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Planning Agricultural Utilization of Olive Oil Mill Wastewater: A Framework Model and Implementation Example in a Mediterranean Area*

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ABSTRACT

The management of olive oil mill wastewater (OMW) poses relevant technical and economic problems due to some factors, such as: the high qualitative and quantitative variability of effluents (mainly due to the seasonal nature of fruit processing); the geographic dispersion of oil mills; the high concentration of organic matter and inhibiting compounds (e.g. polyphenols). Among the different alternatives for OMW management, agricultural utilization, which has been practised for a long time, is able to assure cheapness, reliability and environmental sustainability, using low technology and requiring lower costs. This practice helps to avoid water body and soil pollution, to reduce costs of OMW management and to exploit the fertilising properties of OMW for both herbaceous and tree crops. An evaluation of the soil's suitability for OMW application is needed to allow the planning and monitoring activities of effluent agricultural utilization, thereby avoiding the uncontrolled disposal of OMW and the subsequent environmental risks. An assessment framework model has been therefore purposely arranged and implemented in the Calabrian region. On the basis of the soil morphological, hydrological and pedologic properties, the fundamental geographic are classified by the model in hierarchical levels (orders, classes and sub-classes) of soil's suitability for OMW application, eventually specifying the kind of restrictions. Model implementation in the Calabrian region (Italy) has allowed the drawing-up of the "Plan of OMW agricultural utilization" at 1:250.000 scale (which integrates the technical rules for the agricultural utilization of OMW adopted in 2006 by the Calabrian region) and has pointed out that the geographic distribution of soils suitable for agricultural utilization of OMW basically corresponds to the main olive productive districts.

Keywords: agricultural utilization, framework model, olive oil mill wastewater, planning, soil properties

FOREWORD

The management of olive oil mill wastewater (OMW, the main residue from olive processing for oil production) poses relevant technical and economic problems due to some factors, such as: the high qualitative and quantitative variability of OMW effluents (mainly due to the seasonal nature of fruit processing); the geographic dispersion of oil mills; the high concentration of organic matter (up to 180 g l^{-1} of COD, Tamburino *et al.* 1999) and inhibiting compounds (e.g. polyphenols). Such peculiarities of OMW produce high pollution risks in the case of disposal into surface water bodies without any preliminary treatment. The need of sustainable methods of OMW management, complying with the existing rules at country level, is therefore evident.

The depuration systems commonly used for OMW management are often of poor efficiency and expensive (mainly for small oil mills located in rural areas), due to the inadequate design criteria neglecting the peculiarities of OMW. Therefore alternative management systems must be adopted in order to protect environmental resources as well as to increase profitability and competitiveness of olive processing industries within the agricultural market systems (particularly in Spain, Italy and Greece, where olive growing plays a remarkable role).

Among the different alternatives for managing OMW, agricultural utilization, which has been practised for a long time, is able to assure cheapness, reliability and environmental sustainability, using low technology and requiring lower costs. As shown by many research activities and field experiences carried out in different contexts all over the world in the last three decades, agricultural utilization of OMW helps to:

- avoid risks of water body pollution as well as surface runoff and soil erosion;
- reduce management costs, for example by utilizing the common irrigation equipment;
- reconnect the natural cycles of organic matter and nutrients (particularly in relation to the impoverishment of the soil due to crop rotation neglection or zootechnical practices);
- exploit the fertilising properties of OMW for both herbaceous and tree crops,

thereby providing a tool for the development of an environmentally-sound agriculture (Tamburino *et al.* 1999).

Specific research activities have clearly highlighted the agricultural advantages, the drawbacks and the technical and economic aspects of the agricultural utilization of OMW. The agronomic response of herbaceous crops and olive trees has shown the absence of unfavourable consequences on the growth, yield and health of crops, provided that the applied volumes are limited (150-300 m^3 ha^{-1} per year, even though in some cases higher doses have been well tolerated by crops, Tamburino *et al.* 1999; Andiloro *et al.* 2009). Only temporary phyto-toxic effects (20-50 days, Tamburino *et al.* 1999) on herbaceous crops with radical apparatus within the soil surface layer have been recorded (Gallardo-Lara and Perez 1990; Rinaldi *et al.* 2003; Montemurro *et al.* 2004). From a hydrologic point of view, agricultural utilization of OMW induces an improvement of the physical and chemical properties of soils (in particular infiltrability and organic matter content) (Zenjari and Nejmed-

