A GIS-MCDA Based Model for the Suitability Evaluation of Traditional Grape Varieties:
The Case-Study of 'Mantonico' Grape (Calabria, Italy)

Giuseppe Modica, Dipartimento di Agraria, Università degli Studi Mediterranea di Reggio Calabria, Italy

Luigi Laudari, Dipartimento di Agraria, Università degli Studi Mediterranea di Reggio Calabria, Italy

Francesco Barreca, Dipartimento di Agraria, Università degli Studi Mediterranea di Reggio Calabria, Italy

Carmelo Riccardo Fichera, Dipartimento di Agraria, Università degli Studi Mediterranea di Reggio Calabria, Italy

ABSTRACT

Physical land suitability evaluation is crucial to rural spatial planning, as it directly contributes to designing successful and sustainable interventions. This paper deals with a physical land-suitability evaluation model for Mantonico, a historical and traditional grape variety of Southern Calabria (Italy), which is showing a considerable decline in its cultivation, owing to the abandonment of this cultivar in favor of others that are certainly more quantitatively productive, yet less valuable from a traditional and cultural point of view. The evaluation model developed was based on consolidated GIS-based MCDA (Multi-Criteria Decision Analysis) procedure and showed that the choice of the criteria (factors and constraints), which describe the physical land suitability for a niche product, is important and delicate. In fact, it is not always easy to establish how territorial characteristics may influence the development of the cultivation of an agricultural product. In this paper, the choice and, above all, the values associated to the factors, adequately represented real conditions and, as a consequence, the results of the model showed a clear coherence between suitability gradients and lands with similar cultivations. Results were validated by comparing the real geographical distribution of the current vine growing to the suitability value obtaining a very positive feedback on the robustness of the implemented model. The comparison between current vine-growing areas and the values obtained from the model clearly shows that the current vine-growing sites of the study area fall in suitable and very suitable classes (83.8%).

Keywords: Analytic Network Process (ANP), Calabria (Italy), GIS-Based MCDA (Multi-Criteria Decision Analysis), Mantonico Grape, Physical Land Suitability Evaluation

1. INTRODUCTION

Current rural spatial-planning strategies are increasingly aimed at sustainability criteria and characterized by multi-temporal approaches which integrate the use of territorial resources by enhancing the complex and multifunctional character of rural areas (Barreca, Di Fazio, & Modica, 2004; Modica et al., 2012). The Land Suitability Evaluation (LSE) is a method for assessing the suitability of an area for a specific land use and is based on the explicit identification of constraints and opportunities for the conservation and future development of the territory (FAO, 1976, 1993; Steiner, 1983). The process to determine LSE begins by understanding the problem and defining the alternatives by means of a set of criteria. Today, in a LSE procedure the principles of sustainable development should explicitly be taken into account when choosing and weighting criteria and alternatives.

The LSE can be implemented through a process composed of two phases (Barreca et al., 2004; Fichera & Modica, 2007): 1) a physical LSE (suitability is an intrinsic characteristic of the examined area); 2) a subsequent usability evaluation (usability is the current possibility to use the present resources). As remarked by Steiner, McSherry, & Cohen (2000) suitability techniques are essential for informed decision-making. With specific reference to suitability evaluation analysis for viticulture, several researches have been recently carried out (Bonfante, Basile, Langella, Manna, & Terribile, 2011; Costantini & Barbetti, 2008; Hood, Cechet, Hossain, & Sheffield, 2006; Riccioli, El Asmar, El Asmar, & Fratini, 2013; Stanchi et al., 2013; Watkins, 1997).

Choosing an appropriate location for an activity as well as for a specific land use is normally related to decision support and Multi-Criteria Decision Analysis (MCDA). Scientific works on MCDA techniques, also referred as Multi-Criteria Evaluation (MCE), date to the mid of 1960s in the regional economic planning and decision-making research fields (Carver, 1991;

Keeney & Raiffa, 1993; Nijkamp, Rietveld, & Voogd, 1990; Roy, 1968; Voogd, 1983).

One of the most common procedures in spatial planning and decision-making processes is still the GIS-based Multi-Criteria Decision Analysis (GIS-MCDA) (Carver, 1991; Joerin, Thériault, & Musy, 2001; Malczewski, 1999, 2006) that represents a key element in implementing a Spatial Decision Support System (SDSS). MCDA techniques use geographical data, consider the user's preferences (provided by experts and/or stakeholders), manipulate data, and set preferences according to specified decision rules (Malczewski, 2004). Following what stated before, the most significant difference between spatial Multi-Criteria decision analysis and conventional Multi-Criteria techniques is the explicit presence of a spatial component. In turn, coupling GIS and MCDA increased the use of GIS and its based technology as the basis of a traditional DSS.

GIS-MCDA procedures prevail because they allow to consider, at the same time, the objectives of the analysis and the different criteria which influence land suitability in relation to a specific land use. In the model implementation phases, this characteristic simplifies the weighting of the criteria that concur to the final judgment, overcoming the excessive rigidity and the schematic structure of the original LSE (FAO, 1976, 2007) which is still the international reference procedure for territorial analysis and evaluation studies.

Over the last twenty years, Multi-Criteria evaluation models have played an increasingly important role, also thanks to their integration into GIS decision-making tools (Malczewski, 1999, 2006; Pereira & Duckstein, 1993). As a matter of fact, the introduction of GIS tools in physical LSE, which was concomitant with the scientific and technological advance of such tools, has enabled to see the whole spatial planning approach from a new perspective (Malczewski, 2006). Furthermore, their usefulness is even more increased with the evolution of user-friendly graphic interfaces and thanks to the possibility to employ already developed and suitable decision analysis systems that allow to

process not only spatial data, but also judgments, scales of values, etc. (Malczewski, 1999).

In the last few years, these models have proved to be applicable and reliable, above all when they are adopted in consolidated agricultural productive contexts. Their use has proved to be more complex in limited, niche, or strongly declining productions for which a good knowledge regarding their ecological and agronomic requirements is needed. In addition, suitability evaluations for niche crop productions should be performed at 1:100,000 scale or greater.

The objective of this article is to develop and validate a Multi-Criteria model for the analysis, evaluation, planning and sustainable management of rural areas with diversified farming systems. In particular, the model aims at the revival and development of niche products with a high traditional and quality value. Also considering their significance in characterizing the rural landscape.

From the methodological point of view, the present application proposes the integration between GIS and a specific MCA technique, named Analytic Network Process (ANP) (Saaty, 1996) that represents the evolution of the Analytic Hierarchy Process (AHP) (Saaty, 1980, 2004). Conceptually, ANP is an extension of AHP that enables management of the interdependencies between criteria and alternatives (Saaty, 2004). This is also validated by the more general ANP interdependence feedback approach that involves the concept of dominance and raising the super-matrix that involves all levels analyzed by each AHP procedure (Saaty, 2006). Thus, a Pairwise Comparison Matrix (PCM) of the AHP procedure to compare pairs of (sub)criteria or pairs of criteria (Vizzari & Modica, 2013) can be implemented at node and cluster of the ANP framework. However, as recently highlighted (Ferretti & Pomarico, 2012), there are still few experiences on using ANP procedures in dealing with allocation issues.

