Enhancing the Ecosystem Services in Viticulture Farms: Approaches towards a Sustainable Management

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1. Introduction

At the start of the twenty-first century, the problem of global sustainability is widely recognised by world leaders. The idea of sustainability dates back more than 20 years, the term was coined in the 1987 by the Brundtland Commission that defined, accordingly to the most often-quoted definition, the sustainable development as development that "meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations General Assembly, 1987).
Sustainable development is a tool adopted by world policy-makers to integrate environmental, economic and social issues to contribute to a more balanced development and to prevent problems linked to the environment and the society. This important concept has been drawn in a variety of ways, commonly as interlocking circles (Figure 1).

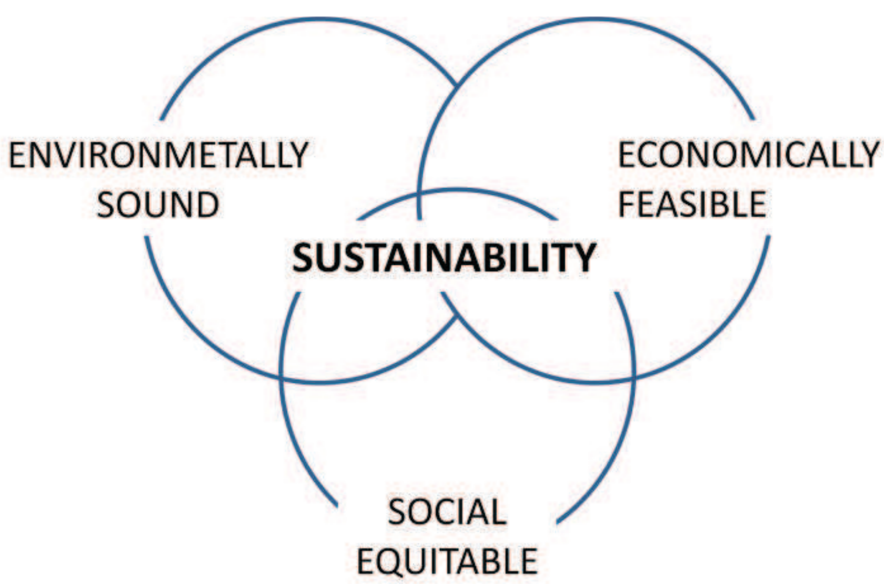

Fig. 1. Graphical definition of Sustainability

The translation of these important concepts in the agriculture, led the American Society of Agronomy in 1989 (FACTA, 1990) to define "Sustainable Agriculture" as an integrated

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system of plant and animal production practices having a site-specific application that will over the long-term:

1. Satisfy human food and fiber needs.
2. Enhance environmental quality and the natural resource base upon which the agriculture economy depends.
3. Make the most efficient use of nonrenewable resources and on-farm resources and integrate, where appropriate, natural biological cycles and controls.
4. Sustain the economic viability of farm operations.
5. Enhance the quality of life for farmers and society as a whole."

In the EU Common Agricultural Policy (CAP), environmental considerations have increasingly been integrated into agricultural policy throughout Europe. Multifunctionality of agriculture (production of environmental, socio-cultural and economic services other than food production) is becoming a key issue in the reforms. "Sustainability" (European Commission, 1998), "sustainable development" and so "sustainable agriculture" are terms that tend to be found very often in the new European Directives, and indicate the general direction of the communitarians policies of this new century.

The present study reports a way to evaluate the environmental impact of viticulture and the use of case study methodology to document how this managing tool has been used in an Italian winegrowing farm. In fact, viticulture represents one of the cultivations most impacting the ecosystem due to its distribution and geographical concentration.

The development and operation of a vineyard can impact on the environment in many ways (table 1). Undesirable impacts can be caused by practices which result in a physical change to the environment caused by activities/practices which cause disturbances to the environment; and substances or organisms being placed or moved to a location where they do not belong. Winegrowing practices can have immediate and long-term negative effects on the environment and may also affect the productivity of the vineyard. The environmental contaminants are substances or organisms that are placed or moved to an unintended location, soils; ground water; surface water; atmosphere; and plants and animals, within the environment are referred to as environmental contaminants. These include: nutrients and their by-products; pesticides and their by-products; salt; sediments; metals; oils; exotic/introduced pests, diseases, weeds; and general waste. The environmental impacts are caused as a direct result of vineyard activities/practices; and as a result of contaminants moving into unintended locations. These have influence on soils; water; air; flora, fauna and ecosystems; natural resources; and regional aesthetics and amenity. It should be noted that the environment is a highly complex system and many factors interact. As a result, impacts on one aspect of the environment can cause follow-on impacts on other aspects of the environment.

The eco-sustainable recovery of viticulture is subordinated to the possibility of management at the farm and basin level, through an integrated assessment that allows to evaluate the risks produced by each productive factor within all the life cycle of the vineyard (Cliff O., 2000).

In Italy the "Università Cattolica del Sacro Cuore" in collaboration with experts on evaluation and management of environmental risks, and on data treatments, have developed SOStain a proactive and voluntary program of Environmental Sustainability. The aim of SOStain program is to increase the Sustainability of Italian winegrowing farms, through a whole of practical recommendations for the vineyard and winery management that can be used by conventional and organic farms. These recommendations are resumed

Threatening process related to viticulture	Main influencing factors	Corresponding Mitigations (Example of sustainable practices)
Loss of ecological processes	Ecosystem fragmentation. Distribution of breeding and regeneration cycles. Imbalances in species populations. Biodiversity loss	Maintain Ecosystem integrity Sustain Biodiversity
Diminished air quality/climate change	Increasing of particulate matter and ozone in the atmosphere Global warming resulting from GHGs (CO_2 and NO_2)	Air quality protection Reduction of emission
Land and water salinisation	The use of water for irrigation	Water conservation & efficiency Maintenance and setup of irrigation system
Water pollution	Pollution from irrigation drainage water, soil erosion, the use of fertilizers and pesticides, and from in channel sediments. Land clearing and agricultural development.	Protection of aquatic ecosystems and aquifers Improvement of discharge water quality
Soil erosion, problems with structure and/or quality of soil	Lack of soil surface cover. Low winter rainfall. Soil compaction Loss of nutrients	Soil conservation & management Monitoring of soil status
Outbreaks of pests	Improper use of pesticides Lack of pest management plan	Integrated pest management Pest, mites, weed, vertebrate monitoring
Changing land use	New vineyard developments	Environmental constraints on vineyard establishment

Table 1. The main threatening factor related to viticulture

in the SOStain Code of Sustainable Practices. The SOStain Code of Sustainable Practice promotes winegrowing and winemaking practices that are compatible with the environment, responsive to the needs and interests of society-at-large, and are economically feasible in practice. It include a self-assessment check-list to assess the sustainability of current practices and to identify areas of excellence and areas where improvements can be made. The assessment and the interpretation of results occurs trough the use of agro-environmental indicators that are significant components of data collection systems. The

indicators help decision-makers by informing them of the linkages and tradeoffs between farm activities and environmental impacts. They can provide an early indication of potential changes in the state of the environment. Because of that the agro environmental indicators plainly have a valuable role to play in progressing sustainable development objectives.
In this work we propose the use of an informatic tool able to assess the environmental performance of vineyard management in a whole, that can be used by single winegrowers at farm level. The software is based on EIOVI, environmental impact of organic viticulture indicator, an indicator developed for the evaluation of the environmental sustainability in the context of organic viticulture (Fragoulis et al., 2009). This paper intends to demonstrate the application of EIOVI to conventional viticulture, and to illustrate the important fast diagnosis of the winegrowing systems and their insertion in the territories that EIOVI permits.

1.2 Agro-environmental Indicators

The agricultural practices vary from the fertilization to the protection of the culture with plant protective products, from the irrigation to the soil cultivation. Effort should be given in developing risk assessment methodologies for the entire environmental compartment using the best science available and including an harmonized procedure for ecotoxicological criteria that combines the principles of European policies.
The Commission of the European Communities (2000) defines "agro-environmental indicators" as a generic term designating a range of indicators aiming at giving synthesized information on complex interactions between agriculture and environment. The EC has provided two key documents on this topic: COM(2000) 20 (European Commission, 2000) provides a partial set of 35 indicators for assessing environmental integration; COM(2001) 144 (European Commission, 2001) used this partial set to identify what statistics are required to underpin the indicators (Enrisk, 2003).
In support of the implementation of the integration objectives of agro-environmental policies, indicators are required to assess progress made and to evaluate the achievement of agronomic and environmental objectives, in order to optimize the systems.

1.3 EIOVI

EIOVI (Environmental Impact of Organic Viticulture Indicator) is an environmental indicator, reliable to EU organic farm management that could help as a decision support system for farmers and other property managers in choosing among options and evaluating the impact of their choices. The indicator aims to measure all the actual environmental impact produced by agro-ecosystem in the spatial boundaries of the farm and to produce advice for improving the sustainability of the human actions.
The indicator is implemented in a, user friendly, software with a graphical user interface (GUI) that allows the user with minimum input data to obtain an overall estimation of the impact of the management of his vineyard on the environment. To describe the relationships between the various management options and the environmental impact, a fuzzy expert system has been adopted.
This important tool could be used also to evaluate the environmental performance of conventional viticulture, with a series of correcting factors that consider the use of non organic fertilizers, and the addition of a range of sub-indicators related to the use of conventional pesticides, as indicated in this paper.

