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Evaluating Responses to Land Degradation Mitigation Measures in Southern Italy

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ABSTRACT: The main factors affecting environmental sensitivity to degradation are soil, vegetation, climate and management, through either their intrinsic characteristics or by their interaction on the landscape. Different levels of degradation risks may be observed in response to particular combinations of the aforementioned factors. For instance, the combination of inappropriate management practices and intrinsically weak soil conditions will result in a severe degradation of the environment, while the combination of the same type of management with better soil conditions may lead to negligible degradation.The aim of this study was to identify factors and their impact on land degradation processes in three areas of the Basilicata region (southern Italy) using a procedure that couples environmental indices, GIS and crop-soil simulation models. Areas prone to desertification were first identified using the Environmental Sensitive Areas (ESA) procedure. An analysis for identifying the weight that each of the contributing factor (climate, soil, vegetation, management) had on the ESA was carried out using GIS techniques. The SALUS model was successfully executed to identify the management practices that could lead to better soil conditions to enhance land use sustainability. The best management practices were found to be those that minimized soil disturbance and increased soil organic carbon. Two alternative scenarios with improved soil quality and subsequently improving soil water holding capacity were used as mitigation measures. The ESA were recalculated and the effects of the mitigation measures suggested by the model were assessed. The new ESA showed a significant reduction on land degradation.

Key words: Desertification, Land degradation, Environment, Sensitivity index, SALUS, GIS

INTRODUCTION

Mediterranean regions have been experiencing severe ecosystem degradation for centuries due to inappropriate land management on steep slopes and more frequent periods of droughts. Marginal areas with poor soil not suitable for agriculture have been put to cultivation, thus increasing soil erosion. Soil organic matter levels have decline which has led to progressive land degradation with reduction in the vegetation cover with respect both to biodiversity and productivity. The development of high input agriculture in the coastal plains provided much higher net financial outputs than those obtained from hilly areas agriculture causing a migration of people to this areas and consequently, land abandonment of the hilly areas. In the flat areas, though, overexploitation of the groundwater is resulting in soil salinization and deterioration of soil physical properties with adverse effects on plant growth and productivity.

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In a global context, desertification is defined by the United Nations Convention to Combat Desertification as “Land degradation in arid, semi-arid and dry subhumid areas resulting from various factors, including climatic variations and human activities”. This degradation is caused by uncontrolled forest destruction, water pollution, wind and water erosion, salinisation, and inadequate soil management under both cultivated and uncultivated regimes. One of the major problems affecting the soil is the severity with which the degradation processes reduce soil biological potential. An unsustainable, rapid reduction, which cannot be mitigated using appropriate mechanisms, leads to desertification (Thornes, 1988).

Environmental sensitivity to desertification can be defined, in this context, as the response of the environment, or part of it, to a change in one or more external factors. The relationships between the cause of the change and the effect is often complex because separate environmental components respond directly, but with differing sensitivities; whilst, because of the interrelationships among the components, they are also affected indirectly. Degradation occurs when the response is considered deleterious to the ‘health’ of the environment. What the health of an environment exactly should be, and how a deleterious change is physically defined, are questions open to considerable debate. The situation is made even more complex when one considers the questions involving scale: changing from micro-, through macro-, from local through regional scales involves changing how the environment is defined, how new variables and factors are embodied, and how others become insignificant. Degradation also depends on the perspective of the observer: there are many environmental components which can be measured and changes in each one can be deemed beneficial or harmful. As degradation can arise from many different factors, the importance and relevance of changes in each component, for an individual observer, depends on the interests of that observer. These measurements can be extremely precise and quantitative, or very broad, nebulous, and qualitative. How can these data be integrated? What are the relationships among the factors? These are major issues which are not easily resolved. It is, however, only through an integrated, multi-level approach that both the different degradation stages and the existing interactions among the individual components of the landscape can be evaluated.

