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Environmental Impact Evaluation of Olive Mill Wastewater Shedding on Cultivated Fields

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ABSTRACT

The olive oil industry in Europe produces a significant amount of olive mill wastewater (OMW) which poses a serious environmental threat if its disposal is not carried out correctly. At the same time, OMW is an important source of useful substances for several activities (e.g. for food, chemical and energy industries; in agriculture as a fertiliser, as a resource for organic matter). Currently in Italy OMW shedding on cultivated fields seems to be the most viable solution. Disposing of OMW appropriately requires specific data on wastewater management (OMW doses and type, the latter depending on the olive oil extraction system, and distribution modality), the shed field (soil type and features, crop typologies, agricultural practises), and the climatic pattern of the area where the field is located. All these data, considered in an integrated evaluation procedure based on the fuzzy logic theory (Sugeno technique), means that the agro-environmental risk can be assessed by calculating a synthetic index ascribable to a specific hypothesis of OMW shedding. This paper presents a multiplatform software application called ICABAS. The software has been adapted to the current Italian legislation and the specific environmental conditions of the Basilicata Region where it has been integrated into the regional laws for olive mill residue management. The evaluation procedure is easy to use and provides a useful tool for administrative and technical purposes and also to support decision systems, at a policy level, for the sustainable management of the resources involved.

Keywords: decision support system software, fuzzy analysis, OMW, risk index

CONTENTS

INTRODUCTION

Each year the European olive oil industry uses more than 8 million tons of freshwater, producing more than 4.6 million tons of olive mill wastewater (OMW) and in addition more than 6.8 million tons of solid waste (pomace) (TDC-OLIVE Project 2007).

Besides the European Community, which is the main olive oil producer in the world (IOC, www. internationaloliveoil.org), and the traditional producers of the Mediterranean Basin (North Africa and Middle-Eastern countries), other countries such as Argentina, Australia, and South Africa, are establishing new olive plantations managed following intensive horticultural models. This increasing production of olive oil worldwide is likely to see a parallel rise in OMW thus making the need to find a suitable solution for its disposal more urgent.

The composition of OMW is strongly affected by the olive variety, the harvesting period, and the oil extraction method. OMW contains several organic components (sugars, lipids, pectins, tannins, polyphenols, polyalcohols), a high organic matter content, and mineral elements such as nitrogen, phosphorous, calcium, magnesium, potassium, and phytotoxic compounds, mainly phenols (Pacifico 1989).

Because of the organic matter and its nutrient contents, OMW can be used in the agricultural sector both as a fertiliser and amendment as well as an integrative water source. Moreover, it represents a valuable source of biomass and high value added compounds (Gortzi *et al.* 2008). In fact, OMW is an important resource in the food industry playing a central role in the production processes of natural pigments, antioxidants, sugars, and animal feed. It can even be used as a substrate to grow fungi, algae, and bacteria, and also to provide biogas and synthesise biopolymers (López *et al.* 2001; Crognale *et al.* 2003).

On the other hand, OMW is potentially polluting for the environment especially when its disposal is carried out using unsuitable or even incorrect procedures, for example excessive doses, localized distribution in a limited time period lasting, generally, from October till February. When the wastewater is accidentally or deliberately disposed in fields without any preliminary detoxification treatment, considerable contamination, especially by organic compounds (fatty acids, organic acids, and phenols) present in

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OMW at very high concentrations, can take place inside the most sensitive systems (e.g. freshwater bodies) (Celano *et al.* 2008; Khatib *et al.* 2009). OMW microbiological stabilization with other solid organic materials by composting could reduce the possible phyto-toxicity and make wastewater use more applicable for several uses (Tomati *et al.* 1995).

At present in the Italian scenario, OMW shedding on cultivated fields seems to be the most feasible solution.