2. Materials and methods

2.1 The fuzzy expert systems

The theory of fuzzy is used to describe relationships that are best characterized by compliance to a collection of attributes (Zadeh, 1965). In classical set theory, an element either belongs or does not belong in a set, this means that the membership function can only take two values: 0 (non-membership) and 1 (membership). The fuzzy set theory addresses this type of problem allowing one to define the degree of membership of an element in a set by means of membership functions that can take any value from the interval [0.0, 1.0]. The value 0.0 represents complete non-membership; the value 1.0 represents complete membership and the values in between represent partial membership. Therefore, for the development of this environmental indicator, for each agronomical practice it has been formulated a set of decision rules attributing values between 0 and 1 to an output variable according to the membership of its input variables to the fuzzy subsets F (favorable) and U (unfavorable). To compute the modules, Sugeno's inference method (Sugeno, 1985) has been used. At the same time, the limit values beyond which the index is certainly F or U must be given. With this procedure, three membership classes are created; F, U, and partial (or fuzzy) membership (Werf & Zimmer, 1998).

These limit values are based on criteria drawn from the literature or on expert judgment. In this software S shaped membership functions are used because they provide smoother variations of the input values than functions that are linear in the transition interval. The hierarchical structure of this technique is used to aggregate indices into first level fuzzy indicators and next, into a second level fuzzy indicator for the whole system. The aggregation process is achieved by combining weighted fuzzy values. In figures 2 is given a graphical presentation of a classical crisp set (A) and a fuzzy set (B) (Bellocchi et al., 2002).

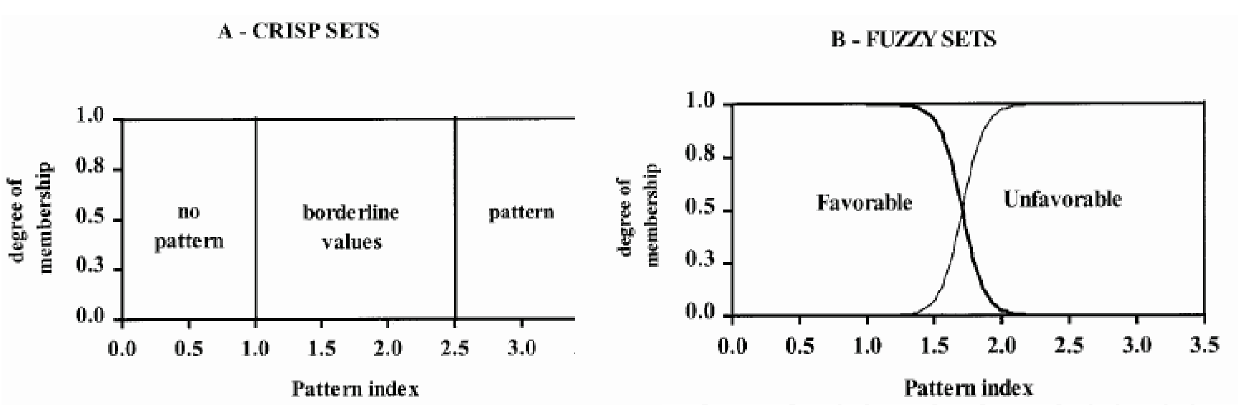

Fig. 2. Graphical presentation of crisp (A) and fuzzy sets (B) for the pattern index

2.2 Modules

The assessment tool is organized into six modules related to the main agronomic practices having an important environmental impact and on soil organic carbon and flora and fauna biodiversity impact. The modules are: (i) pest and disease management, (ii) soil management and machinery use, (ii) fertilizer use management, (iii) irrigation management, (iv) soil organic carbon, and (v) biodiversity of flora and (vi) fauna. The modules are activated one by one. Specific functions are then selected that apply the indicator for assessing the relevant environmental protection end-point.

Only modules relevant to specific geographic conditions are activated, and the flexible framework allows implementation of new ones when available. A number of agro-ecosystem functions takes place within each module.

2.2.1 Pest and disease management

The pest and disease management indicator (PDMI) is based on the EPRIP indicator (Padovani et al., 2004) and uses the concept of “Exposure Toxicity Ratio” (ETR). A ETR is the ratio between a "Predicted Environmental Concentration" (PEC) and a toxicological end point (i.e., legal limit groundwater, LD50, NOEL). This ratio is calculated for each of the environmental compartments at risk: ground water, surface water and soil. Toxicological effects on humans and ecotoxicological effects on aquatic and soil organism are taken into account. The user can select a plant protection product, application type, and application rate and can see the potential environmental impact depending on the soil properties of the farm and the hydrogeologic and meteorologic properties of the area.

2.2.1.1 Exposure to Toxicity Ratio for Soil

The PEC_{soil} is calculated as detailed in the final report of the Soil Modelling Work Group of FOCUS (FOCUS, 1997) and is the same approach as applied in the EPRIP indicator (Padovani et al., 2004). PEC_{soil} is a function of substance properties (DT50), application scheme (application rate, number of applications, and interval between applications), and soil properties (bulk density). For the soil PEC soil compartment, the ETR is

$$ETR_{soil} = PEC_{soil}/LC50 \text{ (earthworms)} \quad (1)$$

PEC_{soil} and LC50 are in mg kg^{-1}.

2.2.1.2 Exposure to Toxicity Ratio for Ground Water

The method of calculation of PEC_{gw} is based on the approach used in the EPRIP indicator using the leaching quantity index (Rao et al., 1985). The leaching quantity index is derived from the attenuation factor and is a function of substance properties (Koc, DT50, and Kh), application rate, crop stage at the time of application, soil properties (sand and clay content, bulk density, and organic carbon content), hydrogeological properties (depth of ground water table and ground water level), and meteorological properties (average annual precipitation). For ground water, the ETR is

$$ETR_{gw} = PEC_{gw}/LegalLimitGroundwater \quad (2)$$

PEC_{gw} and LegalLimitGroundwater are in μg L^{-1}.

2.2.1.3 Exposure to Toxicity Ratio for Surface Water

The PEC_{sw} comprises PEC_{sw} due to drift and PEC_{sw} due to runoff . The mean percent drift loading is estimated as in the FOCUS Drift Calculator (FOCUS, 2001) and is a function of the distance from the edge of the treated field to the closest and farthest edge of water body, application rate, number of applications, and water body depth. Due to run-off , PEC_{sw} is calculated using the same empirical approach as in the EPRIP indicator and is a function of substance properties (Koc, DT50), application scheme (application rate, number of applications, and interval between applications), crop stage at the time of application, distance from the water body, soil properties (bulk density and organic carbon content), hydrogeological properties (slope and quantity of water lost by runoff), and meteorological properties (maximum daily rainfall). For surface water, the ETR is

$$ETR_{sw} = [\max(PEC_{drift}, PEC_{runoff})] / [\min(EC50_{Daphnia}, LC50_{fish}, EC50_{algae})] \quad (3)$$

PEC_{drift} and PEC_{runoff} are in mg L^{-1}.

2.2.1.4 From Exposure to Toxicity Ratio to a Fuzzy Expert System

If x is the value of the index, α is the lower limit, and γ is the upper limit of the index, the S-shaped membership function used for the PMI is flat at a value of 0 and 1 for $x \leq \alpha$ and for $x \geq \gamma$, respectively. Between α and γ, the S function is a quadratic function of x (Bellocchi et al., 2002):

$$S(x,\alpha,\gamma)\begin{cases} 0.0 & x \leq \alpha \\ 2x\left(\frac{x-\alpha}{\gamma-\alpha}\right)^2 & \alpha \leq x \leq \beta \\ 1-2x\left(\frac{x-\gamma}{\gamma-\alpha}\right)^2 & \beta \leq x \leq \gamma \\ 1.0 & x \geq \gamma \end{cases} \quad (4)$$

where $\beta = (\alpha + \gamma)/2$, $S(x, \alpha, \gamma) = 0.0$ means complete membership to F, and $S(x, \alpha, \gamma) = 1.0$ means complete membership to U.
The parameters x, α, and γ for the indicators of soil, ground water, and surface water that constitute the overall PDMI are given in Table 1.

	SW indicators	**GWindicators**	**SWindicators**
x	ETR* soil	ETRgw	ETR sw
α	0.1	0.1	0.001
γ	1	1	0.01

*ETRgw, exposure toxicity ratio for ground water, ETRsoil exposure to toxicity ratio for soil; ETRsw, exposure to toxicity ratio for surface water

Table 2. Parameters x, α, γ for the soil water (SW), ground water (GW), and surface water (SW) indicators.

To assess the overall PDMI, a set of decision rules has been formulated for each module, attributing values of between 0 and 1 to an output variable according to the membership of its input variables to the fuzzy subsets F and U and according to Sugeno's inference method (Sugeno, 1985). When the premises are linked by a conclusion, the truth value of a decision rule is defined as the product of the truth values of its premises. The decision rules describing the effect of different indicators in the overall PDMI are given in Table 2. The score is calculated as the sum of the conclusions of the decision rules, weighted by the sum of their truth values.