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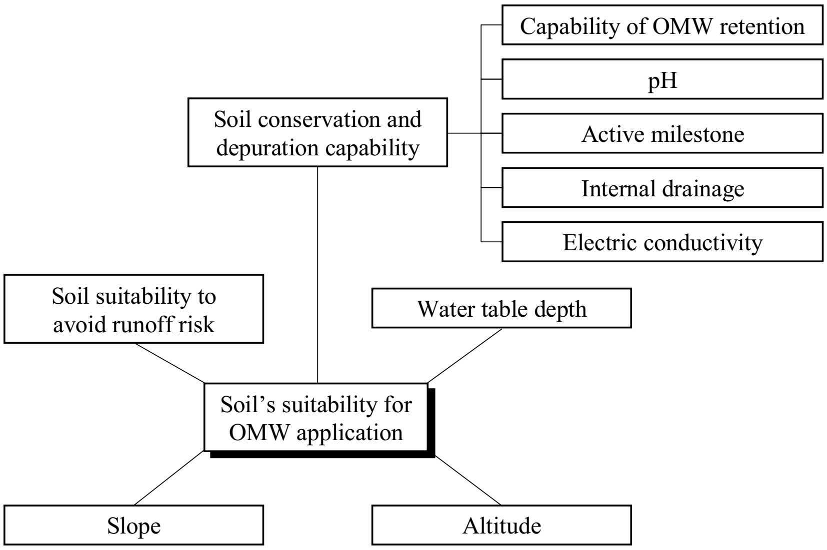

Fig. 1 Layout of evaluation factors controlling soil's suitability for OMW application.

dine 2001; Brunetti *et al.* 2007; Saadi *et al.* 2007). The suitability of drip micro-irrigation systems provided with pre-filtration equipment has been pointed out from the technical and economic aspects (Marrara *et al.* 2002; Capra *et al.* 2007; Andiloro *et al.* 2009).

Therefore from the environmental, technical and economic points of view the agricultural utilization of OMW appears in many contexts the optimal solution. However an assessment framework model of soil's suitability for OMW application is needed, in order to maximize soil self-depuration properties as well as its protection capability of deep water bodies. A planning activity (also on a large scale) of OMW agricultural utilization allows for:

- the provision of an useful tool for OMW management, by indicating the most suitable soils for effluent application on land;
- the regulation and the arrangement of the disposal activities, also from the legal aspects;
- the simplification of control activity by the authorities.

Moreover, planning of OMW agricultural utilization seems to be crucial in zones where olive growing plays a fundamental role for the entire agricultural system, such as in Southern Italy and mainly in Calabria and in Sicily.

To obtain this goal, a framework model to evaluate the soil's suitability for OMW application coupled to an implementation example in the Calabrian region (Italy), in environmental conditions typical of Mediterranean areas, is presented in this paper.

THE FRAMEWORK MODEL FOR PLANNING OMW AGRICULTURAL UTILIZATION ON A REGIONAL SCALE

Introduction

On the basis of common knowledge the evaluation of soil's suitability for OMW application has been performed by arranging an interpretative scheme of soil properties and characteristics affected by the practice of OMW agricultural utilization. The framework model targeted to this goal must take into account:

- the experiences provided by specific research activities and experimental investigation;
- the indications and restrictions provided by national environmental rules;
- the planning scale.

The evaluation must have a prudential approach as well, in order to balance the critical elements related to the available knowledge mentioned above.

Even though the evaluation of soil's suitability for OMW application is not compulsory in many countries, this activity can help to arrange a reference frame to be utilized as a starting point for more detailed studies on the basis of a preliminary zonation of territory in homogenous areas under the aspect of soil's suitability for OMW application. Moreover this activity could also represent a tool for monitoring in the mid and long term the different pedologic types which show different soil's suitability for OMW application.

Methodological aspects

The evaluation of soil's suitability for OMW application is based on the classification scheme provided by FAO (1976), taken as a reference. Among the soil parameters influencing the interactions OMW-soil, the characteristics which induce the potential phyto-toxicity of OMW (linked to its great raw organic matter and saline content, high values of COD and BOD as well as presence of biotoxic compounds) have been taken into account. The soil properties discriminating this evaluation process can be ascribed to pedologic, hydrologic and morphometric aspects (Tamburino *et al.* 1999; Marrara *et al.* 2002). For this purpose the following soil properties have been considered (**Fig. 1**):

- soil suitability to avoid runoff risks;
- soil conservation and depuration capability;
- water table depth;
- altitude;
- slope.