There have been contrasting results and different opinions on the real agro-environmental risks/benefits of OMW distribution in agricultural systems. The response variability is mainly due to the great diversity in the characteristics of the systems studied: dose and modality of the OMW distribution; typologies of the soils; varieties of crop species; soil water regimes of the involved system (e.g. soil water content, run-off, water infiltration); agricultural practises (e.g. tillage depth, use of conservative practises such as cover strips); and climatic conditions especially with respect to temperature, and rainfall patterns (Silvestri *et al.* 2006).

All these different features must be considered in an integrated evaluation procedure, which defines the vulnerability to shedding of the specific site in order to guarantee soil quality, crop development, and environment preservation.

Both farmers and public decision-makers need to be able to take into account the potential environmental impact of OMW shedding. A procedure for estimating the agro-environmental risk ascribable to a specific hypothesis of OMW distribution on cultivated fields was set up by Silvestri *et al.* (2006). It enables a synthetic index (SI) to be calculated, obtained by a weighted aggregation of variables linked both to OMW quanti-qualitative characteristics and agricultural, climatic, pedological, and topographic features of the field that has been destined to receive the wastewater.

This paper describes a Decision Support System Software, ICABAS, to calculate the agro-ecological impact of OMW shedding on cultivated fields. It is multiplatform (e.g. running on Windows, Macintosh, and Linux operating systems) and provides clear and extensive tutorial and documentation. Its features are as follows: it enables operators to minimize the environmental impact associated with field application of OMW, it is easy to use, it includes modular functioning, cost-savings for administrative and technical procedures, and it helps to make administrative decisions more transparent.

The procedure conforms with current Italian legislation and with the specific conditions of the Basilicata Region (Southern Italy), in fact it has been integrated into Basilicata's Regional Laws for olive mill residue management (Regione Basilicata 2007).

The procedure described in this paper has an innovative character. As a matter of fact, to our knowledge, similar procedures based on an integrated evaluation approach were not applied nowhere, although the OMW issue is of extreme importance in the world.

VARIABLE AND MODULE AGGREGATION PROCEDURE

The evaluation procedure considers variables grouped into five modules (Wastewater, Groundwater, Surface Water, Crop, and Soil). The values of the input variables can either be direct measurements or estimations (**Table 1**).

The Wastewater module describes the characteristics of the pollution source and takes into account the olive oil mill technology and OMW quantity and quality (physical and chemical parameters). It also determines the potential agro-environmental risk associated with OMW features (**Table 2**). The Groundwater, Surface Water, Crop, and Soil modules are defined as target systems of the pollution source (OMW). A panel of experts has identified, for each module, one or more variables according to the following parameters: energy, as the capacity of the environmental impact transmission; resistance, which takes into account factors opposing the impact spreading; protection, as the whole elements able to attenuate the impact propagation; vulnerability, considering all those conditions which increase the consequences of the impact (**Table 2**).

In addition, the panel of experts assigned different "weights" to each variable resulting in a total score for each individual module (**Table 2**).

The Groundwater module considers all the components which could lead to groundwater pollution by OMW (leaching). The Surface Water module takes into account the possibility that OMW reaches the surface water through a runoff or drift, thus harming aquatic organisms. The Crop module considers the possible contact of OMW with cultivated crops and the consequent negative effects on crop growth. The Soil module examines the effect on soil quality generated by OMW interaction with soil properties.

More details on the choice of variables to include in the procedure can be found in Silvestri *et al.* (2006).

Table 1 Estimating function of the parameters used in ICABAS procedure.