2.2.2 Fertilizer management indicator

The use of compost as a management tool is highly relevant for the grape growing industry. Although the use of compost in viticulture can result in a wide range of benefits, there is

GW indicator	SW indicator	Soil indicator	PDMI
F	F	F	0.0
U	F	F	0.7
F	U	F	0.7
F	F	U	0.2
F	U	U	0.8
U	F	U	0.8
U	U	F	0.9
U	U	U	1.0

Table 3. Decision rules describing the effect of the different indicators in the pest and disease management indicator (PDMI)

also the risk of potentially detrimental effects (Biala, 2000), such as the oversupply of nutrients and contamination with heavy metals.

In viticulture, the use of temporary or permanent green cover crops in place of crop rotations in permanent cultures of vines and in orchards can bring benefits in addition to the more well known functions of erosion prevention, ground cover, and diminution of ground pressure (Hofmann, 1994), specifically, (i) improvement of soil structure and water conservation by permanent root spreading; (ii) nutrient supply for soil organisms as a basis for high biological activity and availability of soil nutrients; (iii) adaptation of nutrient supply specifically for the growth of grapes through specific mulching management and the use of herbs and nitrogen fixing plants; and (iv) support and stabilization of fauna in the vineyard ecosystem (canopy and green cover) through mowing, cutting, o rolling treatments in alternate rows to enable the blossoming of green manure plants. The use of different kinds of cover crops in viticulture should also be considered.

The fertilizer management indicator (FMI) takes into account the presence, type (legumes, grass or other, and mixture), and yield (kg ha^{-1}) of cover crops, the percentage of the vineyard covered, compost use in the last 4 yr, and the possible use of commercial fertilizer. The FMI is comprised of nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O) sub-indicators. These three sub-indicators are a function of soil organic matter and bulk density; the C/N ratio of the compost; the N, P_2O_5, and K_2O content; and the rate of compost (or fertilizer) application, taking into account the nutrient demand (N, P_2O_5, K_2O) of an organic vineyard with or without cover crops.

The high levels of nutrients contained in compost have a direct effect on plant growth. The nutrient requirements of grapevines should therefore be taken into account when compost is used. Grapevines have a relatively low demand for nutrients, depending on the yield and variety. For organic vineyards, the nitrogen (N) demand from fertilizer (NDF) is estimated to be between 50 and 80 kg N ha^{-1} (Biala, 2000). The compost or fertilizer N indicator (CMFNI) considers NDF, taking into account of the N release from humus mineralization, the cover crop demand/contribution for/of N, and the total N that becomes available for plant uptake during the first year of compost and/or commercial fertilizer use (NAT). Taking into account the latter and the relatively low demand for nutrients by grapevines only small quantities of N must be supplied by compost amendment.

When a cover crop is present, the N demand of the cover crop must be added to the N demand of the vineyard (Bowman et al., 2007). The maximum N demand of a cover crop, assuming two thirds of the soil to be covered with grass, has been estimated to be 30 kg N ha^{-1}. This figure is corrected on the basis of the actual coverage of the vineyard. However, N-fixing plants such as legumes contribute to N fertility, and this is also taken into account where such plants are used as cover crop. Organic N in compost is not immediately available to crops due to the time required for microbial mineralization of organic matter. The C/N ratio of organic material influences microbial activity. The greater the ratio, the more limiting N becomes for the microbial decomposition of organic matter. When composts with C/N ratios greater than 20:1 are added to soil, mineral N and any subsequently mineralized organic N can become "appropriated" by microbes (immobilized in the microbial biomass), leaving plants N deficient. Thus, the C/N ratio of compost is an important factor in the calculation of plant-available N. Availability coefficients are used to calculate plant-available N and thus to predict mineralization in the field.

As a general rule, 10% of the remaining organic N is available in the next season. Only about 40% of the applied N will be available for plant uptake over time (Biala, 2000).

2.2.2.1 Nitrogen Available for Plant Uptake from Commercial Fertilizer

Some organic farmers also use commercial fertilizers. The N from commercial fertilizer is immediately available to the plant. To calculate CMFNI, the NDF is compared with the total NAT. The S-shaped function of Eq. [4] is used with the parameters x, α, and γ for the indicator CMFNI taking the values x = NAT, α =NDFmin, and γ = 2 × NDFmax − NDFmin, where NDFmin and NDFmax depend in each case on the presence and type of cover crop and the percentage of the vineyard covered.

2.2.2.2 Compost or Fertilizer Phosphorus Indicator

The compost or fertilizer phosphorus indicator (CMFPI) considers the phosphorus demand from fertilizer (PDF) of a vineyard with or without cover crops. The total plant-available phosphorus (PAT) of a compost and/or mineral fertilizer is based on the fact that approximately 20% of phosphorus in compost reacts like P in mineral fertilizers and is immediately available for plant uptake, whereas the remainder is more strongly bound and becomes available over time (Biala, 2000). Consequently, during the first year, 30 to 40% of the applied P becomes available to plants. The grapevine has a low demand for P (15–25 kg P_2O_5 ha^{-1} yr^{-1}).

Cover crop plants actively compete for nutrients, and it is essential to maintain an adequate supply in the soil for both. This applies especially for P and K. Fertilizer recommendations are based on the maintenance of adequate availability in the soil and the replacement of any nutrients removed. For a soil of moderate nutrient status, the P demand of a grass and legume mixture cover crop has been estimated to be 40 kg ha^{-1}, based on a coverage of 67% of the vineyard. The actual P demand of the cover crop is corrected on the basis of coverage.

For commercial fertilizer, the same approach is followed as for N. The PAT is compared with the PDF, and the S-shaped function of Eq. [4] is used with the parameters x, α, and γ for the indicator CMFPI taking the values x = PAT, α = PDFmin, and γ = 2 × PDFmax − PDFmin, where PDFmin and PDFmax in each case depend on the presence and the type of cover crop and the percentage of the vineyard covered.

2.2.2.3 Overall Fertilizers Management Indicator

The decision rules describing the effect of the three different sub-indicators of the FMI are indicated in the Table 4.

CMFNI	CMFPI	CMFKI	FMI
F	F	F	0.0
F	U	F	0.7
F	U	U	0.8
F	F	U	0.2
U	F	F	0.7
U	U	F	0.9
U	F	U	0.8
U	U	U	1.0

Table 4. Decision rules describing the effect of the different sub-indicators on the fertilizer management indicator.

2.2.3 Water management indicator

The indicators relevant to water management are (i) the water management quality indicator (WMQI) and (ii) the water management irrigation rate indicator (WMIRI).

2.2.3.1 Water Management Quality Indicator

The WMQI is composed of three sub-indicators. The water management salinity indicator (WMSI) is a function of electrical conductivity (EC; mmhos cm^{-1}) and total dissolved solids (mg L^{-1}) in irrigation water and the irrigation system. The water management infiltration indicator (WMII) is a function of EC and sodium adsorption ratio (mmol L^{-1}) of irrigation water and the irrigation system. The water management ion toxicity indicator (WMITI) is a function of the concentration of sodium (Na; meq L^{-1}), chlorine (Cl; meq L^{-1}), and boron (B; mg L^{-1}) in irrigation water. As for the PDMI, an S-shaped membership function is used that is flat at a value of 0 and 1 for $x \geq \alpha$ and for $x \geq \gamma$, respectively. Between α and γ, the S function is a quadratic function of x (Eq. [4]). The parameters x, α, and γ for the indicators WMITI, WMSI, and WMII that affect the overall WMQI are given in Table 5.

	WMITI			WMSI		WMII	
x	Na	Cl	B	EC	TDS	EC	SAR
α	3	4	0.5	0.7	300	0.2	10
γ	7	8	1	3	1500	2	26

Table 5. EC, electrical conductivity; SAR, sodium adsorption ratio; TDS, total dissolved solids; WMII, water management infiltration indicator; WMITI, water management ion toxicity indicator; WMSI, water management salinity indicator.

For WMII only, S(EC; α; γ) = 0.0 means complete membership to U, and S(EC; α; γ) = 1 means complete membership to F because a very low EC creates infiltration problems in the soil if the sodium adsorption ratio is high.

A set of eight decision rules describes the effect of the three sub-indicators in the overall WMQI.

2.2.3.2 Water Management Irrigation Rate Indicator.

The vine growing season must first be defined. An irrigation scheduling program should indicate when to irrigate and how much water to apply to achieve specific objectives. Yields of most crops are directly related to the volume of water consumed. Maximum potential water use is therefore desirable. However, the production of quality wine grapes usually requires the use of an irrigation strategy providing less than the maximum potential water requirement of the vine. Recent research has shown that water deficits can have a significant, positive impact on wine quality (Prichard, 2004). There are at least two approaches for regulated deficit irrigation (RDI): (i) the volume balance approach (VBA) and (ii) the deficit threshold (DTI) plus RDI method. Using the VBA method, 50 to 70% of the maximum potential water use is sufficient for the grapevine. The DTI method relies on a predetermined level of midday water deficit (the threshold) to initiate irrigation. After the threshold is reached, a reduced water regime is used based on a portion of full water use (RDI%). With this method, irrigation begins only if the threshold is reached. If the DTI method is followed, significantly less irrigation water will be used.

