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A novel fuzzy expert system to assess the sustainability of the viticulture at the wine-estate scale

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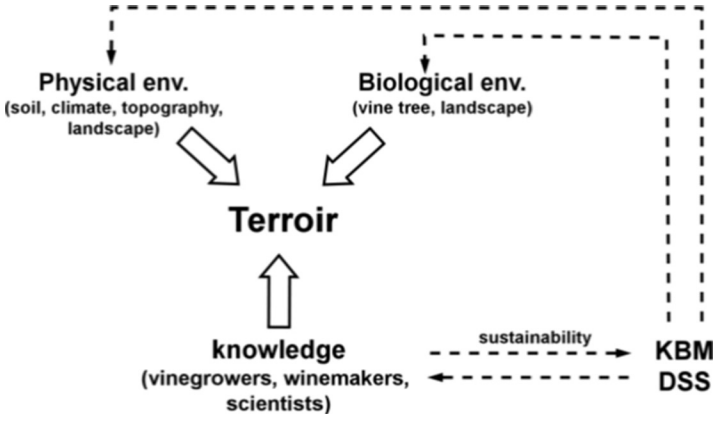
HIGHLIGHTS

- A new multidimensional indicator has been developed to evaluate the sustainability of management options adopted at vineyard scale.
- The indicator considers the main agronomic aspects, related by a hierarchical fuzzy logic and implemented in web GIS software.
- A cross validation approach has been performed on four different wineries.
- Soil and fertility management are the main issues concerning sustainability in viticulture.

GRAPHICAL ABSTRACT



Role of Knowledge Based Model (KBM)/Decision Support System (DSS) like "Vigneto" in the transfer of the sustainability science.

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ABSTRACT

The wine industry is definitely committed in sustainability: the stakeholders' interest for the topic is constantly growing and a wide number of sustainability programs have been launched in recent years. Most of these programs are focusing on the environmental aspects as environmental sustainability indicators, greenhouse gases emissions and the use of Life Cycle Assessment methodology. Among the environmental indicators the carbon and the water footprint are often used. These indicators, while being useful to assess the sustainability performance of the winegrowing farms, do not take into account important aspects related to the agronomic management of the vineyard. To fill this gap a new indicator called "Vigneto" (Vineyard in Italian language) has been developed. "Vigneto" is a multidimensional indicator to evaluate the sustainability of management options adopted at field scale. It considers the main agronomic aspects, which can have an impact on the environment. These include (i) pest management, (ii) soil management (erosion and compaction), (iii) fertility management (soil organic matter management and fertilizer application), (iv) biodiversity management. Those aspects have been related by fuzzy logics and implemented in web GIS software. The application of the model allows obtaining a general judgment of the agronomic sustainability of the vineyard management: the judgment varies from "A" (excellent) to "E" (completely unsustainable). The produced model was validated and tested by four Italian wine estate. The model output reports that the tested wineries have different management strategies: producers

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manage vineyards in different ways, depending on the different geographical position. The main differences are related to the soil management and to the presence of natural areas different from vineyard.
The developed model can be defined as an environmental decision support system that can be used by wine companies' technicians to define the vineyard practices sustainability performance and support them in the definition of more sustainable management practices.

1. Introduction

Sustainable agriculture could be defined as a set of agronomic practices that are economically viable, environmentally safe, and socially acceptable with the aim to create a system that is capable of persisting preserving the same characteristics. In 2004, OIV (Organization Internationale de la Vigne et du Vin, OIV, 2004), defined sustainability as a "global strategy on the scale of the grape production and processing systems, incorporating at the same time the economic sustainability of structures and territories, producing quality products, considering requirements of precision in sustainable viticulture, risks to the environment, products safety and consumer health and valuing of heritage, historical, cultural, ecological and aesthetic aspects". This definition emphasizes the relationship between the sustainability and the "terroir" concept (OIV, 2010). The "terroir viticole" is as an area in which collective knowledge of the interactions between the identifiable physical and biological environment and applied vitivinicultural practices have been developed, providing distinctive characteristics for the products originating from this area. "Terroir" includes specific soil, topography, climate, landscape characteristics, biodiversity features and common knowledge and this concept is strictly linked to the definition of the protected designations of origin and to their promotion. Therefore, "terroir" and sustainability are strongly related concepts.