Parameter	Formulae	Reference
ISSS/USDA Conversion	$P_{2-50} = -18.3914 + 2.0971 (P_{2-20}) + 0.6726 (P_{20-2000}) - 0.0142 (P_{2-20})^2 - 0.0049 (P_{20-2000})^2$ If $P_{2-50} < 0$ then $P_{2-50} = 0.8289 (P_{2-20}) + 0.0198 (P_{20-2000})$ where: P_{2-20} = 2-20 μm fraction; P_{2-50} = 2-50 μm fraction; $P_{20-2000}$ = 20-2000 μm fraction	Minasny 2002
Soil saturation rate (Vs)	Vs = (p / n) / (FC * H) or Vs = (p / n) / ((2.65 - BD) / 2.65 * H * 0.6) Where: p = monthly mean precipitation; n = monthly number of raining days; FC = field capacity; H = tillage depth; BD = bulk density	Saxton *et al.* 1986
Field capacity (FC)	From $\Psi = A * \Theta^{-B}$ where: Ψ = matric potential; Θ = volumetric water content	Saxton *et al.* 1986
Bulk density (BD)	BD = (1 – Θs) * 2.65	Saxton *et al.* 1986
Climatic factor (R) (R - USLE)	R = [4.17 $\Sigma(p^2 / P)$ - 152] * 17.02 where: p = monthly mean precipitation; P = annual mean precipitation	Arnoldus 1980
Soil morphologic factor (SL - USLE)	$SL = (a / 22.13)^b * (0.065 + 0.045 * i + 0.0065 * i^2)$ where: a = length of slope (m); b = 0.5 if i > 5%, 0.4 if 3% < i ≤ 5%, 0.3 if 1 < i ≤ 3%, 0.2 if i ≤ 1%; i = slope steepness (%)	Wischmeier and Smith 1978
Soil Erodibility (K) (K - USLE)	$K = [2.1 * TF^{1.14} * 10^{-4} * (12 - OM) + 3.25 * (SF - 2) + 2.5 * (PF - 3)] * 0.1317 / 100$ where: TF = (silt% + very fine sand %) * (100 – clay%); OM = organic matter %; SF = structure factor (from 1 to 4); PF = permeability factor (from 1 to 6)	Wischmeier and Smith 1978
Macroporosity (MP)	MP = [(2.65 - BD) / 2.65 - FC] * 100 where: BD = bulk density; FC = field capacity	Beven and German 1982
Monthly Mean Temperature T(j)	T(j) = T * f(j) T = 33.73 − 0.0063 * Z − 0.4091 * Lat; f(j) = 1 + Bcos ((2Π/12) * j) + C * sen ((2Π/12) * j) where: T = annual mean temperature; J = from 1 to 12; Z = meters above sea level (m a.s.l.) Lat = Latitude in hexadecimal degree; C = -0.3095 – 0.000236 * Z; B = 0.0579 + 0.990 * C	Mancino and Claps 2002

Table 2 Parameters of each module and their incidence on the value of the Synthetic Index (SI).

Module	Factor	Expert weight
Wastewater module		
Rate of Application	Pollution	10
Time Past from the Last Shedding	Vulnerability	6
Floating Impurities	Pollution	2
pH	Pollution	2
SAR	Pollution	2
Electric Conductivity	Pollution	2
Groundwater module		
Soil Saturation Rate	Energy	6
Saturated Hydraulic Conductivity (Ks)	Resistance	8
Field Distance from Wells	Vulnerability	1
Surface water module		
Rainfall Erosivity (R-factor)	Energy	4
Soil Morphologic Factor (SL)	Energy	4
Soil Erodibility (K)	Resistance	4
Protection Cover Factor (C)	Protection	8
Conservative Management Techniques	Protection	6
Field Distance from Water Bodies	Vulnerability	4
Land use module		
Land use	Vulnerability	10
Soil module		
Mean Temperature in the Month of Shedding	Protection	1
Macroporosity	Resistance	6
Salinity	Resistance	2
pH	Resistance	6
Exchangeable Sodium Percent (ESP)	Resistance	1
Field Distance from Potable Water Sources	Vulnerability	2
Field Distance from Houses	Vulnerability	2

The aggregation of the different nature and size of the variables are based on the theory of fuzzy logic (Sugeno technique) (Bellocchi *et al.* 2002). The method uses assignation (or transition) polynomial functions to give each variable a real value ranging from 0 to 1, corresponding to a "belonging degree" (BG) to one of three different classes: favourable (F), unfavourable (U), and an intermediate value called fuzzy class (F/U). Next, a variable aggregation (first-level aggregation) is carried out using the "decision-making rules" which take the BGs and the weights attributed to the variables according to their importance in attaining the final result (module index).