Detailed analysis of the causes and manifestation of degradation require plot scale data, whereas identification, management, and monitoring require continuous data over large areas. Employing the use of a GIS will not only provide the necessary data but also facilitate the establishment of standardized procedures to integrate alphanumeric and cartographic data with remotely sensed information (Corona *et al.*, 1991; De Jong, 1994; Ferrara *et al.*, 1995; Yassoglu *et al.*, 1995; Basso *et al.*, 2000) and other kinds of data. The objective of this study was to identify the factors responsible for land degradation processes in three areas of the Basilicata region and to simulate through the adoption of a soil-plant-atmosphere system the potential measures to mitigate the processes. Environmental Sensitive Areas (ESA) to desertification were first identified using the Environmental Sensitive Index procedure (ESI; Basso *et al.*, 2000). An analysis for identifying the weight that each of the contributing factors (climate, soil, vegetation, management) had on the ESA was carried out and the SALUS model successfully identified the practices and the areas where the soil could have been improved. The new ESA were recalculated and the effects of the mitigation suggested by the model were assessed.

MATERIALS & METHODS

The methodology of identifying Environmentally Sensitive Areas (ESA) has been developed as results of the Medalus Projects (I, II, III, IV) and is describe by Basso et al. (2000). The environmental degradation or sensitivity of an area is a broad concept, since, depending on context, it can be defined by many different factors, often operating in association. An ESA can be considered, in general, as a specific and delimited entity in which environmental and socio-economical factors are not balanced or are not sustainable for that particular environment. The environmental sensitivity to degradation or desertification of an area can also be seen as *the result of the interactions among elementary factors (information layers) that are differently linked to direct and indirect degradation or desertification phenomena (adopted by Basso et al., 2000).* Severe, irreversible environmental degradation phenomena, for example, could result from a combination of inadequate land management together with a particular set of critical environmental factors: soil, climate and vegetation. The particular set depends on the particular management and environment. From this perspective, a system which summarizes and characterizes the main elements, and their interrelationships and combines to create particular critical situations of varying severity, would be a useful tool for decision-makers.

Two of the most important sets of parameters which affect an environment’s sensitivity to degradation are the ecological and socio-economical ones. Environmental sensitivity is closely related to environmental factors such as climate, soil, vegetation cover, and morphology where their characteristics, and their intensity, contribute to the evolution and characterization of different degradation levels or stages. Sensitivity is also strongly linked to socio-economic factors since man's behaviour and his social and economic actions can greatly influence the evolution of numerous environmental characteristics. The three areas chosen within the Basilicata region are the Melfi, the Vulture, and the Metaponto area (Fig. 1). The current working set of thematic layers, used in the GIS to assess ESI and desertification in those areas are given in Tables 1-3. In this scheme, scores were assigned to the elements of a particular parameter with valid scores ranging from 1, the best conditions, to 2, the worst conditions. A value of 0 was assigned to areas where a measure was not a ppropriate and thus unclassified. This scheme produces results thematic layers that are independent of the structure, number of classes, etc. Thus, the layers can be compared on an equal basis, irrespective of the original data format. Higher level processing is decoupled from the details of the data and layers can be revised or developed without affecting the remaining structures. The classes and scores assigned were based on the influence and strength of the association that the different layers have with the soil degradation processes and their relationships to the onset of irreversible degradation or desertification phenomena (FAO, 1976; Briggs *et al.*, 1992; Kosmas *et al.*, 1993 1997; Basso *et al.*, 1997). A more comprehensive description on how the environmental layers are linked to the degradation or desertification phenomena is given in the works of Basso et al. (2000), Basso et al. (1998); Kosmas et al. (1994) and Kosmas et al. (1998). Incorporation of socio-economic data is more problematic. These data are important in order to evaluate the interactions of mankind with the environment, but their intangibility make them difficult to define. Many indicators have been evaluated to find linkages through spatial distribution and landscape degradation. (Marotta and Quaranta, 1996). Each elementary unit in each Quality Layer is estimated as the geometric mean of its own sub-layers:

$$\text{Quality } x_{ij} = (\text{layer } 1_{ij} * \text{layer } 2_{ij} * \text{layer } 3_{ij} * \ldots\ldots * \text{layer } n_{ij})^{(1/n)} \qquad (1)$$