The water management irrigation rate indicator uses the reference evapotranspiration (ETo), also known as potential evapotranspiration (PET). Rates of ET_o are adjusted by multiplying ET_o by a crop coefficient (Kc) specific to grapevines, and the full potential water use (ET_c) for a vineyard is estimated. A meteorological database in the software contains monthly average air temperature and rainfall data collected from approximately 30 meteorological stations in Italy, Germany, France, and Switzerland. The monthly ET_o is estimated with the Thornthwaite method (Thornthwaite, 1948), using monthly average air temperature data and latitude (daylight coefficient values for the Thornthwaite formula for different latitudes are presented in the database) for the area of interest. Grapevine Kc are a function of the size of the grape canopy and the proportion exposed to direct sunlight. The equation to describe the relationship between the crop coefficient and the percentage shaded area is (Williams, 2000)

$$Kc = 0.002 + 0.017 \times \text{the percent shaded area} \quad (5)$$

The full potential water use (mm) for the whole growing season is estimated using ETo and Kc. Additionally, rainfall (mm) is estimated for each farm for the same period using monthly average rainfall data taken from the meteorological database. The net irrigation requirement (NIR) for the vineyard is

$$NIR = (Etc - rc \times RAIN + IRCC)/Ic \quad (6)$$

where Ic is the efficiency of the irrigation system used, RAIN is the in-season rainfall (mm), rc is the effective rainfall coefficient, and IRCC is the average in-season irrigation requirements for cover crops (estimated to be 100 × cover crop coverage%/67% for annual cover crops and 200 × cover crop coverage%/67% for perennial cover crops).

To calculate the WMIRI, the irrigation water applied during the growing season (mm) is compared with the net irrigation requirements of the vineyard, and the decision rules presented in Table 6 are formulated. To estimate the effect of the different sub-indicators in the overall water management indicator (WMI), decision rules attributing equal weight to both sub-indicators are applied.

2.2.4 Soil management and machinery use indicator

2.2.4.1 Machinery Use Indicator

The environmental objectives of best practice with respect to machinery use are to avoid and minimize generation of greenhouse gas emissions, damage to native vegetation, generation

Decision rules
If IW† = 0 (no-irrigation) then WMIRI = 0.0
If IW < 0.5 × NIR (DTI irrigation) then WMIRI = 0.1
If 0.5 × NIR < IW < 0.7 × NIR (VBA irrigation) then WMIRI = 0.25
If 0.7 × NIR < IW < 0.85 × NIR then WMIRI = 0.5
If 0.85 × NIR < IW < NIR then WMIRI = 0.7
If IW > NIR then WMIRI = 1.0

DTI, deficit threshold indicator, IW, irrigation water applied during the growing season; NIR, net irrigation requirements; VBA, volume balance approach

Table 6. Decision rules describing the effect of the different parameters on the water management irrigation rate indicator (WMIRI)

of noise, and impact on soil structure. Machinery must therefore be used efficiently and sensibly. The parameters that influence the MUI are machinery power (Kw), hours of machinery use per hectare and per year, machinery age (years), and soil compaction. Again, a fuzzy expert system is used with the S-shaped function of Eq. [4].

2.2.4.2 Machinery Power and Age Indicator

Farmers usually keep records of how many hours they use their machinery in the vineyard. A low-power machine has less negative impact on the environment in terms of greenhouse gas emissions, noise generation, and soil compaction than a high power machine. If the hours of machinery use are multiplied by the machinery power, an indirect estimation of environmental impact can be made. For the machinery power per hours of use indicator (MPI) ($Kw\ h\ ha^{-1}\ yr^{-1}$), if we consider, as an average of machinery use in a vineyard, a new 38-Kw four-wheel-drive tractor used for 35 $h\ ha^{-1}\ yr^{-1}$, the fuzzy expert system (Eq. [4]) can be used with the following parameters: x = MPI, $\alpha = 500$, and $\gamma = 1500$. However, machinery age can influence environmental impact. New machinery (expressed as power per hours of use) has less negative impact on the environment compared with older machinery of the same power used for the same number of hours per year. A machinery age correction factor (macc) must therefore be introduced in the MPI. The MPI for each machine must be multiplied by the macc to give the machinery power and age indicator (MPAI). The MPAI for the vineyard is

$$MPAI = \Sigma_1^{mn} MPI \times macc \tag{7}$$

where mn is the number of machines used in the vineyard in the reference year.

2.2.4.3 Level of Soil Compaction Indicator

The degree of soil compaction in the vineyard provides an indicator of soil health. Machinery use on wet soil increases soil compaction. For the level of soil compaction indicator (LSCI, MPa), the fuzzy expert system (Eq. [4]) can be used with the following parameters:

x = LSCI, $\alpha = 1$, and $\gamma = 3$.

The estimation of the effects of the different sub-indicators in the overall soil management and machinery use indicator (SMMUI) follows decision rules that attribute equal weight to both sub-indicators (MPAI and LSCI).

2.2.4.4 Alternative for the Machinery Use Indicator

In the event that farmers do not have records of machinery use (hours) and/or are unable to measure soil compaction, the environmental impact of machinery use can be estimated on the basis of the type of machinery (two-wheel-drive, front-wheel-assist, and four-wheel-drive tractors; track tractors, gantry or caterpillar, all-terrain vehicles, fourwheeled motor bike, or animal trained machinery), the type of wheels and tires (radial tires and bias ply tires), and the potential for use on wet soil. If more than one type of machinery is used, the larger score of MTI is used, thus representing a worst case.

2.2.4.5 Cover Crop Indicator

Although some aspects relating to the use of cover crops (impact on irrigation and fertilizer management) have been implemented in other modules (WMI and FMI), the use of cover crops has other benefits for the environment, such as prevention of soil erosion, improvement of soil health, conservation of soil moisture, and reduced need for herbicide use and mineral fertilizer use. The use of cover crops must therefore be seen as a positive soil management practice. The parameters that influence the cover crop indicator (CVCRI) are the cover crop type (annual/legumes, grass or others, mixture or perennial/ rye grass, sod type grasses) and the cover crop use (incorporation into soil as a green manure or left on the soil surface as a mulch). If no cover crop is used (bare soil), then CVCRI = 1.0.

2.2.4.6 Commercial Fertilizer Use Indicator

The use of commercial fertilizer has been implemented in the FMI. Although if done correctly the use of commercial fertilizer may result in no risk according to FMI, the supply of nutrients in this way cannot be sustained in terms of environmental impact compared with nutrient supply through the use of compost. The use of commercial fertilizer must therefore been seen as a negative soil management practice. If commercial fertilizer is used, commercial fertilizer use indicator (CFUI) = U(1.0). If no commercial fertilizer is used, CFUI = F(0.0).

2.2.4.7 Overall Soil Management and Machinery Use Indicator

The decision rules describing the effect of the different parameters on SMMUI are presented in Table 7.

MUI	CVCRI	CFUI	SMMUI
F	F	F	0.0
F	U	F	0.5
F	U	U	0.7
F	F	U	0.2
U	F	F	0.3
U	F	U	0.5
U	U	F	0.8
U	U	U	1.0

CFUI, commercial fertilizer use indicator; CVCRI, cover crop indicator; MUI, machinery use indicator; SMMUI, soil management and machinery use indicator

Table 7. Decision rules describing the effect of the different parameters in the soil management and machinery use indicator

2.2.5 Soil Organic Matter Indicator

The soil organic matter indicator (SOMI) is based on the organic matter indicator (Bockstaller et al., 1997). This indicator evaluates the effect of management practices on the evolution of soil organic matter to maintain soil organic matter at a satisfactory level. The calculation of the indicator is based on the comparison of the organic matter input in compost and cover crop residues with recommended levels of input for an organic vineyard, as given in Eq. [8].

$$SOMI = RAOMI/AAOMI \quad (8)$$

where RAOMI is the recommended annual organic matter input (kg ha^{-1}) for an organic vineyard (Table 7), and AAOMI is the actual annual organic matter input from compost (or manure) and cover crop residues (kg ha^{-1}).

2.2.5.1 Recommended Annual Organic Matter Input

The recommended levels of OM input for vineyards are given in Table 8 as a function of the clay and loam content of the soil. The recommended levels of inputs are expected to maintain a satisfactory level of soil organic matter in the long term. The initial organic matter level in the vineyard must therefore also be considered. Table 8 refers to a soil with an initial organic carbon content of 2 to 3%. The values in Table 7 must therefore be multiplied by an initial soil organic carbon coefficient that depends on the initial organic carbon content of the vineyard.

Loam	**Clay**			
	<20%	20-25%	25-30%	>35%
0-5%	6000	5600	5400	5000
5-15%	5600	5000	4600	4300
> 15%	5000	4300	4150	4000

Table 8. Recommended level of OM input (Kg OM ha^{-1}) for vineyards

2.2.5.2 Annual Organic Matter Input from Compost (or Manure) and Cover Crop Residues

The AAOMI is the sum of the actual annual organic matter input from compost (or manure) use (AAOMIC) and the annual organic matter input from cover crops (AAOMICCR, kg ha^{-1}). The AAOMIC is calculated as

$$AAOMIC = 1000 \times 0.01 \times 1.72 \times CUR \times N \times CNR \quad (9)$$

where N is the nitrogen concentration of compost on a dry matter basis (%), CNR is the C/N ratio of compost, and CUR is the compost use rate (t ha^{-1} yr^{-1}).
The AAOMICCR is calculated as

$$AAOMICCR = 0.01 \times 1.72 \times CCRY \times NCCR \times CNRCCR \quad (10)$$

where CCRY is the cover crop biomass yield (kg ha^{-1}), NCCR is the nitrogen concentration of cover crop (%), and CNRCCR is the C/N ratio of cover crop. For the NCCR, unless better information is available, the following values are used: for legumes %N = 3.5, for grass %N = 2.5, and for mixtures %N = 3.0.