Then a further aggregation takes place for each module (second-level aggregation) to calculate the SI corresponding to the assessment of the system's environmental vulnerability. The module indices and the SI have real values ranging from 0 (no agro-environmental risk) to 1 (maximum risk) (Silvestri *et al.* 2006).

The incidence of a variable on the final score depends not only on the value assumed by the variable itself, but also on the values of the other inputs, and on the F and U limits.

In setting up other decision rules, the panel of experts has to establish the relative importance of each module, taking into consideration the specific conditions of the application scenario. In our case, in the aggregation of the modules, we decided to give the greatest weight to the Surface Water (30) and Wastewater (25) modules, and the smallest to the other modules (Soil = 20, Groundwater = 15, and Crop = 10).

THE ICABAS SOFTWARE

The general architecture of the program is shown in **Fig. 1**. The development process was as follows: design and development of a generic fuzzy kernel, class design to evaluate risks for each module, development and testing of the classes, development of the graphic user interface (GUI), GUI integration into the existing subsystem to access climatic data, development of the Save & Restore subsystem for the working sessions, development of the HELP on/off line and heavy testing for code robustness.

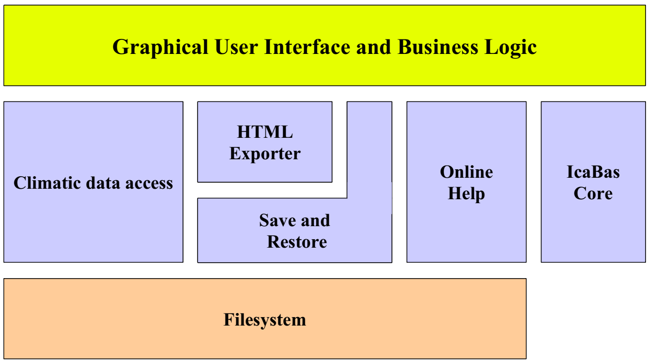

Fig. 1 ICABAS software architecture.

The variables used by the software to assess the risk of OMW shedding are reported in **Table 2**. The values of the variables can be measured directly, estimated or taken from internal tables and databases. Laboratory analytical input data are limited to texture, pH, electrical conductivity, exchangeable bases, and the organic matter of soil samples taken from the cultivated field involved in the shedding.

To reduce the cost associated with laboratory analyses, pedotransfer functions (Saxton *et al.* 1986; Campbell and Shiozawa 1992; Soil Survey Staff and Natural Resource Conservation Service 1993), OMW features available in the literature (Pacifico 1989), tables (Gardin *et al.* 2002), and models to estimate different field characteristics (Wischmeier and Smith 1978; Beven and German 1982), were implemented (**Table 1**). Before the soil pedotransfer application, particle size data must be converted from the ISSS into the USDA texture classification system using the equations reported in Minasny (2002) (**Table 1**). Alternatively, direct certified measurements of some parameters (e.g. soil macroporosity, electrical conductivity of the OMW) can be used to calculate the final SI.

The Basilicata Region database (UTM system georeferred), which is provided along with the software, is a set of 25 binary files reporting the following monthly climatic data: (a) mean precipitation, (b) number of rainy days, (c) R-factor, climatic erodibility factor (Arnoldus 1980) calculated according to Claps and Mancino (2002) (**Table 1**), and Laguardia data (Laguardia 2004). The software automatically produces climatic data when the user types the geographical coordinates of the field under evaluation.