In more details, the model proposed was applied and validated in the Ionian area of the province of Reggio Calabria (Italy), where a high-quality wine, which risks disappearing today, is produced, though in small quantities, from the Mantonico grape. This grape variety is not well known, also compared to other varieties (Sangiovese and Nerello Mascalese) with which a direct parent-child relationship has been shown (Gasparro et al., 2013). Recently, a complete molecular characterization coupled with an ampelographic and bioagronomic description has been carried out for this grape variety (Gasparro et al., 2013; Pellerone, Edwards, & Thomas, 2001; Zappia, Gullo, Mafrica, & Di Lorenzo, 2007). The intrinsic value of Mantonico wine is related to ancientness of its introduction, to the traditional forms of wine-making and to the historical and cultural characteristics of the territory in which is mainly localized, the so-called 'Locride', an historical province of Magna Graecia. These characteristic elements are threatened and risk disappearing because the Mantonico grape cultivation is being abandoned. In this direction, it is important to notice a renewed interest of the provincial administration of Reggio Calabria aiming at the valorization of niche crops.

2. MATERIALS AND METHODS

2.1. Study-Area Characterization

More or less evident traces of the presence of Mantonico grape were gathered from historical surveys and from inspections *in situ*. They were found in a wide geographic area of some 120,000 ha (Figure 1) that includes 38 municipalities of the Ionian coast of the province of Reggio Calabria (Italy), which are involved in the rules and regulations for the Regional Geographical Indication 'Locride'.

The territory is characterized by a remarkable elevation variability that results in the heterogeneous climate conditions of the area. Though, according to the De Martonne aridity index (I_{DM}) (De Martonne, 1926), climate can be generally considered as Mediterranean; it is mild-hot (hot and very dry summers) at lower altitudes, while it is mild-cold (mild and dry summers) at an altitude of over 800 m a.s.l.. In order to implement this model, data from the 15

Figure 1. Geographical location of the study-area
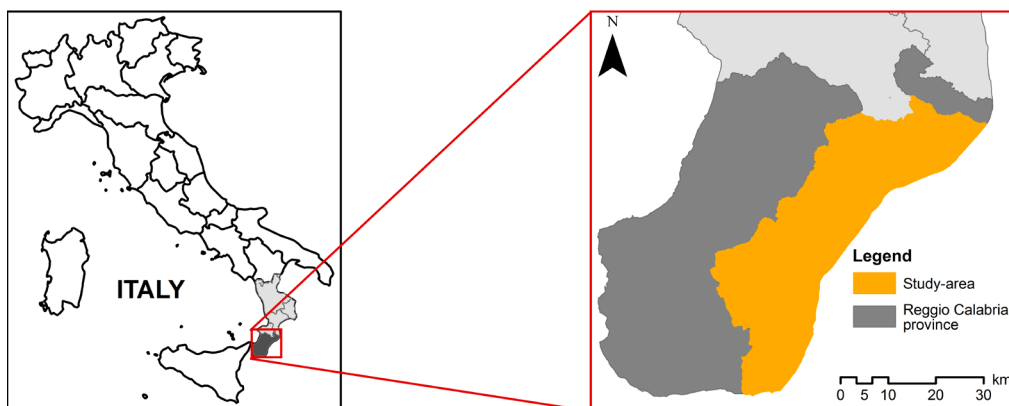
climate stations falling in the study-area with at least 30 year period of consecutive records for temperature and precipitations were used to derive climate averages. The elaborated data allowed to establish that the yearly average temperature of the area statistically ranges between 4.3 °C and 18.3 °C; that of the coldest months ranges between -4.7 °C and 10 °C; while the yearly average precipitation ranges between 900 and 1,870 mm and is strongly concentrated in autumn and winter seasons.

2.2. Scientific Background and Methodological Approach

From a theoretical point of view, the model proposed in this paper refers to the empirical/quantitative modeling approach (Rossiter, 1996). This approach starts from the observation of the relations existing between the characteristics of a certain part of the territory and its potential productions and then extends such relations to the whole area. To reach this goal, the problem facing Decision-Makers concerns the identification of most suitable areas by using a relatively limited number of evaluation criteria, while taking into account constraining elements (Carver, 1991).

Specifically, the model was designed so that it can be open, updated and adapted to the different territorial needs and to the varied characteristics of the examined productions,

and is based on the principles of GIS-MCDA techniques. The procedure can be considered as a Single Objective Multi-Criteria Decision Analysis (SO-MCDA) able to define, in a simple manner, the best suitability conditions for the management of specific productions.

In more details, the model implemented for the suitability evaluation of traditional grape varieties and applied to the Mantonico case-study includes a variety of MCDA techniques based on the same pattern. In order to better explain the model, the overall methodology has been synthesized in the following flow-chart (Figure 2).

The flow-chart schematizes the organization of the information layers which were taken into account for the land suitability evaluation for the cultivation of Mantonico grape, as well as the operations of normalization carried out to ensure their comparison and interoperability. Furthermore, it shows the main decision steps which are implemented in the proposed model.

Summarizing, with the aim to explicitly define the contributions of the different options to the different criteria or attributes, the following phases have been defined:

1. Structuring the decision problem.
2. Choice of the criteria, subdivided into constraints and factors (Eastman, Jin, Kyem, & Toledano, 1995). Constraints represent