For the CNRCCR, unless better information is available, the following values are used: for legumes CNR = 20, for grass CNR = 40, and for mixtures CNR = 30. For the CCRY, unless better information is available, the following values are used: for legumes CCRY = 2000 × cover crop coverage%/67% kg ha^{-1}, for grass CCRY = 3000 × cover crop coverage%/67% kg ha^{-1}, and for mixtures CCRY = 2500 × cover crop coverage%/67% kg ha^{-1}.

2.2.5.3 Calculation of the Soil Organic Matter Indicator

For the SOMI, a fuzzy expert system is used with the S-shaped function (Eq. [4]). In this case, the parameters x, α, and γ are x = SOMI, α = 0.6, and γ = 1.6.

2.2.6 Biodiversity indicator

2.2.6.1 Biological Diversity

Diversity depends on two main factors, richness and evenness, which are taken into account when calculating the biodiversity indicator (BI). The number of species per sample is a measure of richness. The more species present in a sample, the richer the sample. Species richness as a measure on its own takes no account of the number of individuals of each species present. It gives as much weight to species that have very few individuals as to those that have many individuals.

Evenness is a measure of the relative abundance of the different species making up the richness of an area. The indicators relevant to biodiversity are the flora biodiversity indicator and the soil fauna biodiversity indicator. For both indicators, the Simpson's diversity index (D) is used (Simpson, 1949).

2.2.6.2 Simpson's Diversity Index

Simpson's diversity index measures the probability that two individuals randomly selected from a sample will belong to the same species (or some category other than species). The version of the formula of Simpson's Index for calculating D used in the BI is the following:

$$D = \frac{\Sigma n(n-1)}{N(N-1)} \qquad (11)$$

where n = the total number of organisms of a particular species, and N = the total number of organisms of all species.

The value of D ranges from 0 to 1, where 0 represents infinite diversity, and 1 represents no diversity.

2.2.7 Environmental impact of organic viticulture indicator

The indicator of the environmental impact of agronomical practices in organic viticulture (EIOVI) is obtained according to a set of 64 decision rules. These synthesize the indicators of the aforementioned agronomical practices (PDMI, FMI, WMI, and SMMUI) and ecological aspects (SOMI and BI). If one or more of the indicators that form the overall EIOVI cannot be measured due to a lack of data, the EIOVI is calculated using the remaining indicators, and the decision rules are automatically adapted to the number of indicators considered. The indicator was developed for the Organic Viticulture, but with a series of correcting factors that consider the use of non organic fertilizers, and the addition of a range of sub-indicators related to the use of conventional pesticides, EIOVI could be applied also for the conventional Viticulture.

The information that the software requires to consider the environmental impact of synthetic fertilizers are the fertilizer use rate, expressed in kg/ha and the content of Nitrogen (N%); Phosphorus (P%) and Potassium (K%). The environmental impact is calculated as indicated in the previous paragraph.
To introduce an active ingredients between the conventional pesticides used in the pest management plan, a series of information related to the eco-toxycological properties and physical chemical properties are required. The environmental impact is calculated as indicated in the previous paragraph for the organic pesticides applications.

3. Farm testing description and results

The EIOVI indicator was used to calculate the environmental impact and relative ranking for different strategies of treatment with a range of test management scenario, three different vineyards in the same farm. The meteorological conditions are typical for Southern Italy: 350 mm of annual rainfall (RAINFALL), with an average maximum daily rainfall of 45 mm.

3.1 Site 1

In the farm a vineyard of 2 hectare with the a slope of 2% was selected (SITE 1). The soil characteristics were: organic carbon (OC) 0,9%, bulk density (BD) 1.95 g/cm^3, sand content 59%, silt content 18%, and clay content 36%. There was a stream 360 m from the vineyard.
50 % of the total surface was covered with annual cover crops (legumes and grass), which were ploughed in the soil. The total yield of cover crops was around 9000 kg/ha.
The fertilization was carried out using synthetic fertilizer at a rate of 400kg/ha, and N% 7, P_2O_5% 14 and K_2O% 21.
The following active ingredients were used for the crop protection management:

- trifloxystrobin, applied by spraying at a rate of 150 g/ha, in two different application times with an interval of 15 days, when the vine was in the phenological state of flowering (full canopy).
- penconazole, applied by spraying at a rate of 350 g/ha, in two different application times with an interval of 15 days, when the vine was in the phenological state of flowering (full canopy).
- sulfur, powder, applied at a rate of 2500 g/ha, when the vine was in the phenological state of flowering (full canopy).

3.2 Site 2

In the farm a vineyard of 1,5 ha with the slope of 20% was selected (SITE 2). The soil characteristics were: organic carbon (OC) 0,3%, bulk density (BD) 1.13 g/cm^3, sand content 68%, silt content 18%, and clay content 14%. There was a pond at 600m from the vineyard.
50 % of the total surface was covered with annual cover crops (legumes and grass), which were ploughed in the soil. The total yield of cover crops was around 7200 kg/ha.
The fertilization was carried out using compost at a rate of 1 t/ha, and N% 2,5, P_2O_5% 2 and K_2O% 3.
The following active ingredients were used for the crop protection management:

- pyrimethanil applied at a rate of 1000 g/ha, when the vine was in the phenological state of flowering (full canopy).

- trifloxystrobin, applied by spraying at a rate of 100 g/ha, in two different application times with an interval of 15 days, when the vine was in the phenological state of flowering (full canopy).
- penconazole, applied by spraying at a rate of 350 g/ha, in two different application times with an interval of 15 days, when the vine was in the phenological state of fruit-setting.
- sulfur, powder applied at a rate of 2500 g/ha, when the vine was in the phenological state of flowering (full canopy).
- mancozeb, powder applied at a rate of 1000 g/ha, when the vine was in the phenological state of pre-flowering
- deltamethrin, powder applied at a rate of 800 g/ha, when the vine was in the phenological state of flowering (full canopy).

3.3 Site 3

In the farm a vineyard of 3,5 hectares with a slope of 18% was selected (SITE 3). The soil characteristics were: organic carbon (OC) 1,1%, bulk density (BD) 1.62 g/cm^3, sand content 44%, silt content 17%, and clay content 39%. There was a stream at 30m from the vineyard.
50 % of the total surface was covered with annual cover crops (legumes and grass), which were ploughed in the soil. The total yield of cover crops was around 9000 kg/ha.
The fertilization was carried out using synthetic fertilizer at a rate of 400 kg/ha, and N% 7, P% 14 and K% 21.
The following active ingredients were used for the crop protection management:

- trifloxystrobin, applied by spraying at a rate of 150 g/ha, in two different application times with an interval of 15 days, when the vine was in the phenological state of flowering (full canopy).
- penconazole, applied by spraying at a rate of 350 g/ha, in two different application times with an interval of 15 days, when the vine was in the phenological state of fruit-setting.
- sulfur, powder applied at a rate of 2500 g/ha, when the vine was in the phenological state of flowering (full canopy).

In all sites the soil management was carried out using a track tractor (59 Kw) for 35 hours/ha, and a tyre-wheel tractor (67,5 Kw) for 4 hours/ha.
The results of EIOVI simulation (Fig.3; Fig.4; Fig.5) clearly show how the management at the vineyard level could be improved.

4. Discussion and conclusion

SOStain, Sustainable Winegrowing program, is an integral part of the future of Italian wine production. The program aims to constitute a framework for viticultural and winemaking practices that protect the environment while efficiently and economically producing premium winegrapes and wine. The program is clear, solid, flexible and can be implemented through technological innovations and scientific research. The agro-environmental indicators take an essential place in the SOStain program. The use of agro-environmental indicators appears to be indispensable for responsive and cost-effective policies, and to provide harmonized data on environmental progress on Sustainable management. The indicators in this paper provide a basis on which farm manager can have a picture of overall trends that may require action on their part, and as a tool for analyzing the impact of winegrowing and winery activities and policies on the environment. This