Interaction with the end-user is achieved by filling in the fields in the seven tabs. The first requires administrative information related to the mill, the technician responsible for the procedure, the owner of the field, the geographical coordinates (UTM), and the altitude of the field. Four tabs correspond to each individual module of the assessment procedure. The last tab shows the partial indices for each module and the SI generated by the ICABAS software.

The experience gained so far suggests the categorization of SI into three agro-environmental risk classes.

Class I: 0-0.33 - low agro-environmental risk (OMW shedding is allowed without a further risk evaluation for three years).

Class II: 0.33-0.66 - medium agro-environmental risk (OMW shedding is allowed provided that the olive mill manager accepts minor changes in the distribution plan e.g. shedding time, distribution modality, and a duty to perform annual monitoring of the soil parameters such as pH and electrical conductivity).

Class III: 0.66-1.00 - high risk (shedding forbidden).

The input data are carefully checked to verify that they respect the relevant laws. The ICABAS software displays an error message when it finds non-compliance with the procedure and does not calculate the SI. The end-user can interact quickly with the software thanks to the on-line help.

Table 3 Preliminary conditions imposed by the Italian legislation to shed soils with OMW.

Parameter	Italian legislation	Example
OMW maximum dose ($m^3 ha^{-1}$)	≤80	80
Field distance from houses (m)	≥ 200	300
Field distance from potable water sources (m)	≥ 300	600
Groundwater table depth (m)	≥ 10	≥10
Land use: vegetables	No	No
Soil field slope (%)	≤ 15	3
Frozen soil at shedding time	No frost	-
Snowy soil at shedding time	No	-
Saturated soil at shedding time	No	-
Saturated hydraulic conductivity ($\mu m\ s^{-1}$)[a]	≥ 0.1	55
Rainfall accept capacity	No class 5 and 6	1
Soil flood	No presence	No
OMW shedding[b]	According to Best Management Practices	-
OMW burying[b]	Efficient	-

[a] According to Gardin *et al.* (2002)
[b] Olive mill manager must report the shedding modality in the technical report of the authorization procedure

Table 4 Editing input of ICABAS software to evaluate the environmental impact of OMW shedding under three representative field conditions.

Editing input	1st case	2nd case	3rd case
General data			
Field UTM coordinates	4540839 N – 580036 E	4454647 N – 608258 E	4478320 N – 645682 E
Altitude (m a.s.l.)	280	370	115
Slope (%)	3	1	10
Slope length (m)	100	100	100
Wells distance (m)	300	500	400
Houses distance (m)	600	1000	1500
Water bodies distance (m)	800	800	1000
Potable water sources distance (m)	800	800	1000
Land use	olive with other tree species	wheat	grapevine
Support practice	No buffer strips – up and down slope tillage	No buffer strips – cross slope tillage	No buffer strips – up and down slope tillage
Soil parameters			
Soil structure	polyedric	polyedric	polyedric
Saturated hydraulic conductivity ($\mu m\ s^{-1}$)	high	moderately high	moderately high
Clay (%)	11.2	19.7	21.1
Silt (%)	11.1	24.1	11.2
Sand (%)	77.7	56.2	67.7
pH	8.0	8.4	7.2
E.C. ($dS\ m^{-1}$)	0.4	0.4	0.4
Soil organic matter (%)	1.0	1.5	0.6
ESP (%)	0.6	1.0	2.0
Wastewater parameters			
Oil extraction system	Centrifugation	Centrifugation	Centrifugation
Application rate ($m^3 ha^{-1}$)	80	80	80
pH	5	5	5
SAR	12.5	12.5	12.5
E.C. ($dS\ m^{-1}$)	1.375	1.375	1.375
Floating impurities ($g\ m^3$)	140	140	140
Years from last shedding	1	1	1

End users also have an evaluation procedure in text format, a user manual, references, and technical manuals.

The data can be viewed by a common browser as a report in HTML format. The report is generated only when the evaluation is complete and no error has occurred. The output also shows the shedding date and administrative details for the people involved in the shedding process.