Where: i,j = rows and columns of a single elementary pixel (30 x 30 m) of each layer;

n = number of layers used

The first level of the basic data layer isolates the rest of the system from the details of the data. The quality layer, level 2, acts as a buffer between the level

Fig. 1. The three areas within the Basilicata region chosen for this study. The Metaponto area (bottom right), the Melfi area (top right) and the Vulture area (top left)

Table 1. Classes, description and assigned weighing indices for the various parameters used for definition of soil, climate and vegetation quality

TEXTURE

Class	Description	Texture	Index
1	Good	L, SCL, SL, LS, CL	1
2	Moderate	SC, SiL SiCL	1.2
3	Poor	Si, C, SiC	1.6
4	Very poor	S	2

SLOPE

Class	Description	slope (%)	Index
1	Very gentle to flat	<6	1
2	Gentle	6-18	1.2
3	Steep	18-35	1.5
4	Very steep	>35	2

PARENT MATERIAL

Class	Descriptio	parent material	index
1	Good	shale, schist, basic, ultra basic, conglomerates, unconsolidated	1.0
2	Moderate	Limestone, marble, granite, Rhyolite, gneiss, sandstone	1.7
3	Poor	Marl, Pyroclastics	2.0

SOIL DEPTH

Class	Description	depth (cm)	index
1	Deep	>75	1
2	Moderate	75-30	2
3	Shallow	15-30	3
4	Very shallow	<15	4

ROCK FRAGMENT

Class	Description	RF cover (%)	Index
1	Very stony	>60	2
2	Stony	20-60	1.3
3	Free to slightly stony	<20	1

DRAINAGE

Class	Description	index
1	well drained	1
2	Imperfectly drained	1.2
3	Poorly drained	2

SOIL QUALITY

class	Description	range
1	high quality	<1.13
2	moderate quality	1.13 to 1.45
3	low quality	>1.46

Table 2. Classes and weighing indices for climate quality assessment

RAINFALL

class	Rainfall (mm)	Index
1	>650	1
2	280-650	2
3	<280	4

ARIDITY

Class	BGI range	Index
1	<50	1
2	50-75	1.1
3	75-100	1.2
4	100-125	1.4
5	125-150	1.8
6	>150	2

CLIMATE QUALITY

Climate quality index	Description	Range
1	High quality	<1.15
2	Moderate quality	1.15 to 1.81
3	Low quality	>1.81

Table 3. Classes and weighing indices of parameters used for vegetation quality assessment

FIRE RISK

Class	Description	Type of vegetation	index
1	Low	bare land, perennial agricultural crops, annual agricultural crops (maize, tobacco, sunflower)	1
2	Moderate	annual agricultural crops (cereals, grasslands), deciduous oak, (mixed), mixed Mediterranean, macchia/evergreen forests	1.3
3	High	Mediterranean macchia	1.6
4	very high	pine forests	2

EROSION PROTECTION

Class	Description	Vegetation types	Index
1	Very high	Mixed Mediterranean macchia-evergreen forests (with *Q. ilex*)	1
2	High	Mediterranean macchia, pine forests	1.2
3	Moderate high	Deciduous forests (oak mixed), permanent grassland	1.4
4	Moderate	Evergreen perennial agricultural crops (olives)	1.6
5	Low	Deciduous perennial agricultural crops (almonds, orchards)	1.8
6	Very low	Annual agricultural crops (cereals), annual grasslands	2

