Quantitative Tools for Evaluating Biological Processes in Vineyard Agroecosystems: BIOPASS® and QBS-ar

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Abstract Biodiversity is crucial for wine production, but its assessment within complex agro-ecosystems requires specialized tools. This study focuses on a quantitative frameowrk to assess biodiversity in the wine sector. BIOPASS® is a decision support system designed to assess and manage biodiversity at the farm level. BIOPASS® integrates assessments throughout the winemaking process, focusing on soil, vines, and the final wine product. A key component is the evaluation of soil health that encompasses physical, chemical, and biological properties. Specifically, the relationship between biological soil quality (measured by the QBS-ar index), environmental factors, and farming practices (organic vs. conventional) is examined. Since 2014, the BIOPASS® protocol has been implemented in wineries across Italy, generating a substantial dataset of 654 records by 2023. This extensive data collection offers a valuable case study demonstrating how biological data can provide insights into ecosystem responses to environmental and management changes. The large dataset and geographical variability of the observations allow to reveal the impacts of soil abiotic conditions and vineyard management practices on soil arthropod communities. Ultimately, the framework serves as a valuable tool for raising awareness within the agricultural sector about the importance of data-driven decision-making, promoting ecological transition, and advancing sustainability in winemaking.
Keywords: sustainability, soil biodiversity, arthropods, DSS

1. Introduction

In recent years, there has been a growing interest in biodiversity within the agricultural sector, accompanied by the development of various tools to analyze this aspect. However, in the wine industry, understanding and managing agroecosystem biodiversity and its functional role concerning vines, must, and wine remains a challenge. This difficulty stems from the complex interactions within biotic communities in agroecosystems, influenced by environmental conditions and agricultural practices [1].

The Millennium Ecosystem Assessment (MEA) defines biodiversity as "the variability among living organisms and the ecological complexes of which they are part, including terrestrial, marine, and other aquatic systems" [2] It encompasses diversity within species, between species, and across ecosystems. Given this broad definition, monitoring biodiversity in agroecosystems requires considering multiple indicators rather than relying on a single one. This multi-indicator approach is essential to fully comprehend the intricate dynamics characteristic of winemaking systems.

Decision support systems (DSSs) play a crucial role in assessing biodiversity in agroecosystems by integrating various biodiversity indicators. The agricultural sector widely acknowledges the importance of DSSs, and in the wine industry, numerous DSSs have been developed in recent years. However, most of these tools focus on pest and disease management or vinification processes. Despite their relevance, DSSs are often overlooked as practical and accessible tools for biodiversity assessment in viticulture. This gap highlights the need for effective tools that meet the specific demands of the agricultural sector.

Soil quality, encompassing physical, chemical, and biological properties, is fundamental to the sustainability of ecosystems. The significance of soil quality has been recognized for a long time, as it directly impacts agroecosystem functionality and long-term agricultural viability. In this context, soil biological quality serves as a key component of sustainability assessment in viticulture.

In this work, several applications of a specific DSS to assess and manage biodiversity at the farm level are presented. The use of the DSS has enabled the analysis of existing relationships within the vineyard agroecosystem to support the definition of targeted management strategies. This paper presents a DSS developed to evaluate biodiversity and sustainability in the winemaking sector. The tool provides composite indicators across three key dimensions: (1) company biodiversity, (2) company sustainability, and (3) soil quality. By incorporating multiple indicators and integrating them into a structured assessment framework, this DSS enables a comprehensive evaluation of vineyard agroecosystems.

The tool aims to offer a practical and accessible approach for vineyard managers and decision-makers, facilitating the monitoring of biodiversity and sustainability at the farm level. The incorporation of soil biological quality within the assessment underscores the interdependence between soil health and overall agroecosystem sustainability. By utilizing this DSS, vineyard managers can make informed decisions that promote environmental sustainability while maintaining productivity.

2. Methodological framework to assess biodiversity in vine agroecosystems

Biopass® (Italian acronym for Biodiversity, Landscape, Environment, Soil, Society) is a protocol, developed by Sata Studio Agronomico, for assessing the functional quality of soils in viticulture. Since 2021, it has been certified ISO 9001, the internationally recognized reference standard for Quality Management, aimed at increasing the effectiveness and efficiency of internal processes and ensuring customer satisfaction regarding the products and services provided. For this reason, the Biopass method is codified and traceable, following the principles of continuous improvement to ensure the highest reliability of the results. The Biopass protocol includes a series of activities that can be carried out depending on the research objectives. Among these investigations, particularly relevant for assessing the functional quality of soils, are the calculation of the QBS-ar Index, which allows for the evaluation of soil arthropods biodiversity, and chemical-physical analyses, including copper content.