Figure 2. Flow-chart showing the structure of the implemented model for the evaluation of the land suitability for the cultivation of Mantonico grape
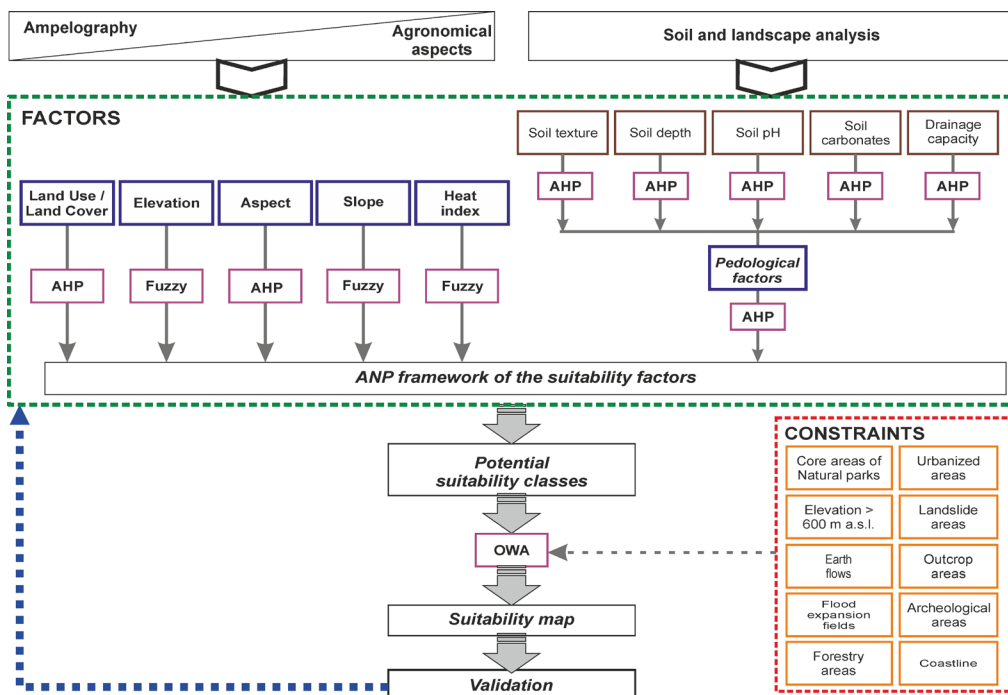
limitation or exclusion of an area for that use. Factors are the decisional variables measured on a continuous scale that, depending on the assumed value, increase or reduce the suitability of an area for a specific use under consideration. In accordance with the ANP approach, in this phase the different factors influencing the final decision have been considered and grouped in homogeneous groups (clusters).

3. Implementation of the geodatabase using existing and derived alphanumeric and geographic data (both raster and vector).

4. Criteria normalization applying a data reference-scale included in the closed interval [0, 1]. For factors, data normalization and reclassification have been carried out through AHP and fuzzy logic (Zadeh, 1983). In the latter case, by choosing those membership functions which best fit the physical quantities examined. In more details, membership functions with two

(monotonic) or four (symmetric) control points have been chosen (Figure 2). Constraints are expressed in the form of a Boolean map: 0 for areas excluded from the evaluation; 1 for those areas open for consideration.

5. Weighting criteria. Since the attributes of the factors analyzed were destructured according to different hierarchical levels, their values were normalized through the implementation of an ANP procedure. In implementing ANP, all dependencies among factors within a cluster (inner dependence) and between clusters (outer dependence) should be defined.

6. Aggregation of results by means of Weighted Linear Combination (WLC) coupled with Ordered Weighted Averaging (OWA) operators (Yager, 1988).

7. Usability evaluation. This step concerns the selection and location of suitable areas

defining a suitability threshold in terms of suitability threshold and minimum area.

The preliminary phase of the choice of the factors is particularly important, since most of the compliance of the model depends on it. The number of factors should be defined so as not to make the application of the model excessively complex, yet they should allow to effectively describe the relations between the characteristics of the territory and its productive potentials. Therefore, it is fundamental to have an in-depth knowledge of the laws governing agricultural production.

However, in the case of niche productions, e.g. of Mantonico grape, they have seldom been specifically studied and, as a consequence, still they are only empirically or descriptively known. In the present research, in order to establish such correlations, they were used: the collaboration of experts in the field; ethnic and historical bibliographies; information from farmers and connoisseurs of the area, and accounts from old farmers.

Following what stated before, the data input (criteria) were divided into two classes:

- Constraints, i.e. all the factors that do not allow or limitate the cultivation of the Mantonico grape on the territory, owing to structural or normative aspects.
- Factors, i.e. those elements that, individually or aggregately, define the potential land suitability for the cultivation of Mantonico grape.

3. APPLICATION AND VALIDATION OF THE LAND SUITABILITY EVALUATION MODEL

Before the description of the implemented model in the case-study application, a short description for each of the above-mentioned criteria (factors and constraints) has been provided.

3.1. Factors

Land Use/Land Cover (LU/LC): LU/LC was analyzed starting from the cartography of the EU Project CORINE Land Cover (EEA, 2000). The original map at IV level of detail was properly updated in order to obtain more details on the territory concerned by the research. In more details, updating regarded both temporal and geometrical resolution and has been carried out by means of a photointerpretation procedure using Microsoft Bing™ maps as base-map and *in situ* verification. The map obtained at 2010 as reference year, has a nominal scale of 1:10,000 with a Minimum Cartographic Unit (MCU) of 0.5 ha. Land Use (LU) classes were gathered in eleven groups (vineyards, arable lands, pasture lands, shrublands, permanent crops, woodlands, sparse vegetation, inland waters, wetlands, beaches, settled areas) corresponding to the most representative contexts of the territory and analyzed through AHP procedure in relation to their suitability for the cultivation of the grape variety concerned.

Elevation: The micro-climate variations depending on this parameter, air temperature variation in particular, have a very important direct influence on the phenology of a crop. Elevation was mapped by means of a DEM (Digital Elevation Model) with a geometric resolution of 20 m. In order to integrate elevation data into the model, they were normalized with fuzzy logic through a monotonically decreasing J-shaped curve (Figure 3-a). Optimal conditions for the cultivation of Mantonico variety were found up to 600 m a.s.l. of altitude. Above that altitude they were considerably less suitable because of the remarkable additional energy investments necessary to manage the vineyard.

Aspect: This factor directly influences the amount of solar radiation to the soil surface during the growing season. Therefore, this factor plays a crucial role for Mantonico variety, which requires very high sugar

Figure 3. Examples of fuzzy membership functions for normalization of factors. Monotonically decreasing j-shaped curves: (a) Elevation, (b) Slope. Symmetric sigmoid: (c) Heat index
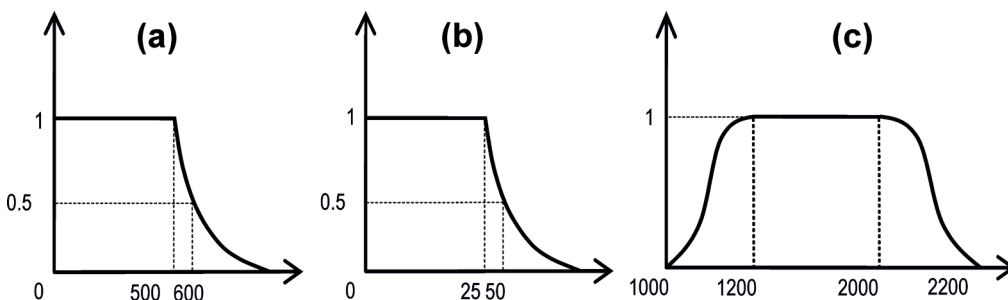
content for its oenological transformation. The qualitative gradient of the aspect was normalized trough AHP by assigning higher levels to southern, eastern and western facing areas and lower values to northern facing areas.