The ICABAS software was created exclusively with open source tools and was published by the Basilicata Region Government in 2008. It is freely distributed to agricultural technicians, agencies involved in administrative controls, and olive mill managers. The software is specific to the Basilicata Region and can be downloaded for free at the following web address: http://www.dia.unisa.it/professori/parente/ICABAS.

EVALUATION PROCEDURE EXAMPLES

Three different examples of the ICABAS software application are reported. The procedure was applied under representative conditions of OMW shedding in the olive growing areas of Basilicata Region. In all cases studied, the OMW was obtained from an olive mill equipped with a centrifugation system. OMW characteristics are showed in **Table 4**.

1st case. The shedding site was an olive orchard in combination with other tree species located in the north of Basilicata. The soil is coarse loamy, mixed, calcareous, superactive, and thermic (Typic Xerofluvent, USDA).

The first step in the administrative procedure to obtain authorization for OMW shedding in Basilicata is to verify whether the preliminary conditions imposed by the Italian legislation to spread soils with OMW are satisfied (**Table 3**). Next, Italian law requires that there is a description of a representative soil profile of the proposed shedding site. The physical and chemical characteristics of the soil used in this example are reported in **Table 4**. Such parameters are expressly required by the evaluation procedure. Both field and cartographical surveys enabled the geographical coordinates of the proposed site to be defined and the general data indispensable to perform the evaluation procedure to be collected (**Table 4**). Cartographical information can be