DROUGHT RESISTANCE

Class	description	Types of vegetation	Index
1	very high	Mixed Mediterranean macchia/evergreen forests, Mediterranean macchia	1
2	high	Conifers, deciduous, olives	1.2
3	moderate	Perennial agricultural trees (vines, almonds, ochrand)	1.4
4	low	Perennial grasslands	1.7
5	very low	Annual agricultural crops, annual grasslands	2

PLANT COVER

class	description	plant cover (%)	Index
1	high	>40	1
2	low	10-40	1.8
3	very low	<10	2

VEGETATION QUALITY

vegetation quality index	Description	Range
1	high quality	<1.13
2	Moderate quality	1.13 to 1.38
3	low quality	>1.38

1 data layers and the derived ESA layer, level 3. The weight of each quality layer is equivalent so, as with the level 1 component, the results are comparable among the layers and the constituents of a particular layer are hidden from the rest of the system. This approach allows the overall abstract «quality» themes (or contexts: soil, climate, vegetation and management), which make up each quality layer, to be developed independently and without changing the structure of the overall methodology. With the four qualities obtained from the above, the ES is estimated by:

$$ES_{ij} = (\text{Quality } 1_{ij} * \text{Quality } 2_{ij} * \text{Quality } 3_{ij} * \text{Quality } 4_{ij})^{(1/4)} \quad (2)$$

Where: i,j= rows and columns of a single elementary pixel (30 x 30 m) of each quality;

Quality n_{ij}= computed values

The structure gives equal weight to each level 1 layer when computing each quality (e.g. soil texture has the same weight as other soil layers) and equal weight to each quality in level 2 when computing the final ES irrespective of the number of contributing level 1 layers; i.e. a single climate parameter has, in this case, a higher influence than a single soil parameter. By doing this, the higher level computations in the model are unaffected by the number of level 1 layers; this means that a component of the quality layer is not penalized because it does not have many information layers, nor is it exaggerated if it is well specified with many layers. Maps of the ES produced using the method outlined above are showed in Fig. 2a-c for the three areas.The model, as implemented, is very simplified and a more complex framework, with non-linear computing and variable weighting factors, could be developed.

All input data were structured in a GeodataBase using Esri Arc GIS: shapefiles were harmonized in a feature dataset using UTM 33N coordinate system and implementing basic topology rules to filter out any eventual geometric error. Input data retrieved in tabular format form the original sources, were converted in .dbf format and uploaded in the GeoDatabase as well.