2.1 The QBS-ar index

The QBS-ar index, is calculated using the methodology proposed by Parisi [2]. For this survey, a cubic sample of soil (with a side length of about 10 cm) is collected from a testing site. The sample is placed in a Berlese-Tullgren funnel and under a 100 W incandescent bulb, the soil is warmed until complete dehydration. Small invertebrates tend to migrate away from the light and take refuge in the damp part of the soil sample (the bottom), then abandoning the soil and dropping into the cavity of the tunnel, from where they slip into a preserving solution. Division into biological forms is carried out in relation to the characteristics of adaptation to the soil, which makes it possible to associate each systematic group with a numerical value defined as the "Ecomorphological Index" (EMI): the higher the number of morphological characteristics linked to adaptation to the soil, the higher the EMI value. The EMI value ranges from 1 to 20. For some systematic groups there is a uniform level of adaptation to edaphic life for various species; in this case assignment of a single EMI value is envisaged. For species with different adaptation to soil, increasing EMI values are assigned according to increased adaptation (e.g., no wings, no eyes, etc.).

If several biological forms are recognized in a group and therefore different EMI values are attributed, only the highest EMI value is considered for calculation of the QBS-ar, which represents the maximum degree of adaptation to life in the soil shown by the group under examination. Calculation of the QBS-ar index value is obtained from the sum of the EMI values attributed to each systematic group. Total QBS-ar scores of a soil can vary from a minimum of 0 to a maximum of 349. The application of the Biopass protocol since 2014 in Companies located throughout Italy has allowed for the creation of a dataset composed, as of 2023, by 654 data. The large size of the dataset and the collaboration with the Agrofood Research Hub of the University of Brescia have made it possible to produce several scientific outputs through the use of this dataset and to find important results regarding the behavior of the index in relation to soil management and the variables that characterize the soil.

3. Case studies

3.1 Biodiversity and organic farming

Through the BIOPASS protocol, it was possible to investigate the relationship between soil biodiversity (measured with QBS-ar) and organic farming. The case study was conducted using data collected between 2014 and 2016 at the national level. The results of the bidirectional stepwise linear regression model indicate a relationship, albeit weak, between the biodiversity index and temperature and precipitation. Specifically, the significant variables include: the number of days in which the daily maximum temperature was below $20°C$ (TmaxLow), the number of days in which the daily maximum temperature was above $30°C$ (TmaxHigh), total cumulative precipitation (mm) (PrecTot), and high precipitation periods, defined as cumulative rainfall of 186.51 mm or more (PrecHigh).

3.2 Biodiversity and soil characteristics: a linear approach

The protocol has also been applied to evaluate the relationship between soil biodiversity, soil characteristics (soil environmental indicators, soil chemical and physical categorical vari-

Coefficient	Estimate	Standard Error	p-Value
Intercept	64.82	20.36	0.002
Organic farming	40.21	13.08	0.003
TmaxLow	-3.21	2.26	0.161
TmaxHigh 3	-4.89	1.57	0.003
PrecTot	0.23	0.13	0.078
PrecHigh	-40.78	21.87	0.067

Table 1: Regression results

ables), and management variables of farms. The analysis was performed on data collected between 2014 and 2019 was used. Results highlighted that the effects of environmental soil indicators on QBS-ar were predominantly associated with soil temperature. These results are fully in agreement with scientific evidence emphasizing the important effects of soil temperature on edaphic arthropod survival, development, and reproduction. In particular, soil temperature in the range of 10-20°C, as evaluated in the medium-term period, has a positive effect on QBS-ar. This positive effect is of greater intensity if the soil temperature ranges from 18-30°C. The analysis of the effect of soil environmental conditions in the short-term period (7 days before sampling) revealed a negative relationship between average temperature and QBS-ar. Soil moisture did not exhibit a significant relationship with QBS-ar as their values are very close to the threshold of 0.35 m3/m3 that is considered as the optimal value for survival and reproduction for some edaphic species. Regarding physical soil parameter, soil texture was the only one that affected QBS-ar, where it caused an increase in this index in soils with loamy soil texture or with loam in association with fine soil fractions (clay loam and silty clay loam) (Figure 1).