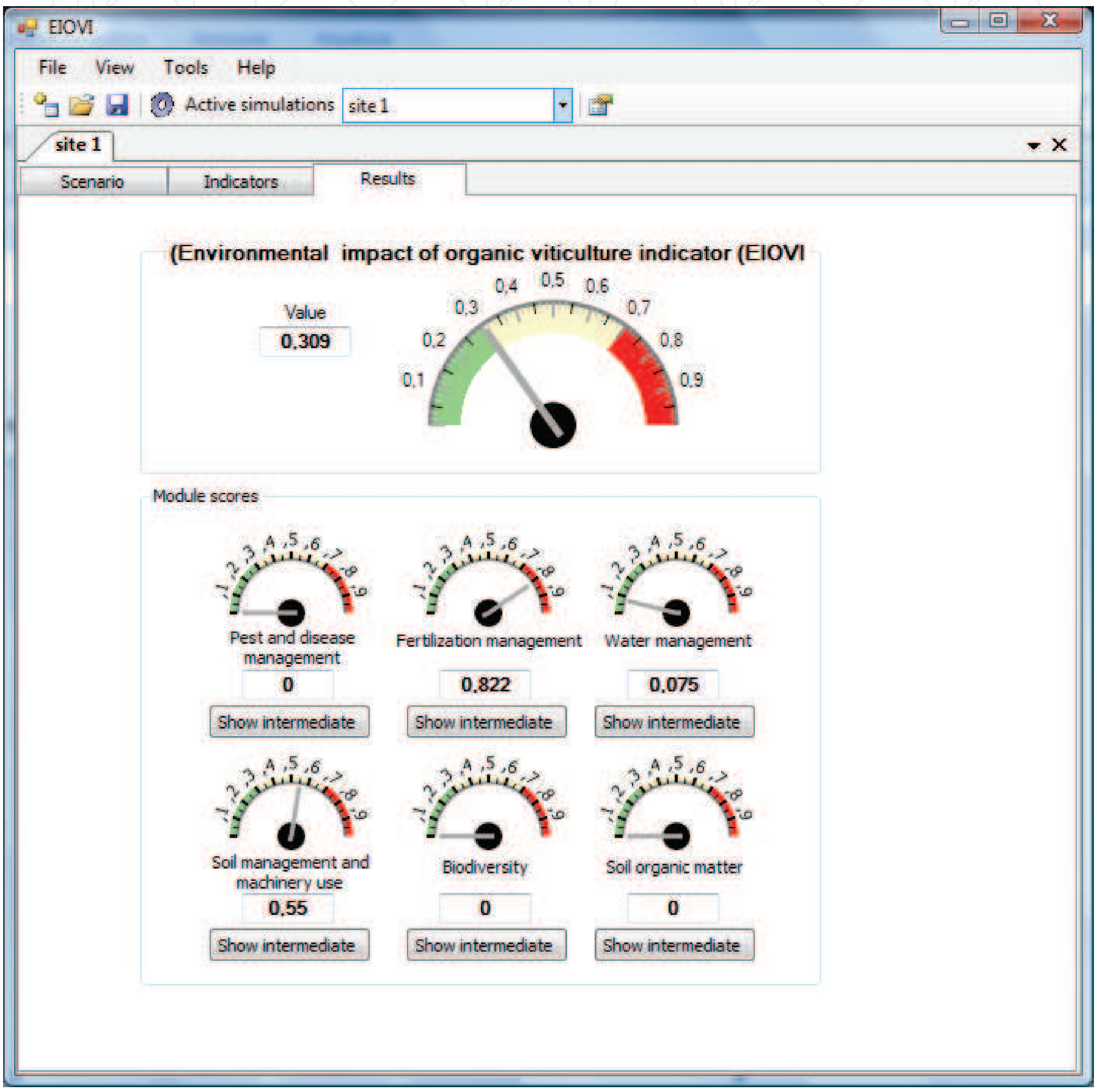

Fig. 3. Environmental impact of organic viticulture indicator (EIOVI) Site 1.

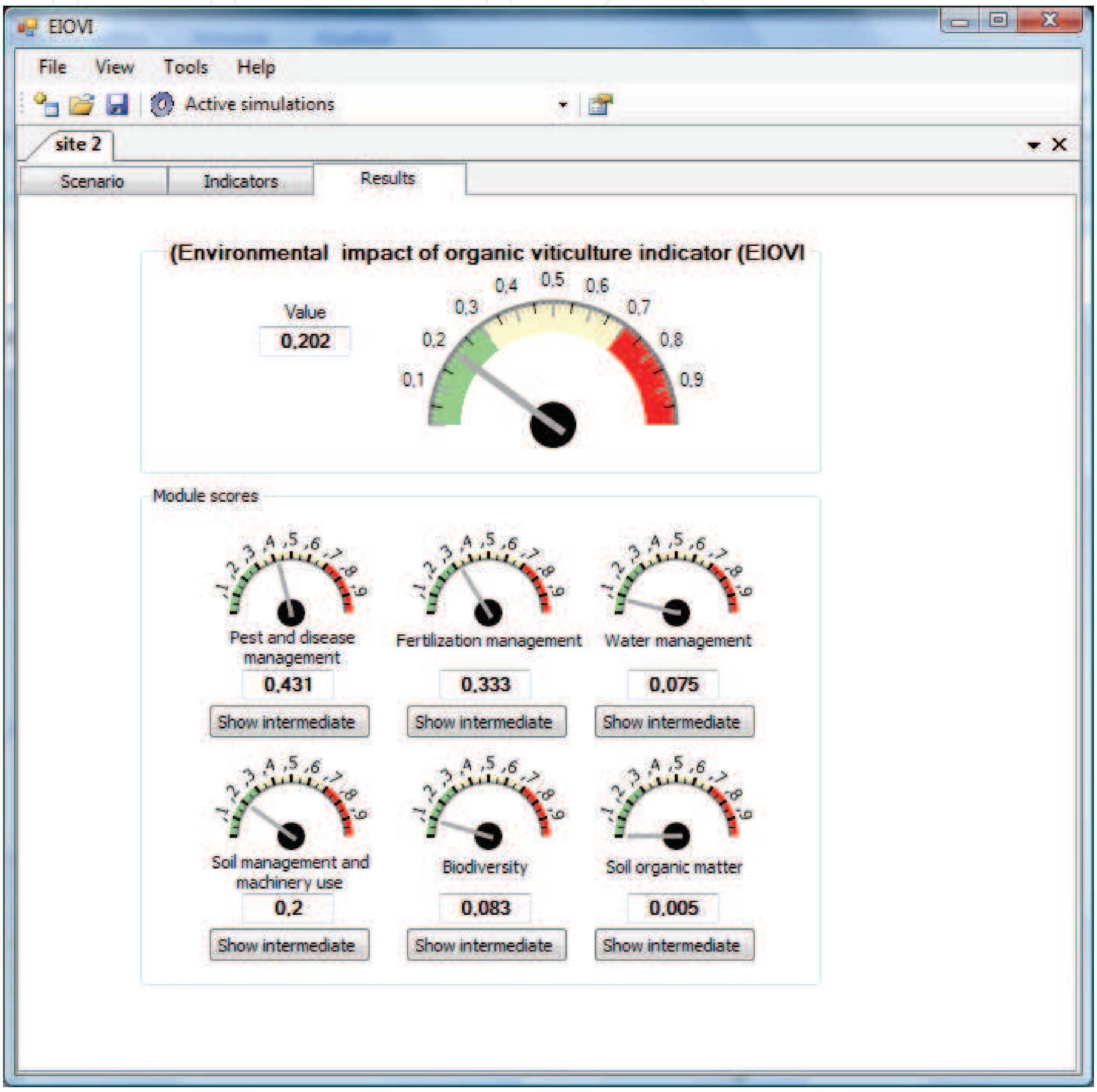

Fig. 4. Environmental impact of organic viticulture indicator (EIOVI) Site 2.