Slope: The slope influences the limits of practicability of agricultural activities especially referred to the mechanization of vineyards. This factor was also investigated through a fuzzy logic procedure and normalized through a monotonically decreasing J-shaped curve (Figure 3-b). It is important to notice that optimal conditions for the cultivation of Mantonico grape were found with slopes of up to 25%. Beyond such a value, mechanization operations would be too expensive or impracticable.

Heat Index: The heat gradient is one of the most important elements for the definition of land suitability for oenological production. It was shown (Fregoni, 2003) that the thermal performance during the growing season directly impacts the production of sugars in grapes and that this element also influences the type and quality of the wines produced. To that end, the thermal data of the territory under investigation were spatialized over the whole study area and, through an IDW (Inverse Distance Weighted) procedure, they were turned into input data for the calculation of Winkler Heat Index (Amerine & Winkler, 1944). This index, also known as heat sum, expresses the summation of the average daily temperatures ($T_{av.}$) throughout the growing season of the vine (which, in the case study, was from May 1st to September 30th) and does not include values lower than 10 °C (i.e. the temperature below which the physiological processes of the vine halting). This index originates from the experimental observation that the higher the heat input during the period of development of bunches, the higher their content in sugars. The data obtained for the study area were then normalized through fuzzy logic with a symmetric sigmoid function (Figure 3-c).

Pedological Factors: Pedological factors category include the chemical and physical characteristics of the soils that directly influence the definition of the optimum growing conditions of Mantonico grape (Texture, Depth, pH, Carbonates and Drainage capacity). All the examined sub-factors were normalized through an AHP methodology in order to highlight the change occurring in the suitability for each factor as the characteristics of Mantonico grape change. Then, they were correlated so as to define the gradient of influence of the pedological characteristics on the whole study area. Certain factors are more closely related than others to the vegetation characteristics of the crop analyzed. In the

specific case of Mantonico, land drainage is fundamental to prevent the development of oidium and grape mildew (phytopathologies to which Mantonico grape is particularly susceptible if humidity is stagnant). Soil depth is equally important because "thin soils" (presence of limiting horizons below 25 cm of depth) hamper the growth of the fascicled root system of the vine.

3.2. Constraints

Core areas of Natural Parks: Pursuant to the Italian Framework Law on the Protected Areas (Framework Law 394/1991 and subsequent amendments and additions), no anthropic activity is allowed in core area of natural parks (so-called 'Zona A'). These areas correspond to the IUCN (International Union for Conservation of Nature) category Ia (Strict nature reserve).

Urbanized Areas: Based on the layer "Urban Centers" of the 'DBprior10k' (Priority Information Layers) (Remotti, 2004) released by the Cartographic Center of Region Calabria at a nominal scale of 1:10,000.

Archaeological Areas: Pursuant to the ICCLH (Italian Code of the Cultural and Landscape Heritage, Italian Legislative Decree n° 42 of 22/01/2004) these areas are not suitable for crop production.

Areas Over 600 m.a.s.l.: This elevation constraint has been defined in accordance with what reported by scholars in specific literature and following what expressed by experts involved in the present research. Furthermore, although the cultivation of Mantonico grape is still possible at higher altitudes, high-impact external interventions would be needed to obtain qualitatively significant productions.

Landslide and Earth-Flow Areas: Layer based on the Hydrogeological Hazard & Risk Assessment Plan (HHRAP, in Italian also known as PAI, that stands for 'Piano di Assetto Idrogeologico') that defines the areas of the territory where the risk of damage to people, facilities, activities and environmental heritage is high.

Outcrop Areas: Layer based on the HHRAP, involving areas characterize by ongoing and intensive erosion phenomena.

Flood Expansion Fields: Bed of the so-called "fiumare" (typical Calabrian torrents) serving as flood expansion fields.

Forestry Areas: Pursuant to the ICCLH these areas are not suitable for crop production.

Coastline: Pursuant the ICCLH and considering the presence of protected dune phytocoenoses along the coast of the territory concerned.

## 3.3. Data Aggregation and Classification

The factors, which had been individually normalized, were then aggregated in the ANP super-matrix in which three clusters were defined: 1. Geomorphology; 2. Soil & Land Cover; 3. Climate (Figure 4).

To obtain the overall evaluation, the weight of each element is derived from paired comparisons inside a cluster as well as between clusters. To this end, judgments provided by experts according to the Saaty's fundamental scale (Saaty, 1980) were entered. As in other experiences carried out by the research group (Fichera & Modica, 2007), the aggregation of the evaluation results was obtained through an OWA procedure (Jiang & Eastman, 2000; Yager, 1988) that extends the Weighted Linear Combination (WLC) allowing to control the trade-off between factors. Using a WLC of the above-mentioned factors allows to obtain the spatialized level of the land potential suitability for the cultivation of Mantonico grape. Once obtained, the results of the WLC are subjected to subtractive masking with the normalized constraints by Boolean intersection (AND type operator). In mathematical terms, this may be expressed by the following formula:

$$SI_j = \left(\sum_{i=1}^{n} w_{ji} \cdot x_i \right) \cdot \prod_{k=1}^{m} c_{jk} \qquad (1)$$

Figure 4. The ANP network structure for the Mantonico land-suitability analysis
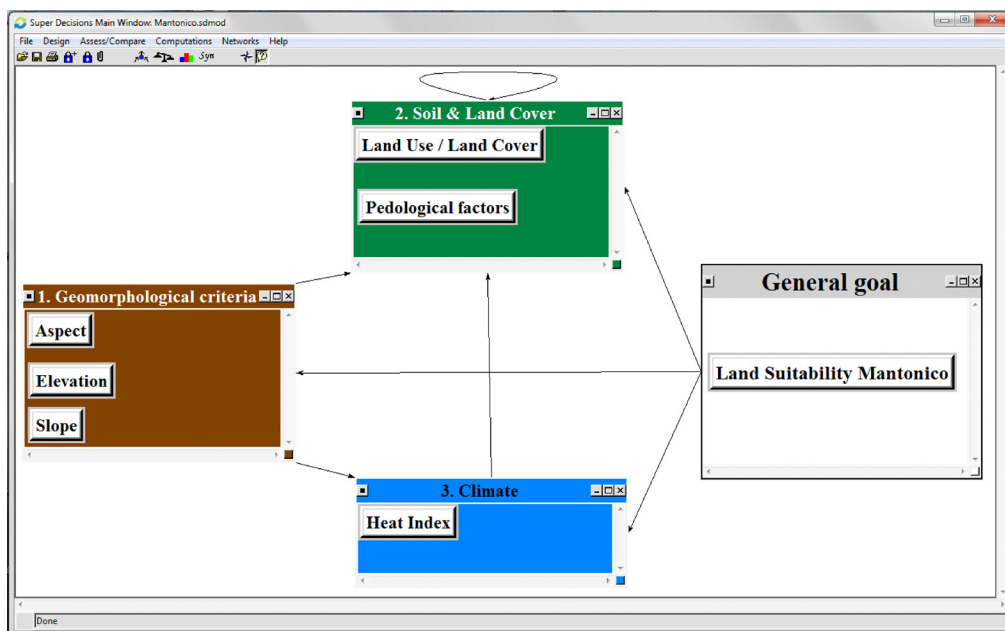
where:

SI_j is the Suitability Index of the area (raster cell) j;

w_i is the i-th factor weight;

x_i is the i-th factor inserted in the model;

c_{jk} are the k constraints present in the area (cell) j.