The fundamental geographic units are classified by the model in hierarchical levels: orders, classes and sub-classes. Therefore the model provides:

- two orders (soils suitable/unsuitable for agricultural utilization of OMW);
- four classes within the order of suitable soils, outlining its aptitude as OMW recipient (soils without restrictions or with moderate/high/very high restrictions);
- other sub-classes, specifying the kind of restriction for each class.

The evaluation process has sprung from the idea of sustainable utilization of natural resources, which, in the specific case, can be simplified in the need to avoid:

- soil degradation. For this purpose the physical and chemical soil properties (such as oxygen availability, pH, active limestone, electric conductivity) must help degradation and stabilisation of substances provided through OMW pouring. Therefore this limits the risks of their accumulation into the soil;
- risks of water depth pollution, which could follow deep percolation through the soil surface and subsurface layers without adequate depuration capability;
- water bodies pollution, linked to runoff phenomena;
- damage to crops, as well as to improve the economic

Table 1 Classification of soil's suitability to avoid runoff risk by the framework model for planning OMW agricultural utilization.

Slope (%)	Soil infiltrability					
	Very high	**High**	**Moderately high**	**Moderately low**	**Low**	**Very high**
< 1	Very high	Very high	Very high	Very high	Very high	Very high
1-5	Very high	Very high	High	High	Moderate	Moderate
6-12	Very high	High	High	Moderate	Moderate	Low
13-20	High	High	Moderate	Moderate	Low	Low
> 20	High	Moderate	Moderate	Low	Low	Very low

Table 2 Classification of soil infiltrability by the framework model for planning OMW agricultural utilization.

Saturated hydraulic conductivity (K_s, cm h^{-1})	Crusting risk (I_c, -)		
	< 1.2	**1.2-1.6**	**> 1.6**
> 35	Very high	Very high	High
3.5-35	Very high	High	Moderately high
0.35-3.5	High	Moderately high	Moderately low
0.035-0.35	Moderately high	Moderately low	Low
0.0035-0.035	Moderately low	Low	Very low
< 0.0035	Low	Very low	Very low

value of a residue with a certain fertilising capability, with particular reference to the high potassium content of OMW.

Soil suitability to avoid runoff risk

Surface runoff of OMW is considered a crucial factor, in order to control water bodies pollution, even far from the treated zone. The runoff risk assessment has been considered as a function of soil slope and infiltrability. As the evaluation matrix reported in **Table 1** highlights, the soil suitability to avoid runoff risk increases when infiltrability rises up and slope decreases.

Infiltrability is classified on the basis of the saturated hydraulic conductivity and the crusting risk, according to the indications reported in **Table 2**. The crusting risk is evaluated by the following index I_c:

$$I_c = \frac{1.5\ Z_f + 0.5\ Z_c}{C + 10\ OM}$$

where:
Z_f = weight percentage of fine silt
Z_c = weight percentage of coarse silt
C = weight percentage of clay
OM = weight percentage of organic matter.

Soil conservation and depuration capability (modified by the unsaturated soil permeability)

Among its various actions soil acts as a protective barrier against potential polluting substances. In the case of agricultural utilization of OMW, soil performs its action by retaining and subsequently degrading organic compounds contained in OMW through biologic oxidation.

Soil conservation and depuration capability depends on physical, chemical and biological properties of different soils. A soil with a quick drainage action, for example, shows a good suitability to "metabolize" organic matter applied with OMW, but at the same time it can be permeated by potential polluting substances. Conversely, a soil with blocked drainage performs a very good barrier action towards the lower water bodies. However, the low oxygen availability slows down the degradation of organic compounds contained in OMW. Given that soil conservation and depuration capacities are necessary for OMW disposal, an approach with a combined interpretation of the two evaluation criteria above mentioned is followed.

For these criteria the following factors are considered: soil capability of OMW retention, pH, active limestone, internal drainage and electric conductivity (**Fig. 1**). Some of these parameters (in particular the electric conductivity) are also significant in terms of evaluation of soil's suitability for OMW application without any degradation effect from the agronomic aspect.

1. Soil capability of OMW retention

Deep percolation risks of applied OMW can be minimised by a good soil capability of OMW retention. The evaluation of such a capability is very important on account of the positive water balance with a supply surplus during the period of agricultural utilization of OMW. In the case of distribution on soil with a low capability of OMW retention, the risk of deep percolation is relevant. The soil capability of OMW retention varies, depending on the texture and the skeleton content of different soil horizons (which affects the soil capability of OMW retention per volume unit) as well as on soil depth.