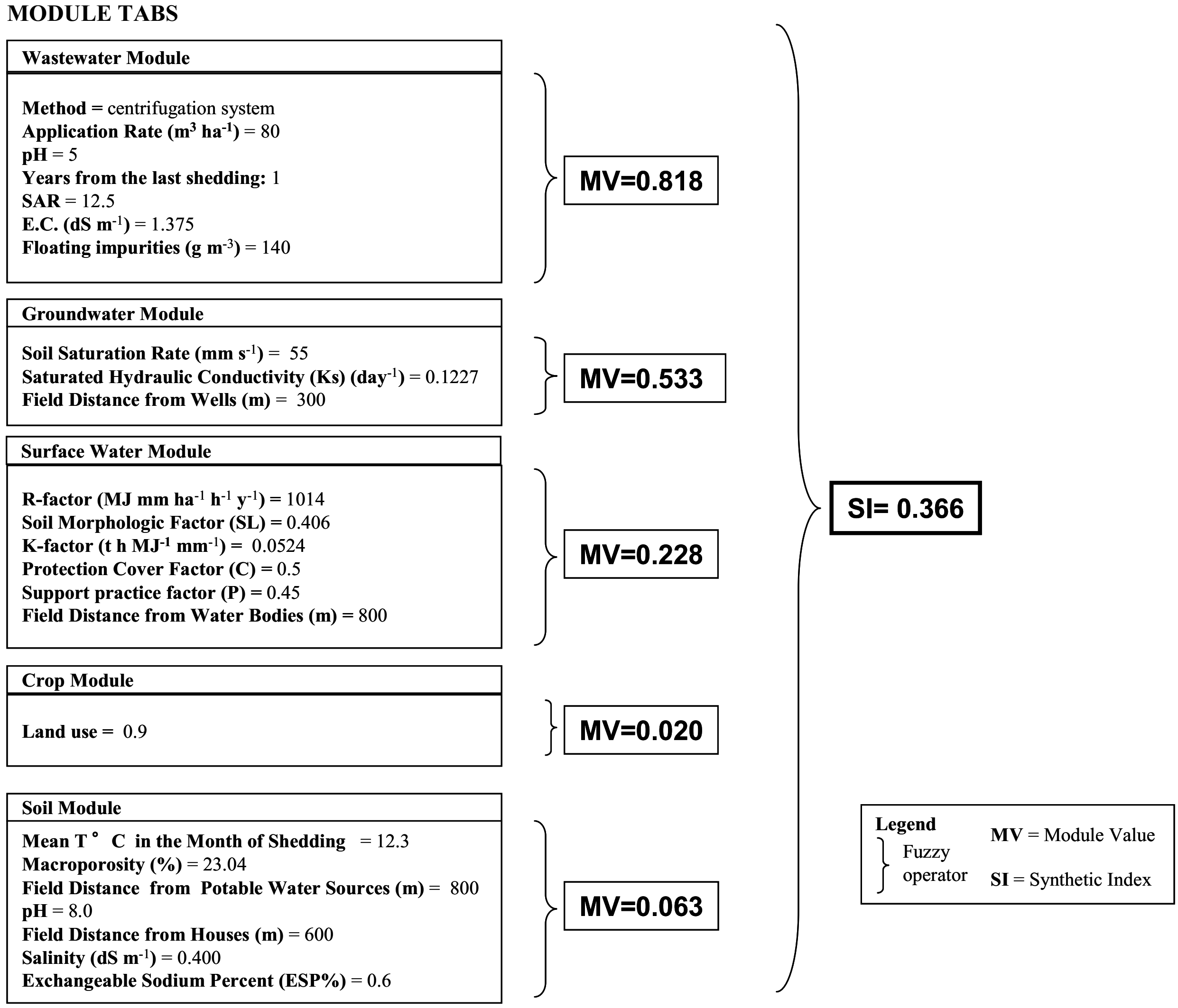

Fig. 2 Example of ICABAS software application using the editing input referred to the 1st case (see Table 4).

found on websites (e.g. http://www.pcn.minambiente.it/PCN/). Finally, after data collection, the user can calculate the risk linked to OMW shedding in the identified field by filling in the different tabs of the ICABAS software (**Fig. 2** – Module tabs). In this 1st case, the evaluation procedure achieves a SI value of 0.366 (Class Index II) (**Fig. 2**). The user is therefore able to modify the input parameters (especially those showing a high potential impact on the environment, i.e. OMW dose) in order to achieve a SI value belonging to Class I, which is also subject to a simplification of the administrative procedure by local regulations (Regione Basilicata 2007). The user simulates to distribute OMW on a field with the same characteristics but used for OMW shedding four years before (SI = 0.307; Class Index I) or hypothesize to change the OMW dose from 80 to 60 m^3 ha^{-1} (SI = 0.3275; Class Index I). Both options reduce the environmental risk connected to OMW shedding.

2nd and 3rd case. The OMW shedding sites were a wheatfield and a vineyard located under different pedoclimatic conditions (**Table 4**). In particular, the shed soils are classified as Typic Haploxerept and Typic Haploxeralf in the 2nd and 3rd case, respectively. The evaluation procedure achieves a SI value of 0.387 in the 2nd case and of 0.450 in the 3rd case. As in the 1st case, the SI values fall within the Class Index II.

CONCLUSIONS

ICABAS software is an important and functional tool to support decision-making for OMW shedding in fields. Further improvements could be achieved by testing the procedure in a high number of fields and involving the stakeholders in an evaluation of the results.

The software could also be used at a catchment basin level. The working session performed and saved by the user (a Java serialized class) could be transferred, after authorization, to a server to create a geographical database, which could be consulted using a common browser. In addition, ICABAS could be useful for the application of agro-environmental regional policies (Council Regulation, EC - No 1698/2005). For instance, a low value of SI (<0.33) could be linked to some kind a reward for olive mill owners who respect the environment.

The ICABAS software was programmed to be implemented in a regional Geographic Information System (GIS) and to be utilised to make regional maps on the vulnerability to OMW shedding and to prepare shedding plans that meet the requirements of Italian law. If the geographical database is updated regularly, it could provide many practical benefits in terms of simplifying and speeding up the authorization and control procedures of the administrative organs.

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