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A geospatial decision support system for supporting quality viticulture at the landscape scale

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ABSTRACT

The world of viticulture connected to wine making has become a very important activity in many inland areas permitting both the generation of important income and the sustaining of agriculture systems.

Recent progress in both crop modeling and Decision Support Systems (DSS) applied to viticulture promises important changes that combine both high quality production and environmental sustainability. However, most of this progress is only addressed at the farm level and does not challenge the viticulture landscape, which is a key issue when facing DOC, DOCG areas, wine growers' cooperatives and consortiums and strategic viticulture planning.

Thus, this paper aims to demonstrate that a new type of DSS, which is developed on a Geospatial Cyberinfrastructure (GCI) platform, may provide an important web-based operational tool for high quality viticulture as it connects farm and landscape levels better.

The GCI platform supports acquisition, management, processing of both static and dynamic data (e.g. pedological, daily climatic, and vineyard distribution), data visualization, and on-the-fly computer applications in order to perform simulation modeling (e.g. grapevine water stress, evaluation of ecosystem services, etc.). These are all potentially accessible via the Web.

This is possible thanks to the implementation of a set of modeling clusters that is strongly rooted in soil-plant-atmosphere and physically based simulation modeling.

The DSS tool, applied to an area of 20,000 ha in Southern Italy, is designed to address viticulture planning and management by providing operational support for farmers, farmer associations and decision makers involved in the viticulture landscape.

Output of the system includes viticulture planning and management scenario analysis, maps and evaluation of potential and current plant water stress.

The tool will also be demonstrated through a short selection of practical case studies.

1. Introduction

1.1. High quality viticulture towards high quality wine

All around the world, viticulture connected to wine making has today become a very important activity for both generating income and trade (OIV, 2016a) and sustaining agriculture.

This is due to consumers, who have a very important role in high quality viticulture since they increasingly associate the quality of wines with the quality of their geographical origin and the sustainability of production (Warner, 2007). Addressing this viticulture-terroir relationship can be a rather difficult task since vineyard and grape production is highly affected by many problems such as new or recruiting plant diseases (e.g. Kiss et al., 2016; OIV, 2016b). Nevertheless, in response to consumer concerns for the environment, an increasing number of studies have been published since the 90s with the aim of both reducing the environmental impact of viticulture and improving its efficiency (Hill et al., 1999; Rivera-Ferre et al., 2013).

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In this respect, progress in modelling and in its implementation in the Decision Support Systems (DSS) applied to viticulture promises to bring important changes to the combining of high quality production and environmental sustainability.

To be more precise, crop models applied to viticulture are typically classified as either empirical/statistical or dynamic (Costa et al., 2015; Moriondo et al., 2015).

Empirical models – which exploit the statistical relationship between environmental parameters- are computationally simple (e.g. regressions), and often intuitive and widely accepted. These include those models based on climate data (e.g. Santos et al., 2011; Fraga et al., 2014), those based on remotely sensed indices (e.g. Rodriguez et al., 2004; Gouveia et al., 2009; Cunha et al., 2010) which aim to identify phenology phases (e.g. Winkler et al., 1975; Parker et al., 2011) and also, most importantly, those which address risks from insects and plant diseases (Calonnec et al., 2008; Caffarra et al., 2012).

These models, although highly used (Costa et al., 2015), have various weak points (e.g. Shin et al., 2010) such as the high level of calibration required (when applied to a new environment) and, most importantly, they do not address the non-linear relationships between plant and environmental factors. For instance, they have difficulty in addressing water resource management, which is a key dynamic issue in viticulture, and in modelling crop-soil water balance and crop yield. In fact, growth and development of grapevines, grape yield and quality build-up are known to be closely related to water constraints (Gómez-del-Campo et al., 2002; Gu et al., 2004).

Dynamic models, on the other hand, attempt to solve these non-linear relationships and allow greater generalization of crop growth processes and, consequently, a better adaptation to new environments and an overall much better performance. Generally, dynamic models simulate plant growth development on a daily basis and consider site features at specific locations. Moreover, they need cropping parameters, climate data, soil data and farm management data. Highly specialized dynamic models have been used in viticulture to simulate the seasonal dynamics of vineyard water availability (e.g. Lebon et al., 2003), nitrogen dynamics (VineLogic, Nendel and Kersebaum, 2004; Walker et al., 2005), salinity (SWAP, Ben-Asher et al., 2006), carbon balance (Poni et al., 2006), the timing of vine phenological phases (Godwin et al., 2002) and expected grape quality, yield and phenology under climate change (SWAP, Bonfante et al., 2015; Fraga et al., 2016).