In the specific case it is useful to consider the "grain size classes" identified by the USDA Soil Taxonomy classification on the basis of texture, skeleton content and horizons profile. The soil capability of OMW retention rises up when the soil depth increases and the coarse fractions decrease, as can be deduced from **Table 3**.

With a deep percolation a further water table protection can be assured by removing the permeated compounds from the liquid phase (which are retained by the soil through mechanic filtration, adsorption, etc.). This action, which is hard to represent by a model, is nevertheless correlated to the parameters utilized for the evaluation of soil capability of OMW retention.

Table 3 Classification of soil capability of OMW retention by the framework model for planning OMW agricultural utilization.

Soil depth	Grain size class		
(cm)	Very fine, fine, silty fine, loamy fine, silty coarse, loam, clayey with skeleton, medial	Loamy coarse, loamy with skeleton and all classes strongly contrasting, included classes on sandy, sandy with skeleton and fragmented with fine, very fine and silty fine first component	Sandy, sandy with skeleton and fragmented and all the remaining classes on sandy, sandy with skeleton and fragmented as well as all classes strongly contrasting with sandy, sandy with skeleton and fragmented first component
> 100	High	High	Moderate
100-50	High	Moderate	Low
50-25	Moderate	Low	Low
< 25	Very low	Very low	Very low

2. pH and active limestone

The soil reaction is a parameter usually utilized for the evaluation of water retention capability, because it affects the grain mobility. In the case of the agricultural utilization of OMW, pH influences directly the microbial activity, affecting biochemical dynamics of organic matter oxidation. Values of pH close to neutrality are considered optimal for most of the micro-organisms living in the soil. OMW shows an acid pH (in the range 4-5.5), which generally induces an acidification of treated soils, even during a time interval of a few months.

According to the models evaluating the soil's suitability for wastewater application available in literature, in this work pH is considered as a discriminating parameter which induces a precautionary use of acid or sub-acid soils such as OMW receptors.

The presence of active limestone assures a buffering action with respect to the acid reaction of OMW. By playing a positive role on the soil structuring processes, this also encourages both infiltration and oxygenation of surface layers.

3. Internal drainage

Internal drainage expresses the duration and frequency of time intervals of partial or total soil saturation. The oxygen availability and, as a consequence, the microbial activity as well as the oxidation processes within the soil are linked to this parameter. A good oxygen availability corresponds to a good drainage capability. On the other hand, an exceedingly quick drainage increases the deep percolation risk of organic compounds, which are not yet degraded, into the soil surface layers. Therefore in the framework model the evaluation is performed by assigning a low score to soils with drainage difficulties or over-drained.

4. Electric conductivity

Electric conductivity, expressing the soluble salt content in the soil, is considered a discriminating factor in the evaluation process because of OMW high salinity. The repeated applications of OMW on soils showing a tendential difficulty of salt leaching could negatively affect the physical and chemical properties of soils with particular relevance to destructuring processes.

5. Classification of soil conservation and depuration capability

On the basis of the soil properties and quality above mentioned (capability of OMW retention, pH, active limestone, internal drainage and electric conductivity), the classes related to soil conservation and depuration capability are determined according to the matrix reported in **Table 4**.

In the case of insufficiently protective soils, due to low or very low retention capability or quick drainage, the mitigating action of unsaturated soil is considered. If the soil is the first barrier against the pollution risk of the water table, the unsaturated soil also induces a protective action. In the specific case the results of the evaluation of soil conservation and depuration capability are modified in relation to the unsaturated soil permeability, as indicated in **Table 4**. For this purpose, according to the scheme of the simplified Sintacs model (Civita and De Maio 2001), two lithologic classes are considered: "non-pervious" and "pervious" (**Table 5**).

Water table depth

The national law n. 574 of 1996 excludes the possibility of agricultural utilization of OMW on soils with water table depth lower than 10 metres. This restriction is adopted in the framework model proposed in this study. Nevertheless, according to many Authors, the limit is extremely precautionary, preventing the agricultural utilization of OMW on the majority of alluvial plains.

Altitude and slope

An altitude limit equal to 800 m a.s.l. is adopted in the evaluation process to discriminate suitable/unsuitable soils to OMW agricultural utilization, thereby excluding foothill and mountain zones. These are often not interested in the problems of OMW management, because of the long distance from oil mills.

A slope limit equal to 20%, adopted in the framework model, derives from difficulties of agricultural utilization of OMW through common equipment besides the aspects related to runoff risks.

Table 4 Classification of soil conservation and depuration capability by the framework model for planning OMW agricultural utilization.