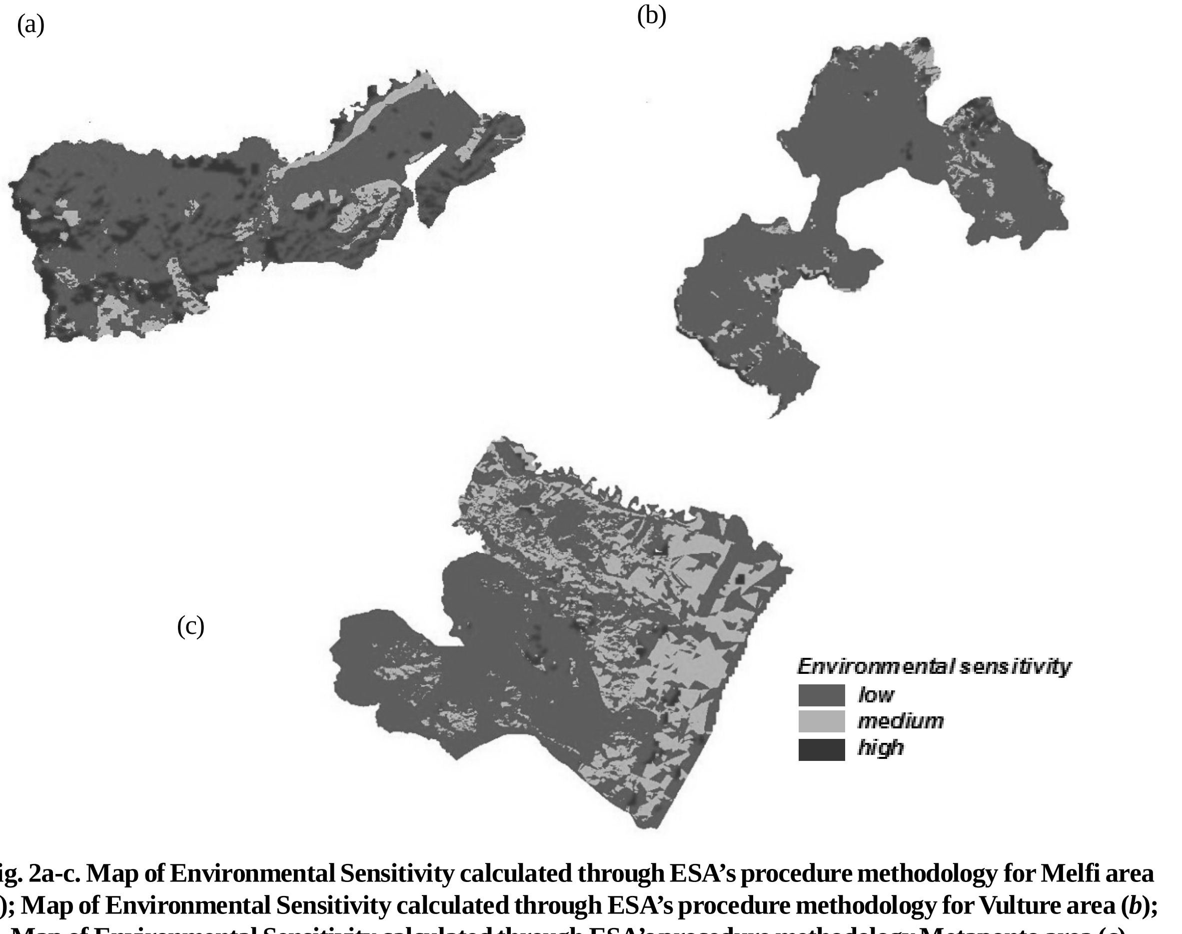

Fig. 2a-c. Map of Environmental Sensitivity calculated through ESA's procedure methodology for Melfi area (*a*); Map of Environmental Sensitivity calculated through ESA's procedure methodology for Vulture area (*b*); Map of Environmental Sensitivity calculated through ESA's procedure methodology Metaponto area (*c*)

A semi-detailed survey of the above land parameters was conducted during the execution of the European Commission funded research project of MEDALUS (Mediterranean Desertification and Land Use). Part of the data related mainly to rainfall, air temperature, geology and topography were collected from already existing databases. Soil data such as soil texture, depth to bedrock, stoniness, and drainage were measured in a dense network of field observations. The boundaries of the mapping units were drawn on topographic maps of scale 1:50,000. Vegetation was defined on the basis of the dominant species such as macchia, shrubs, olives, pines, evergreen or deciduous oaks, cereals, etc. Plant cover was determined from aerial photo-interpretation and ground data at a scale 1:30,000. All these data have been introduced to geographical information systems (GIS) and the corresponding maps of the land parameters used for the comparison of the target areas have been derived, and the area corresponding to the various classes of each parameter was determined (Ferrara *et al.,* 2005).

In this section of the materials and methods we will describe the *biophysical quality thematic layers: soil, climate, vegetation and management.*