Thus, starting from these specialized models, new more integrated modelling approaches have been developed to address holistic vineyard management. These were designed to maintain a high detail modelling of plant growth processes, but within the framework of larger vineyard integrated management. Among the most important of the models is certainly STICS (Brisson et al., 2003), developed at INRA, which was adapted for grapevines and evaluated for many vineyards throughout France, Chile (Garcia De Cortázar, 2006; Valdes-Gomez et al., 2009) and Portugal (Fraga et al., 2015).

In recent years, further development has been achieved by implementing some of these models in truly operational DSS for vine management. Among these are MoDeM_IVM DSS (Cola et al., 2014) and Vite.net (Rossi et al., 2014).

Currently a proper update on these agricultural-based DSS is lacking (Manos et al., 2004) since a good review (ENDURE, 2010) is only provided for the plant protection DSS. In general terms however, all these viticulture-DSS have a similar basic architecture where the farmer enters, via web, some site-specific information (e.g. soil management) for each vineyard decision unit (e.g. Rossi et al., 2014), while other data are obtained automatically (often in real time) by sensors positioned on the farm (e.g. http://www.adviclim.eu/project-2/). All this information is then processed by a server that provides output to the farmer to support his vineyard management (e.g. expected grape quality/quantity, pest management). Several of these systems – built within the framework of research projects – are now marketed as commercial services offered to single farms.

Indeed, these DSS systems have been built, maintained, and evolved at the farm level, where the farm is typically considered an individual point in space or, in the case of very large viticulture farms, "a small set" of individual points.

While fully recognizing the great importance of these farm approaches, it is also important to stress that these systems do not adapt easily to landscape complexity, which has its own space-time variability. Indeed, climate, soils and their properties (as well as many other environmental factors) vary continuously in space.

This evidence becomes a problem when considering that many wine-growing settings in many countries refer to consortium, associations and wine growers' cooperatives, legal bodies devoted to the production of "Quality Wines Produced in Specified Regions" (QWpsr), such as the Italian DOC and DOCG areas. These administrative (and functional) entities typically govern large spatially-continuous territories. In these cases, if the farm DSS approach were applied, it would be necessary to engineer an entire viticulture landscape with sensors to provide input parameters to the "n" farm-based DSS. It is self-evident that this would be very demanding and possibly not the best solution when dealing with large areas (e.g. viticulture district or landscape).

Moreover, it is also clear that today's high-quality viticulture is asked to provide multifunctional results including proper ecosystem services (e.g. Brunori et al., 2016) and even support for wine tourism (e.g. Sánchez, 2010). However, this multifunctionality needs to be developed into a coherent landscape framework rather than at an isolated farm level.

This landscape argument gains further importance when we consider strategic viticulture planning (Costa et al., 2015) and then long term scenario (e.g. climate change) where the landscape level becomes a prerequisite.

Therefore we here claim that when dealing with viticulture planning and management there is somehow a disconnection between the large significant advances in research achieved at farm level and the research progress made at landscape level, such as those dealing with terroir analysis (Bonfante et al., 2011; Bramley et al., 2011; Priori et al., 2013).

Therefore, it seems evident that it is important to better connect and/or combine farm and landscape levels if we are seeking sustainable and high-quality viticulture planning and management. We also believe that this must be done through the development of operational DSS tools for end-users and stakeholders, which address the complexity of the physical landscape in the viticulture framework.

1.2. Aims

Considering the above framework, the general aim of this paper is to demonstrate that a new type of DSS developed on a Geospatial Cyberinfrastructure (GCI) platform can provide a valuable web-based operational tool to manage high quality viticulture at the landscape level, but with a demonstration of potential deliveries at the farm level (e.g. Cadastral ID). The platform has also been designed to encourage use by the multiuser community (from farmers, to wine associations and public bodies).

Here, we shall describe a viticulture Web tool developed within the framework of the SOILCONSWEB EU project (Terribile et al., 2015). The tool, named *GeoVit* and applied to an area of 20,000 ha in the South of Italy, is designed to address sustainable viticulture planning and management by providing operational