	Capability of OMW retention	pH	Active limestone (%)	Internal drainage	Electric conductivity ($mS\ cm^{-1}$)
High	4 – high	> 6.4	Present	Good, medium	< 0.5
Moderate	3 – moderately high	6.4-5.6	Absent	Good, medium	0.5-1
Low[a]	2 – low	6.4-5.6	Absent	Slow, quick, very slow	1-2
Very low[b]	1 – very low	< 5.6	Absent	Blocked	> 2

[a] The class becomes "moderate" in the case of non-pervious unsaturated soil
[b] The class becomes "low" in case of non-pervious unsaturated soil. This condition is valid only when the attribution of the "soil conservation and depuration capability" class ("low" or "very low") is determined by the drainage or by the water retention capability and retention-degradation of organic matter

Table 5 Mitigating action of saturated soil rocks and relative scores from the simplified Sintacs model (Civita and De Maio 2000), modified.

Unsaturated soil characteristics	Non-pervious					Pervious				
	1	2	3	4	5	6	7	8	9	10
Coarse alluvial deposit								x	x	
Karstified limestone									x	x
Fractured limestone						x	x	x	x	x
Fissured Dolomite			x	x	x					
Medium-fine alluvial deposits				x	x					
Sand complex						x	x			
Sandstone, Conglomerate						x	x	x		
Fissure plutonic rock				x	x					
Turbidic sequence			x	x	x					
Marl, Claystone		x								
Clay, Silt, Peat		x								
Pyroclastic rock			x	x	x					
Fissured methamorphic rock			x	x	x					

Soil's suitability for OMW application

The combined analysis of the soil properties above mentioned (capability of OMW retention, conservation and depuration capability, water table depth, altitude and slope), according to the evaluation matrix reported in **Table 6**, allows the establishment of the different soil classes in relation to its suitability for OMW application (soils without restrictions S1, soils with limited restrictions S2, soils with high restrictions S3, soils with very high restrictions S4, unsuitable soils N) of the framework model.

MODEL IMPLEMENTATION IN THE CALABRIAN REGION, ITALY

The framework model to evaluate the soil's suitability for OMW application has been implemented in the Calabrian region (Southern Italy), which contributes by about 20% to the national production of olive oil. In this region, which yearly produces about 1×10^6 m^3 of oil mill effluents, OMW management represents a relevant problem from both the economic and environmental points of view.

Materials and methods

The fundamental geographic information required by the evaluation process has been gathered mostly from the database of the "Soil map of the Calabrian region at 1:250.000 scale" (ARSSA 2003). The morphometric parameters have been drawn from a 40 × 40 m DTM.

Due to the small scale of the plan and the objective difficulties of map compiling, some factors, provided instead in the Italian law n. 574 of 1996, have not been pointed out (in particular for zones within 30 m from water bodies for human consumption and 200 m from urban areas).

The database of the above mentioned "Soil map of the Calabrian region at 1:250.000 scale" has also allowed the collection of the information related to the saturated hydraulic conductivity and the crusting risk (required to evaluate the soil suitability to avoid runoff risk) as well as the grain size classes of regional soils (in order to evaluate the soil capability of OMW retention).

The data available within the "Map of soil vulnerability on agricultural nitrates in the Calabrian region" (drawn up by "ARSSA", the Regional Agency for Development and Services in Agriculture, in 2002) have been utilized to modify the results of the evaluation of soil conservation and depuration capability in relation to the unsaturated soil permeability (**Table 4**).

Moreover, in order to take into account the presence and the depth of the aquifer (free or hydraulically linked to the surface), an information layer obtained from the "Plans of piezometric lines and water quality" (drawn up by CASMEZ, the Agency for Southern Italy Development, in 1970) has been utilized. This work, carried out in the '70s-'80s, represents an organic study of water resources in the Calabrian region. More recent and accurate data have shown that a general level reduction has occurred in the last decades: it confirms, besides, the prudential approach followed within this work.

RESULTS

The combined analysis of the parameters within the assessment framework model, according to the evaluation matrix reported in **Table 6**, has allowed the establishment of the different classes of soil's suitability for OMW application in the Calabrian region and the drawing-up of the relative map at 1:250.000 scale. **Table 7** reports the regional territory distribution into the five suitability classes together with the ratio between the yearly volume of produced OMW and the surface area suitable to effluent agricultural utilization.

As mentioned above, the data processing provided by the model implementation in the Calabrian region allows the deduction that a relevant part of the territory is suitable for agricultural utilization of OMW. A significant part (about 36%) of the total area (1.5×10^6 ha) falls in the classes S1, S2, S3 and S4 (**Fig. 2**), in correspondence to suitable soils with different restriction levels.