Adopting an OWA procedure, in addition to factor weights, a second set of weights, the so-called *order weights* (v_i), are to be considered. Order weights are a set of weights assigned not to factors themselves but to ranking the order position of factor values for a given location (i.e. the raster cell). While in WLC full trade-off is always assumed, the order weights of the OWA operators will allow for direct control over the levels of trade-off and risk in decision making. In other words, the order weights allow to control the degree of risk between the minimization (AND operation) and maximization (OR operation) of areas to be considered suitable in the final result.

In formula:

$$OWA_i = \varphi\left(x_{i,j}\right) = \sum v_i \cdot z_{i,j} \quad (2)$$

$x_{i,j}$ is the i-th factor inserted in the model;

$v_i = (w_i \cdot x_{i,j})$;

$z_{i,j}$ is the sequence of the reordered weighted factors ($x_{i,j}$) with $z_{i,1} \geq z_{i,2} \geq ... z_{i,n}$.

Referring to the OWA parameters α (ORness) and D (OWA weights dispersion) (Gorsevski, Donevska, Mitrovski, & Frizado, 2012; Yager, 1988), a substantially pessimistic approach ($\alpha=0.19$; $D=1.54$) has been adopted. In other words, this corresponds to a proximal risk-taking procedure in the OWA decision strategy space (Jiang & Eastman, 2000). This approach was justified by the goal itself of the research, i.e. the selection of the most valuable areas by highlighting the influence of the most limiting factors. The superposition of constraints with the spatialization of the above-stated potential suitability allowed to map the level of land suitability for the production of Mantonico grapes. In this final step, the suitability map has been

Table 1. Factors' weight (limiting priorities of all nodes) and order weights developed starting from judgments from multiple experts

Clusters	Factors	Factor weights	Order weights
Soil & Land use	*Land use/Land Cover*	0.075	0.1
	Pedological factors	0.253	0.2
Climate	*Heat index*	0.294	0.25
Geomorphology	*Elevation*	0.054	0.03
	Slope	0.248	0.2
	Aspect	0.075	0.07

also reclassified according to four suitability classes (Table 2).

A class with suitability equal to 0 was included in the reclassification procedure in order to consider those areas having no specific constraints but which prove completely unsuitable for the Mantonico grape cultivation. In the final step of the model, a usability evaluation was performed selecting areas with a minimum surface of 1 ha and belonging to the medium and high suitability classes. The final results following the usability evaluation are shown in the map Figure 5, in which also low suitable areas are reported (in red).

4. DISCUSSION AND FINAL CONSIDERATIONS

Analyses show that the overall study area (Figure 6) of 121,684 ha is composed for around 47% (57,339 ha) of territories where the cultivation of Mantonico grape is not allowed because they are occupied by areas under constraints. About 34,687 ha of these areas (around 60%

of all the excluded areas) are made up of territories located at an altitude over 600 m a.s.l., and 22,652 ha consist in territories under all the other forms of constraint (around 39% of all the excluded areas).

The remaining part of the study area is composed of: not suitable areas, for 1,308 ha (around 1%); low suitable areas, for 9,459 ha (around 8%); medium suitable areas, for 41,504 ha (around 34%); high suitable areas, for 12,073 ha (around 10%). With reference to the areas which are not under constraint, the most representative areas show a medium suitability for the cultivation of Mantonico grape (41,504.3 ha, i.e. 64.5% of the territory without any constraint). They are followed by high and low suitability areas (12,073.4 ha, 18.7%, and 9,459.1 ha, 14.7%, respectively) and by null suitability areas, which occupy only 1,308.2 ha (2.03%).

Such a distribution shows that the whole examined territory is suitable for the cultivation of Mantonico grape and that the greatest barriers to this cultivation are not adverse vegetation con-

Table 2. Suitability classes for the cultivation of 'Mantonico' grape

Suitability class	Description
I	High suitability
II	Medium suitability
III	Low (Marginal) suitability
0	Not suitable

Figure 5. Map of land suitability gradients for the cultivation of Mantonico grape
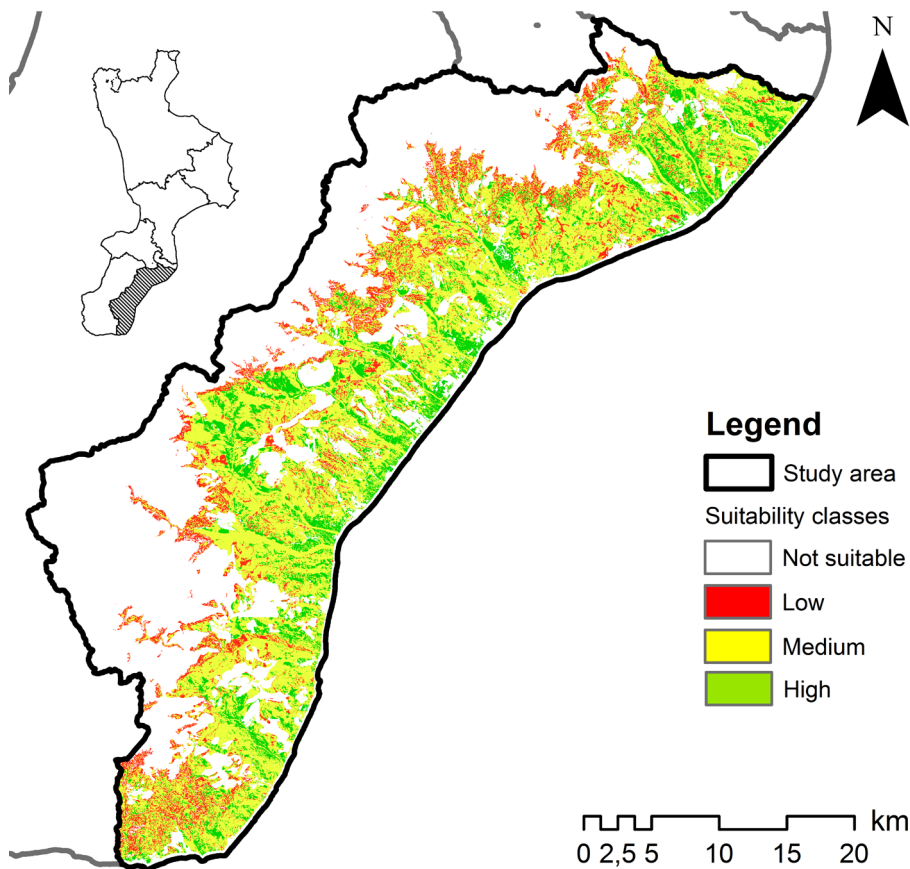
ditions, but objective regulatory and structural restrictions linked to the hydrogeological risk.

