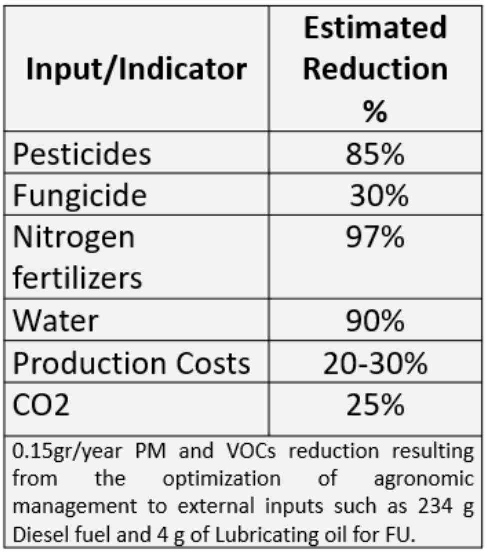
Fig.4. Eco-physiological indices (chlorophyll content in leaves by Grover’s platform data collection according to canopy integrated managements (standard – C; leaf removal – LR, foliar nutrition – N).

4. CONCLUSIONS

GRover's platform sensors with the configuration proposed in our approach provide a feasible method to monitor within-field vines eco-physiological traits and berry quality variability and can have several applications in precision viticulture.

According to findings the proximal sensing is a major candidate for becoming the favoured technique for identification of pest and disease but detection sensitivity of symptoms in the early-middle stage. This is possible while vines produce metabolic responses to biotic and abiotic stressors that could be detected by GRover's platform sensors.

The optimisation of agronomic management, such as leaf removal, and vineyard defense according to vegetational indices, vine health status, berry quality parameters could reduce the use of pesticides up to 85% and of the use of fungicide up to 30%. On the other hands all the external inputs will be reduced up to 97% for nitrogen applied to vineyards, up to 90% of water consumption thanks to precision drip vines irrigation linked to crops water stress index (CWSI) and in addition also the production costs will be improved by a reduction between 20 and 30% compared to no precision farming management. These results are summarized in the next Fig. 5 while all the external inputs for an average vineyard (area of 1 hectare characterized by a standard production of 10-15 tons of grape resulting from 5000-6000 vines and with a standard agronomic and phytosanitary management of 10 treatments per year among fungicide and insecticide are presented in Appendix A.



Input/Indicator	Estimated Reduction %
Pesticides	85%
Fungicide	30%
Nitrogen fertilizers	97%
Water	90%
Production Costs	20-30%
CO2	25%
0.15gr/year PM and VOCs reduction resulting from the optimization of agronomic management to external inputs such as 234 g Diesel fuel and 4 g of Lubricating oil for FU.	

Fig.5. Reduction of Input/indicators due to the optimization of agronomic management.

5. ACKNOWLEDGMENTS

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Appendix A: Viticulture Inputs