The geographic distribution of soils potentially suitable for agricultural utilization of OMW basically corresponds to the main olive growing districts of the Calabrian region (**Figs. 2, 3**). Useful information can be drawn by examining the ratio between the yearly volume of produced OMW and the surface area suitable to its agricultural utilization. In the case of the Calabrian region this parameter is in the order of magnitude of 1.66 m^3 ha^{-1} (**Table 7**) and shows that the OMW management could have a generally simple solution on a regional scale. Even considering only the most suitable soils to the agricultural utilization of OMW (suitability classes S1 and S2), the above mentioned ratio basically is still low compared to the limit of 50-80 m^3 ha^{-1} (the former for mill effluents of traditional oil extraction cycle for pressure, the latter for oil extraction cycle for centrifugation), provided by the present Italian regulations (L. n. 574 of 1996). However it is evident that the data deriving from the ratio "produced OMW/suitable soils" is simply an approximation of the magnitude of the OMW management problem on a regional scale, because also economic and organizational factors must be taken into account (for example the distance from oil mills, their accessibility, the management methods of olive groves, the technical means of transport and distribution of OMW). The performed evaluation in fact does not take into account the fact that not all the potentially suitable soils are really available to agricultural utilization of OMW. The information layers utilized for the evaluation do not allow, for example, the exclusion of soils with herbaceous crops in their growing phases, zones within

Table 6 Evaluation matrix of soil's suitability for OMW application by the framework model for planning OMW agricultural utilization.

Suitability class	Soil suitability to avoid runoff risk	Soil conservation and depuration capability	Water table depth (m)	Altitude (m)	Slope (%)
Soils without restrictions (S1)	High/Very high	High	> 10	< 800	< 20
Soils with limited restrictions (S2)	Moderate	Moderate	> 10	< 800	< 20
Soils with high restrictions (S3)	Low	Low	> 10	< 800	< 20
Soils with very high restrictions (S4)	Very low	Very low	> 10	< 800	< 20
Unsuitable soils (N)	-	-	< 10	> 800	> 20

Table 7 Distribution of Calabrian territory in the suitability classes and ratio between the yearly volume of produced OMW and the surface area suitable to its application performed by the framework model for planning OMW agricultural utilization.

Order	Suitability class	Surface area (ha)	Produced OMW (m^3)	Produced OMW/suitable soils (m^3 ha^{-1})	Produced OMW/soils S1 and S2 (m^3 ha^{-1})
Unsuitable soils	N	963.826	902.266		
Suitable soils	S1	6.164	902.266	1.66	3.72
	S2	236.302			
	S3	198.851			
	S4	99.610			

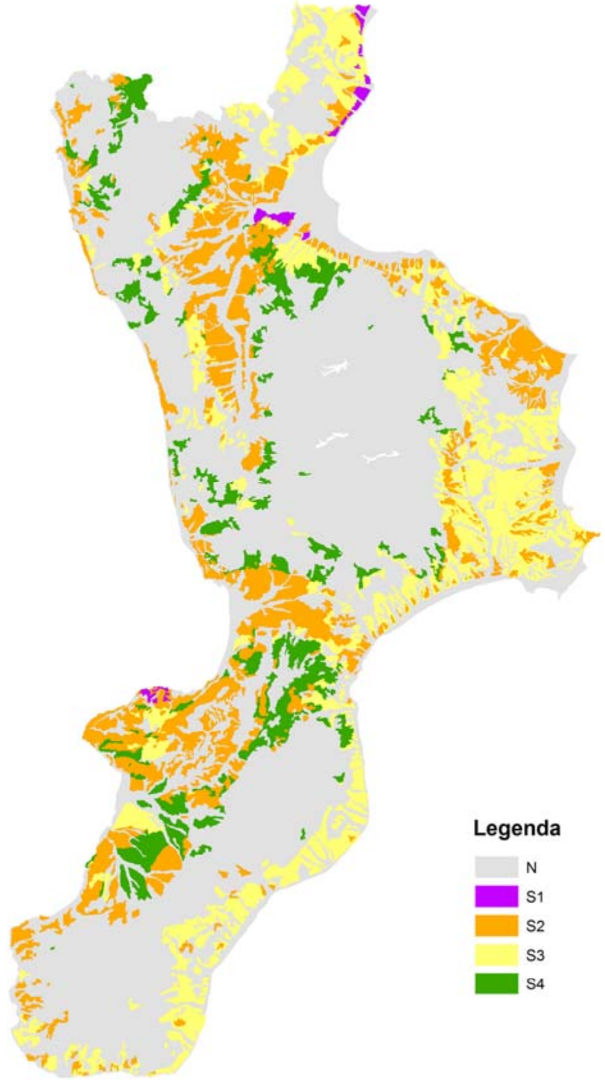

Fig. 2 Classes of soil's suitability for OMW application derived from the model implementation in the Calabrian region. N = unsuitable soils; S1 = soils without restrictions; S2 = soils with limited restrictions; S3 = soils with high restrictions; S4 = soils with very high restrictions.