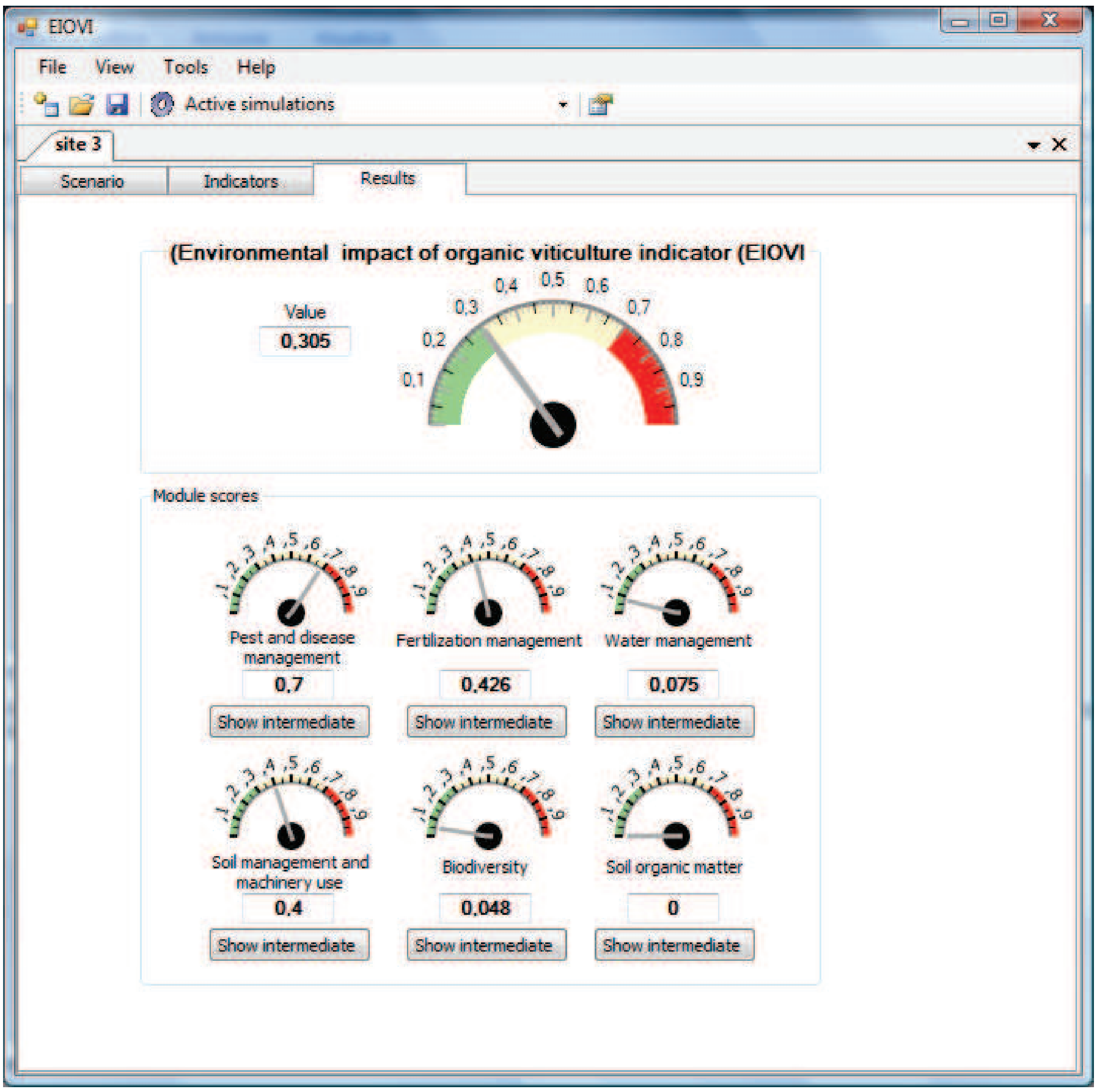

Fig. 5. Environmental impact of organic viticulture indicator (EIOVI) Site 3.

paper presents the use of EIOVI, a fuzzy expert system, that reflects an expert perception of the potential environmental impact of viticulture, in the sustainable farm management. Agro-environmental indicators are necessary to monitor the effectiveness of policies which promote sustainable agriculture. In fact, the objective of an agro-ecological indicator is to render reality intelligible, and the objective of an expert system is the simulation of human actions.The modular organization of EIOVI reflects the complexity of agriculture and can also be used for management planning.

This can be done by applying the indicator, looking at the final score (Figures 3, 4, 5), identifying the management practice (sub-indicator) that affects most the overall score, changing some parameters in that sub-indicator, and going back to the results page to see how the applied changes have affected the indicator's score.

An example is given in Fig. 3, SITE 1. In this case, the FMI has been identified as the sub-indicator having the greatest impact on the overall EIOVI. The application of 400 kg ha^{-1} of a synthetic fertilizer resulted in a FMI score of 0.822, with the intermediate indicators having the values of Fig. 6. Fertilizer nitrogen Indicator (CMFNI) considers the nitrogen demand from fertilization (NDF) of the vineyard taking into account the N release from humus mineralization (NRHM), the cover crop demand/contribution for/of N and the total N that becomes available for the plant uptake during the first year of compost and/or mineral fertilizer use (NAT). On this basis, the application of less fertilizers, and the use of cover crop in soil surface, without incorporation in soil could significantly lowered the FMI (values of intermediate indicators in Fig. 6). In fact particularly nitrogen and phosphorus have the potential of causing detrimental environmental effects if fertilization is used inappropriately. Generally, if large quantities of fertilizers are used (mulching) or if

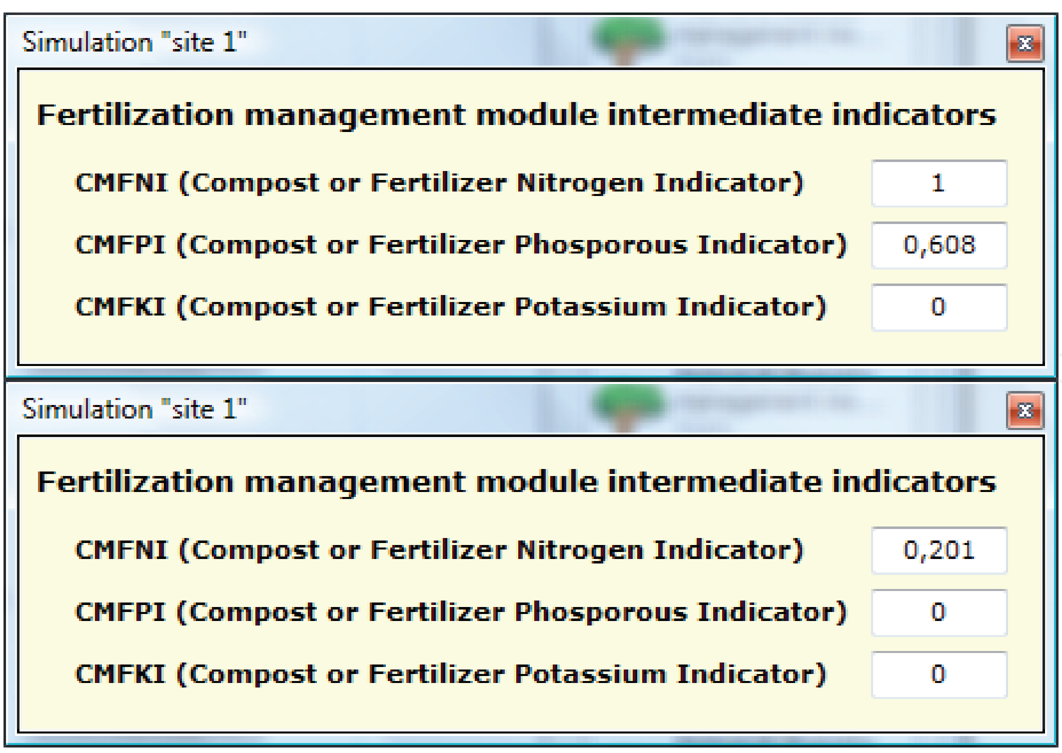

Fig. 6. Intermediate indicators for two management options with different fertilizer use rate, and cover crops use. In the second case the vineyard manager used less fertilizer, and cover crops mulching.

fertilizers is applied to soils where high quantity of cover crops are incorporated, nitrate leaching can occur.
This is a potential problem particularly in viticulture since grapes have relatively little nutrient requirements and many vineyard soils are already very well supplied with phosphorus.
Another example is given in Fig. 4, SITE 2. In this case the PDMI has been identified as the sub-indicator having the greatest impact on the overall EIOVI. The applications of pesticides as indicated in the previous chapter resulted in a PDMI score of 0,431 , with the intermediate indicators having the values of Fig. 7. The high score in the surface water indicator SWI depends on high PEC_{sw}. The PEC_{sw} comprises PEC_{sw} due to drift and PEC_{sw} due to runoff . The drift loading is estimated as in the FOCUS Drift Calculator (FOCUS, 2001) and in this case is high due to short distance of water body, and depends on application rate, number of applications, and water body depth. The application rate reduction, could significantly lowered the SWI and consequentially the PDMI. Moreover a number of mitigation practices could be improved to reduce the pesticides drift in the close water body.
The last example given in Fig. 5, represents the SITE 3. Also in this case the PDMI appears to be the sub-indicators having the greatest impact on the overall EIOVI with the resulting PDMI score of 0,7. The values of the intermediate indicators are reported in the figure 8. The PDMI score is based on PEC_{drift} that is higher than the $PECr_{unoff}$. The reduction in treatment number and in active ingredient quantities employed could reduce the SWI and consequentially also the PDMI.
The EIOVI indicator is the first known tool to evaluate the environmental impact of viticulture. It takes into account the different agronomical practices used in organic viticulture (pest and disease management, fertilizer and irrigation management, soil management, and machinery use) and estimates the effect of vineyard management on soil organic matter and the biodiversity.
Although developed for organic viticulture, it was been extended to conventional viticulture. This was been done by adding new non-organic plant protective products in the active ingredients database of the PDMI. The FMI includes the option to use commercial fertilizer, and the other four sub-indicators can be used for conventional viticulture.
The fuzzy set theory adopted provides an elegant and quantitative solution to determine cut-off values for input variables and for output results. The hierarchical structure of this technique, through the use of decision rules and by combining weighted fuzzy values, allows the aggregation of indices into first-level fuzzy indicators and then into a second-level fuzzy indicator for the whole system. The system has a modular structure and thus provides a synthetic indicator reflecting the overall impact for the whole system as well as detailed information through its six modules.
In conclusion, if some improvements to the tool are implemented, EIOVI will be a helpful assessment tool for vine growers, consultants, environmental agencies, and scientists. EIOVI indicator can drive sustainable pest management practices, and increases the awareness on environmental topics, underlining the critical aspects in the current farm management.
New modules can be added and the flexibility of the system permits the tuning related to expert perception. Therefore, and despite the fact that the theory behind the indicator is quite exhaustive, the tool is provided with a graphical user interface (GUI) that is easy to use (even by the winemakers) and requires only basic input data that are not too expensive or too difficult to be obtained by the users. The tool could be extended to other branches of agricultural production by including perennial cultures, vegetable crops, crop rotation, or livestock husbandry.