The model was validated by comparing the real geographical distribution of the current vine growing, regardless of the cultivar actually grown, to the suitability value obtained by spatializing the model results. Although this validation procedure is simplified because, owing to the limited number of areas currently under Mantonico grape cultivation, the control points correspond to vineyards where generic cultivars are grown. However it allows to carry out important and significant evaluations on the methodological robustness of the model.

Moreover, the model validation phase allowed to obtain data particularly reassuring on the methodological correctness of the evalua-

tion model proposed. In fact, the comparison between current vine growing areas and the values obtained from the model clearly shows that the vine-growing sites of the study area are included within medium and high suitability classes (with values of 36.2% and 47.6%, respectively) (Figure 7), while the vine-growing sites included in low and null suitability classes are insignificant (with values of 1.5% and 0.03%, respectively).

The considerable presence of vine-growing areas in the territory under constraints is due to the cultivation of grape varieties in areas of high hydrogeological risk (especially in case of slope instability) and, to a very limited extent, to those grape varieties cultivated in areas with restrictions established by the ICCLH.

Figure 6. Graph reporting the suitable area for the Mantonico grape cultivation according to the defined suitability classes
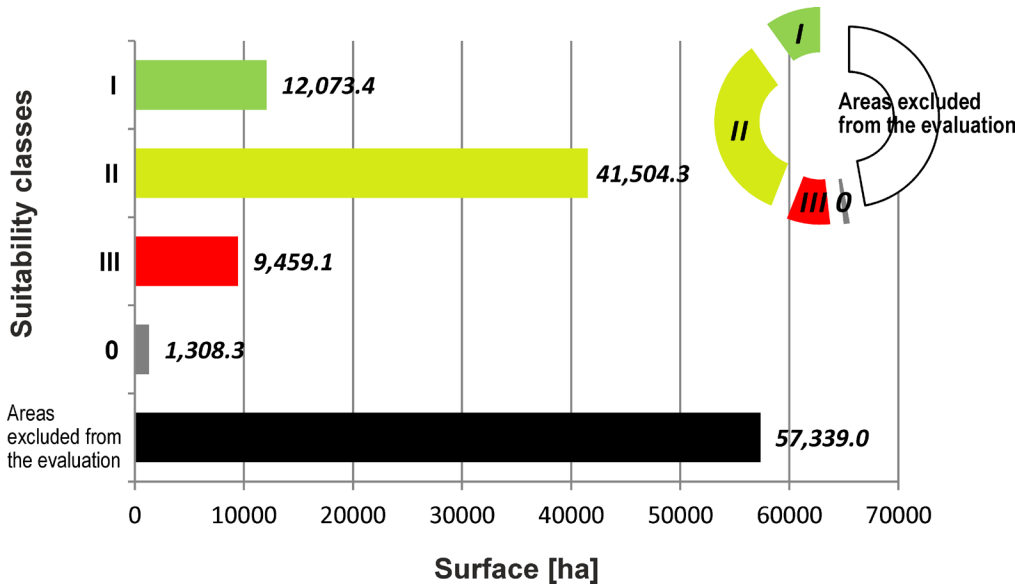
The results of the validation process allowed to formulate a first positive judgment on the validity of the model. Certainly, the model verification should be carried out considering the current productions, in terms of amount of grapes, but also in terms of quality of the wine produced. Only when the first productions are obtained will it be possible to perform this

Figure 7. Graph of the model validation comparing the current vine-growing areas distribution in the study-area to the suitability classes defined
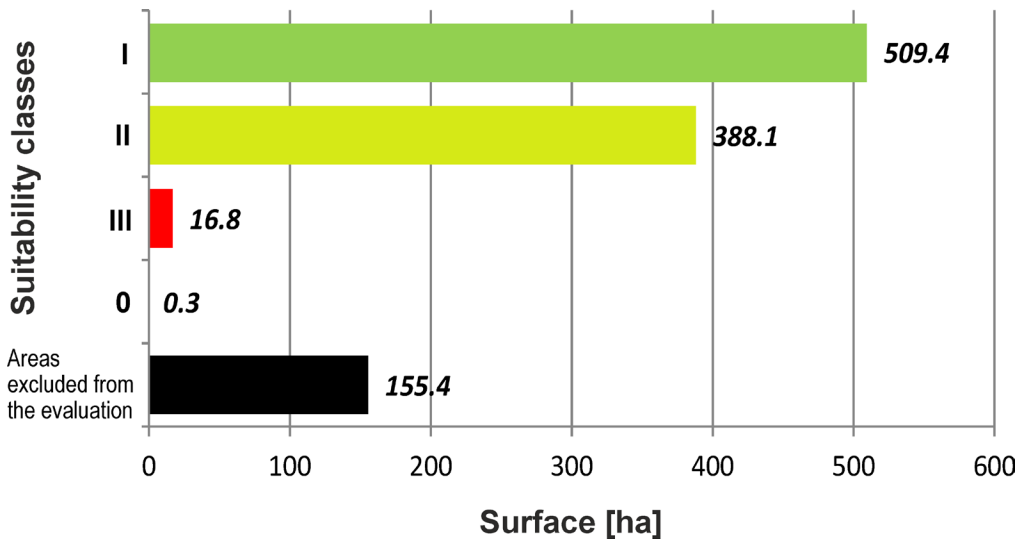
verification and properly adjust and improve the model.

In the present article, the advantages of GIS-MCDA approaches with specific reference to their capacity to support the planning process through transparent and replicable procedure have been highlighted. Considering its adaptive approach, the model for the land suitability evaluation of the Mantonico grape can be implemented for other niche crops as well as for different geographical contexts. The results can be utilized by government bodies as a reference base in programming new interventions for the valorization of niche crops. Regarding their applicability, at the present stage of the research, results can be utilized in strategic planning actions at a reference scale of 1:100,000. Additional data and further developments (e.g. cadastral data, direct farm surveys, soil analyses, etc.) are needed to refine the model in view of its applicability at macro-scale (1:5,000÷1:10,000) or at farm level.

Therefore, it is important not to forget that, in general, even complex and refined evaluation models should be considered as tools guiding and supporting planners in their evaluations and that they cannot and must not replace man's interpretation and sensibility when making choices and decisions on the development of a territory. Without the knowledge and the expertise of planners and decision-makers, and without completeness and consistency of base-data, such tools would be useless. In other words, it is still worthwhile to highlight that GIS-MCDA procedures have to be considered tools which provide data and information in making an informed decision. An arising question that should be more explicitly considered in researches deal with land suitability evaluation is the temporal dimension of the landscape planning process. This is an important issue, *a fortiori* in geographical contexts such as the one investigated in which urban sprawl phenomena affect a large part of the coastal and hilly areas. In fact, it should be considered that understanding evolutionary landscape trends, particularly where the urban/rural dynamic relations play a significant role, is crucial to their sustainable planning (Modica et al., 2012).