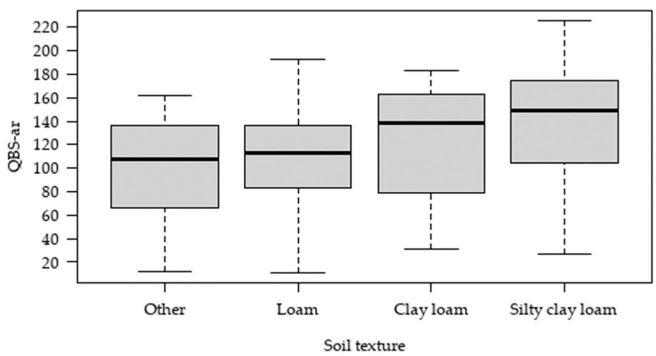

Figure 1: QBS-ar values in the 168 soil samples divided according to soil texture categories. The category 'Other' includes clay, silty clay, silt loam, and sandy loam soils

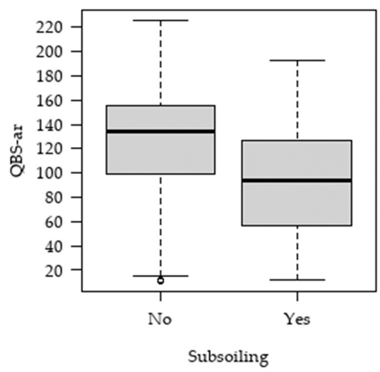

Figure 2: QBS-ar values in the soil samples with (right) and without (left) subsoiling

Results of experiments investigating the role of management in influencing edaphic arthropod community responses revealed that arthropod communities are positively influenced by organic management with respect to conventional management. Regarding the timing of the adoption of organic management, QBS-ar value is significantly improved during the first 3 years of adoption according to other experiences carried out in vineyard ecosystems. Considering soil management practices, the negative effect of soil disturbance on the QBS-ar Index can be highlighted. In particular, these results revealed that subsoiling led to a decrease in QBS-ar values, thus supporting the scientific evidence that emphasizes the sensitivity of edaphic arthropods to soil tillage in the short term (Figure 2).

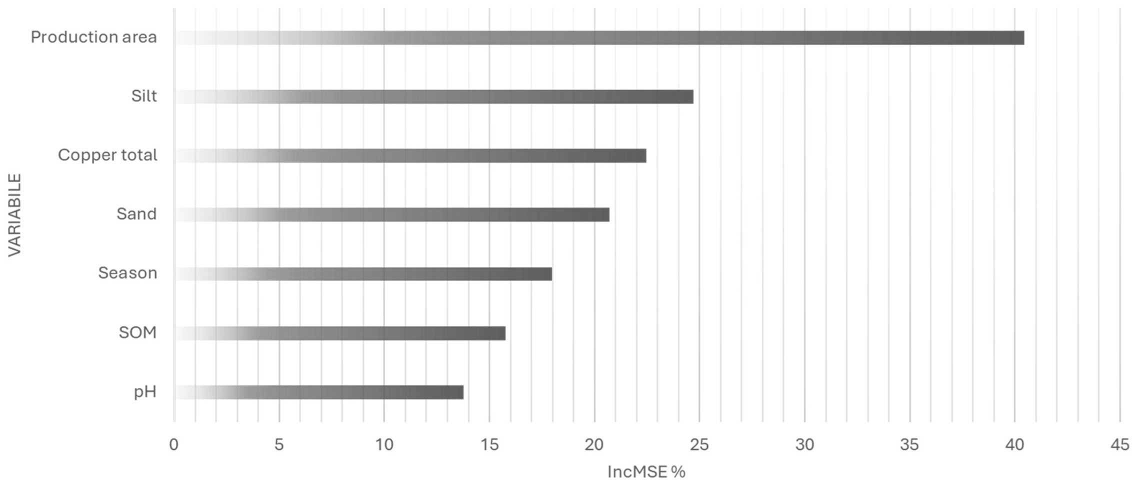

Figure 3: Random forest model highlighting the effect that contextual variables (i.e. production area, the season of soil sample collection, soil texture, soil organic matter, pH and total copper) have on the QBS-ar Index

3.3 Biodiversity and soil characteristics: a not linear approach

The last case study concerns the use of nonlinear approaches (Random Forest) to evaluate the relationship between biodiversity and soil characteristics. The dataset referred to 654 samples collected between 2014 and 2023. The model shows the significant influence on the QBS-ar Index of the production area, season of soil sample collection, soil texture, confirming results described above, and total cooper content in the soil. Therefore, the significant variables explain about 20% of the variability in the QBS-ar, and further exploration of other agroecosystem characteristics is needed to understand the factors that most influence the index. The presented case is of particular interest for agronomic applications, as the relationship between biodiversity and copper is widely debated. The study's results, which demonstrate a not-negative relationship between biodiversity and copper, have underscored the need for further investigation into this topic; consequently, several specific projects have recently been initiated to explore this relationship in greater depth (Figure 3).

4. Conclusions

In conclusion, the application of the protocol has allowed for the collection of useful data and information to begin investigating the relationships between agroecosystem conditions and biodiversity levels. One critical issue that emerged was the low fitche indices; although acceptable in the analyzed context, they nevertheless indicate that it is necessary to work on increasing the amount of collected data, ideally by extending the protocol to different business realities.

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