Presently different wines which have "sustainability-sounding" names and adjectives (such as sustainable, organic, natural, free, eco-friendly) are offered to the consumer and a large number of different strategies, guidelines and practices are available (Corbo et al., 2014, Santiago-Brown et al., 2014). From the consumers point of view the term sustainability is mainly associated with the environmental dimension and in some cases only with the carbon footprint (Szolnoki, 2013). From the corporate perspective sustainability is subjectively interpreted and the existing programs cover more or less completely the sustainability areas. Sustainability being based on three generic pillars (environment, society and economy) is difficult to measure and the risk of drifts and commodification of its principles are present (Parr, 2009). Strategies for measuring the sustainability in an objective manner are necessary for limit the use of sustainability as mere marketing leverage. The introduction of sustainability indicators and direct measures, such as field experiments, although being time-consuming and not always completely understood by all the stakeholders are required to analyze complex systems. Most sustainability approaches focus only on pesticide impact, carbon emissions or water use. In fact several works are present in the literature focused on the carbon and water footprint of the Italian wines (Bonamente et al., 2015, 2016). Organic carbon, potentially mineralizable nitrogen, and microbial biomass are the most important among soil indicators (Cardoso et al., 2013; Riches et al., 2013), whereas biodiversity indicators are often related only to species richness (Büchs, 2003).

The aim of this work is to develop a multidimensional (space and time) indicator to evaluate the sustainability of management options adopted at field scale. "Vigneto" indicator is an indicator which considers the main agronomic practices which have an impact on the environment. These include (i) pest management, (ii) soil management (erosion and compaction), (iii) fertility management (soil organic matter management and fertilizer application), (iv) biodiversity management.

The paper details a fuzzy expert system connected to web GIS software, which is a useful instrument for measuring the environmental impact of viticulture in a holistic way. The easy-to-use software could be used by farmers and other decision makers to perform a sustainability assessment at vineyard scale, and help to improve their performance, adopting effective measures to improve the sustainability of the wine estate.

"Vigneto" was developed in the framework of the "V.I.V.A. sustainable wine" project, launched in 2011 by the Italian Ministry for the Environment, Land and Sea. The final output of the project is a sustainability label that signals to the consumers the sustainability attributes of the products and provides easily interpretable information about four selected indicators. The wine label shows the V.I.V.A. logo and through a QR code it is possible to consult the results obtained in the four selected indicators: in addition to "vigneto" the other indicators are "Aria" (Carbon Footprint), "Acqua" (Water Footprint, Lamastra et al., 2014), and "Territorio" (a selection of quality indicators to evaluate the socio-economic aspects of sustainability).

2. Material and methods

"Vigneto" indicator has been developed following agronomist expertise rules instead of implementing complex mathematical models The model temporal scale was set to the agricultural year (from pruning to harvest), the model spatial scale was set to the farm and the modeling boundary was the exit of the grape from the vineyard. "Vigneto" is based on six sub-indicators with different spatial scales: five of them are field scale indicators (pest management, fertilization management, soil organic matter, and soil compaction and soil erosion indicators) and one of them is working as a farm scale indicator (landscape quality indicator). The development of the six indicators (Table 1; Fig. 1) was based on validated models available in the literature (Table 1), new indicators were developed for soil erosion, soil compaction and landscape quality due to the lack of simple indicators required by the definition of the fuzzy index (Wieland and Gutzler, 2014).

In the indicator "Vigneto" sustainability was modeled by a logic-based knowledge-based model (KMB) where knowledge is encoded into a database. An inference engine uses logic to infer conclusions and the models are expressed as a series of facts formalized according a logic system. KBM requires that the knowledge is elicited from viticulture and sustainability experts and encoded in facts and rules that can be used to explain the deductions based on chains of rules application (Kelly et al., 2013). The integration of experts and stakeholders' knowledge into the impact assessment process was reached by fuzzy simulation of environmental systems (Wieland and Gutzler, 2014). The elicitation process (Page et al., 2012) started with the development of the idea and required the determination of the processes and of the impacts of agricultural practices on environmental compartments defined by stakeholders. The final output of the elicitation process was a single indicator made from six separate sub indicators related by two levels of fuzzy logic (Fig. 1). The indicators are initially calculated at the field scale and after adjusted to the wine estate scale giving the wine-estate judgment (Fig. 2). An intermediate level called "product" was developed responding to the need of the certification procedure. In fact, a producer can ask to certificate only one or few labels of his product

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