Future research developments will provide a suitable free WebGIS platform allowing access to data and maps of the project through the Web. One of the recognized advantages of this methodology is in providing a very useful tool that improve land planning and decision making also by favoring the e-participation of citizen since the earlier stages of the planning process (Pollino & Modica, 2013). Moreover, in the Web-GIS platform, different scenarios can be directly evaluated by decision-makers that can also receive a direct feedback on a certain planning action. In this direction, a sensitivity analysis of the effect of the different criterion weights on the results can be useful in making the final decision. Another future development of the research regards an improvement of the expert participation in the evaluation process so as to implement multidisciplinary focus groups. This will allow to improve collaborative decision processes.

ACKNOWLEDGMENT

REFERENCES

Amerine, M., & Winkler, A. (1944). Composition and quality of musts and wines of California grapes. Hilgardia, A Journal of Agricultural Science Published by the California Agricultural Experiment Station, 15(6), 493–675.

Barreca, F., Di Fazio, S., & Modica, G. (2004). A GIS-based decision support system for the sustainable management of grazing in protected areas. In International Symposium Of The CIGR 2nd Technical Section "New trends in farm buildings." 2-6 May, Evora, Portugal.

Bonfante, a., Basile, A., Langella, G., Manna, P., & Terribile, F. (2011). A physically oriented approach to analysis and mapping of terroirs. Geoderma, 167-168, 103–117. doi:10.1016/j.geoderma.2011.08.004

Carver, S. J. (1991). Integrating multi-criteria evaluation with geographical information systems. *International Journal of Geographical Information Systems*, *5*(3), 321–339. doi:10.1080/02693799108927858

Costantini, E. C., & Barbetti, R. (2008). Environmental and visual impact analysis of viticulture and olive tree cultivation in the province of Siena (Italy). *European Journal of Agronomy*, *28*(3), 412–426. doi:10.1016/j.eja.2007.11.012

De Martonne, E. (1926). Une Nouvelle fonction climatologique. L'Indice d'aridité. *Meteorologie (Paris)*, 449–458.

Eastman, R., Jin, W., Kyem, P. A. K., & Toledano, J. (1995). Raster Procedures for Multi-Criteria/Multi-Objective Decisions. *Photogrammetric Engineering and Remote Sensing*, *61*(5), 539–547.

FAO. (1976). A framework for land evaluation. *FAO Soil Bulletin*, *9*(3), 186–189.

FAO. (1993). Guidelines for land-use planning. FAO Development Series 1. Rome: FAO Development Series 1.

FAO. (2007). Land evaluation. Towards a revised framework. Land and Water Discussion Paper n. 6 (p. 108). Rome.

Ferretti, V., & Pomarico, S. (2012). An integrated approach for studying the land suitability for ecological corridors through spatial multicriteria evaluations. *Environment, Development and Sustainability*, *15*(3), 859–885. doi:10.1007/s10668-012-9400-6

Fichera, C. R., & Modica, G. (2007). L'analisi multiobiettivo della suscettività dello spazio rurale a supporto della pianificazione territoriale sostenibile. Il caso studio del versante tirrenico reggino. In C. R. Fichera (Ed.), *Multifunzionalità e sviluppo sostenibile del territorio rurale* (pp. 55–105). Reggio Calabria, Italy: Iiriti Editore.

Fregoni, M. (2003). L'indice bioclimatico di qualità Fregoni. In M. Fregoni, D. Schuster, & A. Paoletti (Eds.), Terroir Zonazione Viticoltura (pp. 115–128). Rivoli Veronese: Phytoline Editore.

Gasparro, M., Caputo, A. R., Bergamini, C., Crupi, P., Cardone, M. F., Perniola, R., & Antonacci, D. (2013). Sangiovese and its offspring in southern Italy. *Molecular Biotechnology*, *54*(2), 581–589. doi:10.1007/s12033-012-9600-1 PMID:23001829

Gorsevski, P. V., Donevska, K. R., Mitrovski, C. D., & Frizado, J. P. (2012). Integrating multi-criteria evaluation techniques with geographic information systems for landfill site selection: A case study using ordered weighted average. *Waste Management (New York, N.Y.)*, *32*(2), 287–296. doi:10.1016/j.wasman.2011.09.023 PMID:22030279

Hood, A., Cechet, B., Hossain, H., & Sheffield, K. (2006). Options for Victorian agriculture in a "new" climate: Pilot study linking climate change and land suitability modelling. *Environmental Modelling & Software*, *21*(9), 1280–1289. doi:10.1016/j.envsoft.2005.04.022

Jiang, H., & Eastman, J. R. (2000). Application of fuzzy measures in multi-criteria evaluation in GIS. *International Journal of Geographical Information Science*, *14*(2), 173–184. doi:10.1080/136588100240903

Joerin, F., Thériault, M., & Musy, A. (2001). Using GIS and outranking multicriteria analysis for land-use suitability assessment. *International Journal of Geographical Information Science*, *15*(2), 153–174. doi:10.1080/13658810051030487

Keeney, R. L., & Raiffa, H. (1993). *Decisions with Multiple Objectives: Preferences and Value Trade-Offs* (2nd ed., p. 569). Cambridge, England: Cambridge University Press. doi:10.1017/CBO9781139174084

Malczewski, J. (1999). GIS and multicriteria decision analysis. (J. Malczewski, Ed.)Engineering (Vol. 31, p. 392). J. Wiley & Sons.

Malczewski, J. (2004). GIS-based land-use suitability analysis: A critical overview. *Progress in Planning*, *62*(1), 3–65. doi:10.1016/j.progress.2003.09.002

Malczewski, J. (2006). GIS-based multicriteria decision analysis: A survey of the literature. *International Journal of Geographical Information Science*, *20*(7), 703–726. doi:10.1080/13658810600661508

Modica, G., Vizzari, M., Pollino, M., Fichera, C. R., Zoccali, P., & Di Fazio, S. (2012). Spatio-temporal analysis of the urban–rural gradient structure: An application in a Mediterranean mountainous landscape (Serra San Bruno, Italy). *Earth System Dynamics*, *3*(2), 263–279. doi:10.5194/esd-3-263-2012

Nijkamp, P., Rietveld, P., & Voogd, H. (1990). *Multicriteria evaluation in physical planning* (p. 232). Oxford: Elsevier Science Ltd.