Fig. 3 Main olive-growing districts of the Calabrian region.

200 m from urban areas and 30 m from water bodies for human consumption together with areas interested by infrastructures.

The about 1200 oil mills, operating in the Calabrian region in the time period of 1998-2007, produce on the whole about 900.000 m^3 of OMW (these average data are relating to the last 3-5 years of production). Assuming an annual distribution rate of OMW equal to 80 m^3 ha^{-1}, therefore it can be deduced that in Calabria each oil mill must have on the average about 9 ha of suitable soils.

In concrete details, the framework model implementation has indicated that in 72.6% of cases the surface area needed by each oil mill for agricultural utilization of OMW is lower than 10 ha, in 23.6% it ranges from 10 to 30 ha and only in 3.8% of cases the required surface area is higher than 30 ha.

Considering that transport operations have a strong influence on the economic nature of the agricultural utilization of OMW, the area of suitable soils within 3 km from the urban area of each municipality has been calculated and highlighted. Moreover, in most cases oil mills are very close to urban areas. From the performed data processing, it can be deduced that suitable soils within 3 km are larger than the needed area, except in very rare cases. In concrete terms, the ratio "suitable soils within 3 km/soils needed by agricultural utilization of OMW" shows that in 92% of cases the suitable soils are 10 times greater than the needed area. It should balance the fact that not all the potentially suitable soils are really available to agricultural utilization of OMW.

Besides the "Map of the soil's suitability for OMW application", a cartographic tool related to the OMW production on a regional scale has been processed. Such a map has been arranged by utilizing as cartographic base the administrative boundaries of municipalities and attributing to them, in ARC-VIEW® environment, the volumes of produced OMW according to the data provided from "Agecontrol" (the Italian public Agency for Control in Agriculture). This map, in which the regional territory has been divided into seven classes in relation to the produced volumes of OMW, directly highlights the areas most interested in the problems of OMW disposal.

Resulting indications

The framework model discussed above allows the division of the Calabrian territory into orders, classes and subclasses of soil's suitability for OMW application. Within the suitable soils, classes indicate the level of restrictions, absent in class S1, moderate in S2, high in S3 and very high in S4. The increasing restrictions must be considered as a rising risk of environment degradation, mainly of soil and water resources. Nevertheless it seems clear that the type and magnitude of restrictions can be set as a basis for the management method of OMW and/or of soils subjected to effluent agricultural utilization. In many cases the adoption of particular techniques and monitoring actions allows for the restrictions set by the physical environment to be dealt with.

In this study, for each "limiting factor" and on the basis

Table 8 Indications for suitability class and limiting factor provided by the framework model for planning OMW agricultural utilization.

Limiting factor	Indications		
	S2 → limited restrictions	**S3 → high restrictions**	**S4 → very high restrictions**
r Soil suitability to avoid runoff risk	Maximum application rates of 40 m^3 ha^{-1} per each OMW application at time interval longer than 15 days or mechanical tillage along contour lines by equipment maximising soil roughness or proper vegetal soil coverage (> 50%) with weeds and/or pruning residues.	Maximum application rates of 40 m^3 ha^{-1} per each OMW application at time interval longer than 15 days and mechanical tillage along contour lines by equipment maximising soil roughness or maximum application rates of OMW as reported above and proper vegetal soil coverage (> 50%) with weeds and/or pruning residues.	Unavailable sub-class.
t Soil capability of OMW retention	Maximum application rates of 40 m^3 ha^{-1} per OMW each application at time interval longer than 15 days.	Maximum application rates of 40 m^3 ha^{-1} per OMW each application at time interval longer than 15 days	Maximum application rates of 20 m^3 ha^{-1} per each OMW application at time interval longer than 30 days.
d Internal drainage	Unavailable sub-class.	Separate OMW applications through single hydraulic load lower than 40 m^3 ha^{-1} at time interval longer than one month and agricultural operations encouraging soil drainage.	Unavailable sub-class.
p pH	Maximum application rates of 40 m^3 ha^{-1} per OMW each application at time interval longer than 15 days and monitoring of the main chemical parameters of the soil surface horizon at least each 3 years. As an alternative, OMW neutralisation with CaO.	Unavailable sub-class.	Maximum application rates of 20 m^3 ha^{-1} per each OMW application at time interval longer than 30 days and monitoring of the main chemical parameters of the soil surface horizon at least each 2 years. As an alternative, OMW neutralisation with CaO.
c Active limestone	Monitoring of the main chemical parameters of the soil surface horizon at least each 3 years.	Monitoring of the main chemical parameters of the soil surface horizon at least each 3 years.	Monitoring of the main chemical parameters of the soil surface horizon at least each 3 years.