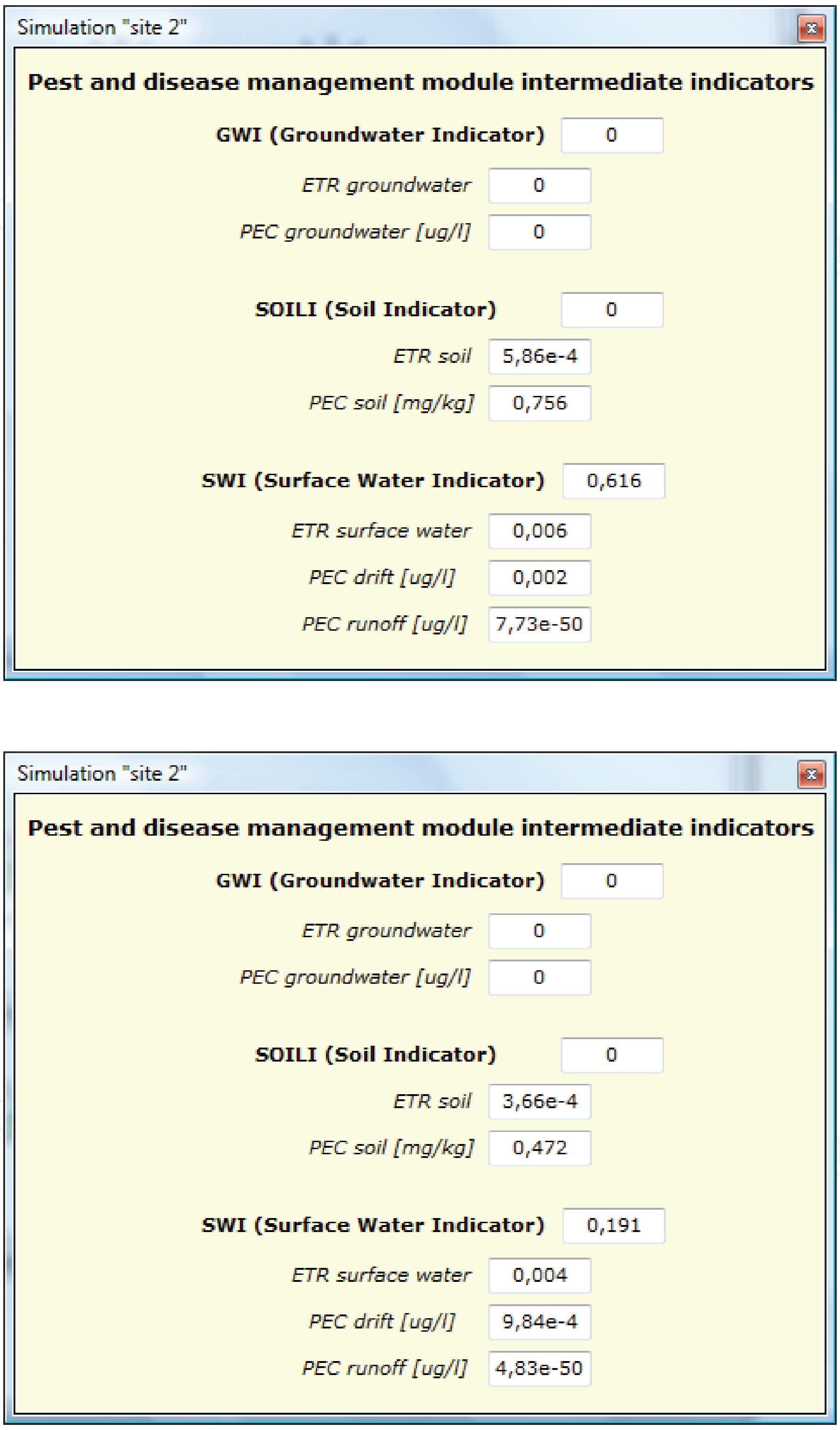

Fig. 7. Intermediate indicators for two management options with different pesticides use rate. In the second case the vineyard manager reduced the treatment rates.

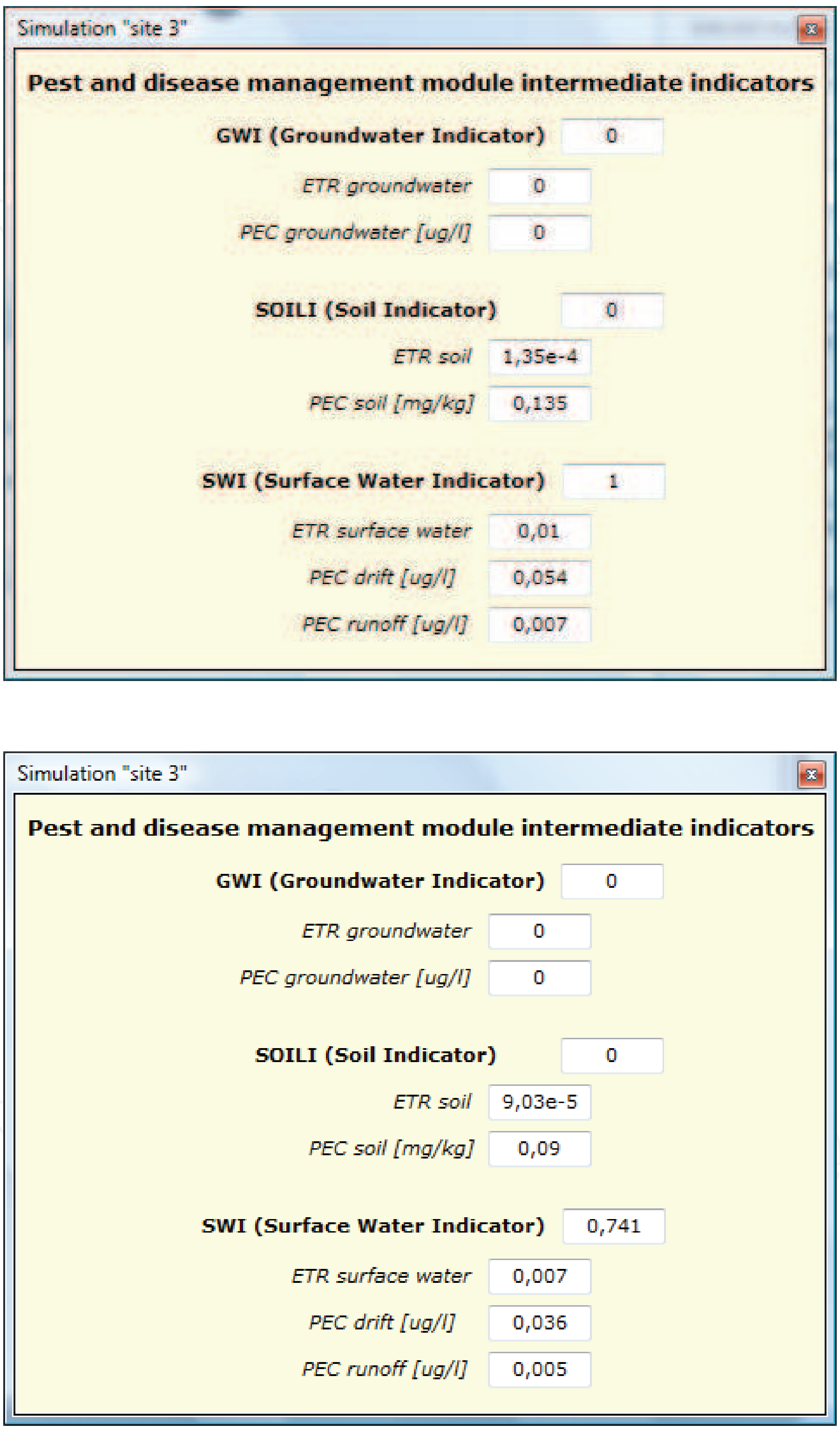

Fig. 8. Intermediate indicators for two management options at different pesticides use rate. In the second case the vineyard manager reduced the treatment rates.

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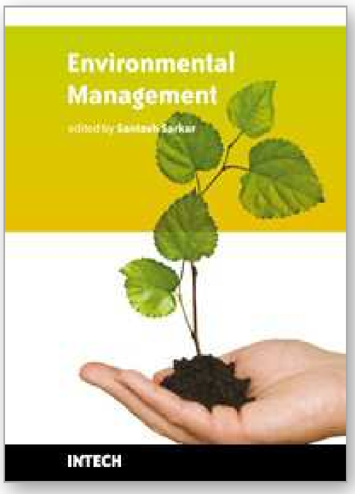

Environmental Management
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There has been a steady increase in anthropogenic pressure over the past few years due to rapid industrialization, urbanization and population growth, causing frequent environmental hazards. Threats of global environmental change, such as climate change and sea level rise, will exacerbate such problems. Therefore, appropriate policies and measures are needed for management to address both local and global trends. The book 'Environmental Management' provides a comprehensive and authoritative account of sustainable environmental management of diverse ecotypes, from tropical to temperate. A variety of regional environmental issues with the respective remedial measures has been precisely illustrated. The book provides an excellent text which offers a versatile and in-depth account of management of wide perspectives, e.g. waste management, lake, coastal and water management, high mountain ecosystem as well as viticulture management. We hope that this publication will be a reference document to serve the needs of researchers of various disciplines, policy makers, planners and administrators as well as stakeholders to formulate strategies for sustainable management of emerging environmental issues.

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