Viticulture inputs:	**1kg grape**		**100 q/ha**	**150 q/ha**	
Water	0.00073	m3	7.26	10.89	m3/ha
Land occupation	0.00011	ha	1.08	1.62	
Electricity	0.25900	kWh	2590	3885	kWh/ha
Diesel (agricultural machinery)	0.23400	kg	2340	3510	kg/ha
Phytosanitary products:					
Dithiocarbamate compounds					
Metiram	0.00103	kg	10.3	15.45	kg/ha
Thiocarbamate compounds					
Cymoxanil	0.00015	kg	1.51	2.265	kg/ha
Iprovalicarb	0.00021	kg	2.14	3.21	kg/ha
Acetamide-aniline compounds					
Phenexamid	0.00094	kg	9.4	14.1	kg/ha
Cyclic–N					
Tebuconazol	0.00013	kg	1.25	1.875	kg/ha
Penconazole	0.00004	kg	0.44	0.66	kg/ha
Phtalamide					
Folpet	0.00597	kg	59.7	89.55	kg/ha
Organophosphorus compounds					
Fosetyl-Al	0.00754	kg	75.4	113.1	kg/ha
Glyphosate	0.00396	kg	39.6	59.4	kg/ha
Unspecified					
Sulphur	0.02980	kg	298	447	kg/ha
Copper	0.00172	kg	17.2	25.8	kg/ha
Pyraclostrobin	0.00019	kg	1.94	2.91	kg/ha
Synthetic fertilisers:					
Ammonia nitrate	0.00780	kg	78	117	kg/ha
Ammonia sulphate	0.06480	kg	648	972	kg/ha
Urea ammonia nitrate	0.06280	kg	628	942	kg/ha
Solid manure	1.26000	kg	12600	18900	kg/ha
Transport of grape	0.01860	t.km	186	279	kg/ha
Transport of wine and must	0.01090	t.km	109	163.5	kg/ha
Emissions to air (due to fertilisers use):					
Ammonia	0.00002	kg	0.188	0.282	kg/ha
Nitrous oxide	0.00086	kg	8.59	12.885	kg/ha
Nitrogen oxides	0.00020	kg	2	3	kg/ha
Carbon dioxide (fossil)	0.01970	kg	197	295.5	kg/ha
Emissions to air (due to phytosanit products):					kg/ha
Dithiocarbamate compounds					kg/ha
Metiram	0.00026	kg	2.58	3.87	kg/ha
Thiocarbamate compounds					kg/ha
Cymoxanil	0.00004	kg	0.377	0.5655	kg/ha
Iprovalicarb	0.00007	kg	0.73	1.095	kg/ha
Acetamide-aniline compounds					kg/ha
Phenexamid	0.00024	kg	2.35	3.525	kg/ha
Cyclic–N compounds					kg/ha
Tebuconazol	0.00003	kg	0.314	0.471	kg/ha
Penconazole	0.00001	kg	0.11	0.165	kg/ha
Phtalamide compounds					kg/ha
Folpet	0.00149	kg	14.9	22.35	kg/ha

Organophosphorus compounds					kg/ha
Fosetyl-Al	0.00189	kg	18.9	28.35	kg/ha
Glyphosate	0.00099	kg	9.9	14.85	kg/ha
Unspecified					kg/ha
Pyraclostrobin	0.00002	kg	0.235	0.3525	kg/ha
Emissions to air (from diesel combustion):					
Carbon dioxide (fossil)	0.73900000	kg	7390	11085	kg/ha
Carbon monoxide (fossil)	0.00139	kg	13.9	20.85	kg/ha
Methane	0.000004450	kg	0.0445	0.06675	kg/ha
Nitrous oxide	0.000032300	kg	0.323	0.4845	kg/ha
Ammonia	0.00000187	kg	0.0187	0.02805	kg/ha
NMVOC	0.00027	kg	2.74	4.11	kg/ha
Nitrogen oxides	0.00482	kg	48.2	72.3	kg/ha
Particulates	0.00015	kg	1.47	2.205	kg/ha
Emissions to water (due to fertilizer)					
Nitrate	0.05760	kg	576	864	q/ha
Emissions to soil (due to phytosanit products):					
Dithiocarbamate compounds					
Metiram	0.00078	kg	7.75	11.625	kg/ha
Thiocarbamate compounds					
Cymoxanil	0.00011	kg	1.13	1.695	kg/ha
Iprovalicarb	0.00022	kg	2.19	3.285	kg/ha
Acetamide–aniline compounds					
Phenexamid	0.00071	kg	7.05	10.575	kg/ha
Cyclic–N compounds					
Tebuconazol	0.00009	kg	0.943	1.4145	kg/ha
Penconazole	0.00003	kg	0.33	0.495	kg/ha
Phtalamide compounds					
Folpet	0.00448	kg	44.8	67.2	kg/ha
Organophosphorus					
Fosetyl-Al	0.00566	kg	56.6	84.9	kg/ha
Glyphosate	0.00297	kg	29.7	44.55	kg/ha
Unspecified					
Sulphur	0.02240	kg	224	336	kg/ha
Copper	0.00099	kg	9.9	14.85	kg/ha
Pyraclostrobin	0.00015	kg	1.46	2.19	kg/ha
Wood wastes from vineyard	0.88000	kg	8800	13200	kg/ha