of the increasing magnitude of such restrictions, a set of possible "restrictions", summarized in **Table 8**, has been defined. When restrictions are linked to runoff risk, the adoption of tillage techniques along contour lines (preferably by equipment preventing excessive soil fining and maximizing its roughness) can allow the agricultural utilization of OMW without particular environmental risks.

As an alternative, in order to encourage infiltration, it is necessary to avoid exceeding 40 m^3 ha^{-1} of distributed OMW per each application at time intervals longer than 15 days. An adequate soil coverage with spontaneous vegetation and/or agricultural residues reduces significantly runoff risks. The combined adoption of such measures allows the agricultural utilization of OMW also in the case of high runoff risk (suitability class S3). The restrictions linked to soil capability of OMW retention depend on soil texture and depth. Coarse texture class and low depth negatively affect the agricultural utilization of OMW. In this case it is necessary to keep under control the maximum rates and application frequency, limiting in the extreme conditions the hydraulic loads down to 20 m^3 ha^{-1} at time intervals not shorter than 30 days.

In the case of the restrictions linked to soil drainage, which basically explains the soil suitability to "metabolize" the organic component of OMW, it is necessary to control the oxygen availability as well, encouraging soil aeration through agricultural operations.

In soils with low pH, a constant monitoring of the main chemical properties of soils allows significant trends indicating degradation phenomena and eventually suggests a cessation of the agricultural utilization. However, given the present knowledge, limiting OMW distribution rates in relation to pH values is convenient. The problem of soil response can be neglected in the case of OMW neutralization preliminary to agricultural utilization.

Finally, the presence of active limestone in the soil assures a buffering action with respect to the acid reaction of OMW. In the case of non-calcareous soils the periodic monitoring of the main chemical parameters is a valid precautionary measure. In any case the OMW seepage represents an appreciable solution to initial soil waterproofing following the agricultural utilization, because of the hydrophobic action of fat compounds and pores clogging by suspended solids.

CONCLUSIONS

The agricultural utilization of OMW produced by oil mills turns out to be a suitable management method due to the many agricultural, environmental and economic advantages induced by this practice. However an evaluation activity of soil's suitability for OMW application – also on a large scale – is required in order to avoid the uncontrolled disposal of OMW and the consequent environmental risks.

The assessment framework model proposed in this paper allows the recognition of soils suitable to the agricultural utilization of OMW by the analysis of many environmental parameters which interact with the peculiar properties of OMW. This model, starting from the assumption that the environment receiving OMW varies spatially, highlights the restrictions to the specific use for each soil type on the basis of the evaluation of soil morphological, hydrological and pedologic properties. The management strategies of OMW and soils subjected to agricultural utilization can be therefore calibrated on the basis of the suggested specific restrictions. The type and magnitude of the reported restrictions must be considered as increasing risks of environmental system degradation. Moreover the model provides the knowledge tools which help to support the regulation, the planning and the monitoring activities targeted to a sustainable exploitation of OMW.

The model implementation in the Calabrian region, allowing a zonation of territory in terms of soil's suitability for OMW application, has pointed out that the extent of suitable soils is largely higher with respect to that needed by distribution of produced OMW. This planning activity has therefore highlighted the suitability of the majority of olive growing districts to agricultural utilization of OMW. The "Map of the soil's suitability for OMW application" (at the scale 1:250.000), drawn for the Calabrian region on the basis of the model implementation results, has been adopted by the regional authorities as "Plan of OMW agricultural utilization", which integrates the "Technical rules for OMW agricultural utilization" issued in 2006. This plan simplifies also the authorities' control activity prescribed by the technical rules: a technical-scientific committee periodically carries out monitoring programs of soils, water bodies and other environmental resources affected by OMW agricultural utilization activities.

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