Pellerone, F., Edwards, K., & Thomas, M. (2001). Grapevine microsatellite repeats: Isolation, characterisation and use for genotyping of grape germplasm from Southern Italy. *Vitis*, *40*(4), 179–186.

Pereira, J. M. C., & Duckstein, L. (1993). A multiple criteria decision-making approach to GIS-based land suitability evaluation. *International Journal of Geographical Information Systems*, *7*(5), 407–424. doi:10.1080/02693799308901971

Pollino, M., & Modica, G. (2013). Free Web Mapping Tools to Characterise Landscape Dynamics and to Favour e-Participation. Computational Science and Its Applications – ICCSA 2013. *Lecture Notes in Computer Science*, *7973*, 566–581. doi:10.1007/978-3-642-39646-5_41

Remotti, D. (2004). The National Database of "Priority Information Layers": A first step for a National Spatial Data Infrastructure. In 10th EC GI & GIS Workshop, "ESDI State of the Art." Warsaw, Poland.

Riccioli, F., El Asmar, T., El Asmar, J.-P., & Fratini, R. (2013). Use of cellular automata in the study of variables involved in land use changes: An application in the wine production sector. *Environmental Monitoring and Assessment*, *185*(7), 5361–5374. doi:10.1007/s10661-012-2951-z PMID:23076871

Rossiter, D. G. (1996). A theoretical framework for land evaluation. *Geoderma*, *72*(3-4), 165–190. doi:10.1016/0016-7061(96)00031-6

Roy, B. (1968). Classement et choix en présence de points de vue multiples. RAIRO - Operations Research - Recherche Opérationnelle, 2(V1), 57–75.

Saaty, T. L. (1980). *The Analytic Hierarchy Process: Planning, Priority Setting, Resource Allocation* (p. 287). New York: McGraw-Hill.

Saaty, T. L. (1996). *Decision making with dependence and feedback: The analytic network process*. Pittsburgh, PA, USA: RWS Publications.

Saaty, T. L. (2004). Decision making — the Analytic Hierarchy and Network Processes (AHP/ANP). *Journal of Systems Science and Systems Engineering*, *13*(1), 1–35. doi:10.1007/s11518-006-0151-5

Saaty, T. L. (2006). Rank from comparisons and from ratings in the analytic hierarchy/network processes. *European Journal of Operational Research*, *168*(2), 557–570. doi:10.1016/j.ejor.2004.04.032

Stanchi, S., Godone, D., Belmonte, S., Freppaz, M., Galliani, C., & Zanini, E. (2013). Land suitability map for mountain viticulture: A case study in Aosta Valley (NW Italy). *Journal of Maps*, *9*(3), 367–372. doi:10.1080/17445647.2013.785986

Steiner, F. (1983). Resource suitability: Methods for analyses. *Environmental Management*, *7*(5), 401–420. doi:10.1007/BF01867120

Steiner, F., McSherry, L., & Cohen, J. (2000). Land suitability analysis for the upper Gila River watershed. *Landscape and Urban Planning*, *50*(4), 199–214. doi:10.1016/S0169-2046(00)00093-1

Vizzari, M., & Modica, G. (2013). Environmental Effectiveness of Swine Sewage Management: A Multicriteria AHP-Based Model for a Reliable Quick Assessment. *Environmental Management*, *52*(4), 1023–1039. doi:10.1007/s00267-013-0149-y PMID:23974904

Voogd, H. (1983). *Multicriteria evaluation for urban and regional planning*. London, UK: Pion Ltd.

Watkins, R. (1997). Vineyard site suitability in Eastern California. *GeoJournal*, *1997*(3), 229–239. doi:10.1023/A:1006879927146

Yager, R. R. (1988). On ordered weighted averaging aggregation operators in multicriteria decision-making. *IEEE Transactions on Systems, Man, and Cybernetics*, *18*(1), 183–190. doi:10.1109/21.87068

Zadeh, L. A. (1983). A computational approach to fuzzy quantifiers in natural languages. *Computers & Mathematics with Applications (Oxford, England)*, *9*(1), 149–184. doi:10.1016/0898-1221(83)90013-5

Zappia, R., Gullo, G., Mafrica, R., & Di Lorenzo, R. (2007). Mantonico vera e Mantonico pizzutella: Descrizione ampelografica, analisi microsatellite e comportamento bio-agronomico. *Italus Hortus*, *14*(3), 59–62.

Giuseppe Modica, PhD in Environmental and Agri-forestry Engineering, is researcher and assistant professor in Rural Buildings and Rural Landscape at the Department of Agraria of the Mediterranea University of Reggio Calabria. Member of AIIA (Italian Association of Agricultural Engineering), CIGR (Commission International du Génie Rural) and AgEng (International Association of Agricultural Engineers). Person in charge of the GIS and cartographic section of the AGROMATER-LAB research laboratory (Technological Innovation, Research and Services for quality and typical Agri-food products and for the Valorization of the typical labour places). His main research interests focusing on sustainable landscape planning, landscape services, geospatial information in decision support systems, multi-criteria evaluation. He has been chair of several national and international workshops and seminars.

Luigi Laudari is a PhD in Environmental and Agri-forestry Engineering and research fellow at the AGROMATER-LAB research laboratory (Technological Innovation, Research and Services for quality and typical Agri-food products and for the Valorization of the typical labour places) of the Mediterranea University of Reggio Calabria. Research interests: Geographic information systems; Landscape ecological planning; Ecological networks.

Francesco Barreca is associate professor of Rural buildings and Rural Landscape at the Department of Agraria of the Mediterranea University of Reggio Calabria. Member of AIIA (Italian Association of Agricultural Engineering), CIGR (Commmission International du Génie Rural) and AgEng (International Association of Agricultural Engineers). Activity responsible for food processing buildings evaluation and sustainable building of the AGROMATER-LAB research laboratory (Technological Innovation, Research and Services for quality and typical Agri-food products and for the Valorization of the typical labour places). His main research interests focusing on: design and technical innovation in farm buildings, rehabilitation and valorization of the rural architectural heritage, models of planning of the rural and agricultural landscape, GIS, agricultural buildings and sustainability, design of food industry facilities.

Carmelo Riccardo Fichera is full professor in Rural Buildings and Rural Landscape and Pro-Rector for teaching and learning activities at the Mediterranea University of Reggio Calabria. President of the II Technical section of the Italian Society of Agricultural Engineering (AIIA). Scientific coordinator of the AGROMATER-LAB research laboratory (Technological Innovation, Research and Services for quality and typical Agri-food products and for the Valorization of the typical labour places). Member of GIGR (Commission International du Génie Rural), AgEng (International Association of Agricultural Engineers), AIIA and RURALIA (Italian Association for re-utilization of agricultural sites). His main research interests focusing on landscape planning and environmental sustainability, Geographic Information Systems for rural planning, rehabilitation and valorization of the rural architectural heritage, technical innovation and sustainability in farm building.