Soil is one of the most important factors of the terrestrial ecosystem due to its crucial role in providing physical support and supply of nutrients to the plants. Soil quality varies with respect to its organic matter content and water availability. These qualities can be evaluated using simple soil properties or characteristics given in regular soil survey such as texture, parent material, soil depth and slope/gradient. In this study, soil data were retrieved from the soil map of Basilicata released by Regione Basilicata in 2005. The nominal scale of the map is 1:250.000, and constitutes a compromise between data generalization and intensity of soils surveys (1300 soil profiles from March 2002 through April 2004). Overall, a total of 154 soil types have been classified in the map, and labelled according the UTS (unitá tipologiche di suolo). USDA's Soil Taxonomy was also used as a reference for the definition of taxonomic aspects. Furthermore, to facilitate the integration of such a regional database into the more general national one, the soil types were also classified according to the World Reference Base (WRB) which has been developed by FAO and ISRIC in 1998. The resulting soil map was converted in ARCGIS shapefile format and implemented in this study. The shapefile featured 485 records each representing a single spatial entity linked to the geo-litho-pedologic characterization contained in the soil atlas. After the conversion of the soil map in a GIS environment the soil type for each has been chosen by overlaying the soil map with the boundaries of each area.

Soil texture is related to erodibility, water retention capacity, crusting and aggregate stability. The amount of available water is related to both texture and structure. Soils with high amount of silt and clay are characterized by a higher water holding capacity compared to sandy soils. The soil textural classes are grouped according to their water-holding capacity in four classes (Table 1).

Soils derived from different parent materials react differently to soil erosion, vegetation and desertification. For example, limestone produces shallow soils with a relatively dry moisture regime. In contrast, soils formed in plysh are deep, well vegetated and protected from erosion. Several areas on limestone formations in the Mediterranean region are already desertified with the soil mantle eroded and the vegetation cover completely removed. Similarly, acid igneous parent materials such as pyroclastics produce shallow soils with high erodibility and high desertification risk. As Table 1 shows, the various parent materials can be classified for their sensitivity to desertification into three classes.

Rock fragments present in the soil surface have a great but variable effect on runoff and soil erosion (Danalatos *et al.*, 1995), soil moisture conservation (Wesemael, *et al.*, 1995; Moustakas *et al.*, 1995) and biomass production, which plays an important role on land protection in the Mediterranean region. Rock fragments present in the soil surface are classified in three classes according to their capacity to conserve soil water and protect the soils from erosion (Table 1). Soils in hilly areas formed on consolidated parent materials usually have a shallow limiting layer due to the presence of bedrock at certain depth restricting the ability to support a considerable vegetation cover under Mediterranean climatic conditions. Below a critical depth, depending on the parent material, the woody plant species disappear (Kosmas *et al.*, 1998) and only some annual plants can survive. The erosion rate below the critical depth is very high, favoring the appearance of the underlying bedrock on the surface. Soil depth is defined as the depth of the soil profile from the soil surface to the top of the regolith or unweathered parent material and it is classified into four classes (Table 1). Soil depth is considered as one of the most important soil parameters affecting desertification and therefore a higher weighing factor is assigned to this parameter.

Slope angle and generally topography is undoubtedly considered one of the most important determinants of soil erosion. Erosion becomes acute when slope angle exceeds a critical value and then increases logarithmically. Slope grade is classified in four classes according to the effect on soil erosion (Table 1).

Soil drainage condition is mainly used for assessing desertification risk due to salinization of flat areas located mainly in alluvial plains along the coastal line or in depressions inside valleys. Three drainage classes are classified with respect to their effect on salinization (Table 1) taking into consideration the depth of ground water table and the presence of hydromorphic characteristics such as iron and maganese mottles or concretions.

Soil quality index (SQI) is then calculated as the product of the above parameters, namely soil texture, parent material, rock fragment content, soil depth, slope grade, and drainage conditions using the following equation:

$$SQI = (texture * parent\ material * RF * depth * slope * drainage)^{1/6}$$

The soil quality index is then scaled into three categories with respect to water availability and erosion resistance (Table 1).

Climate quality is assessed using parameters that influence water availability to the plants such as amount of rainfall, air temperature and aridity. Annual precipitation is classified in three classes considering the annual precipitation of 280 mm as a crucial value for soil erosion (Kosmas *et al*., 1997) and plant growth (Table 2).

The most effective measure of soil water availability is the assessment of precipitation minus evapotranspiration and run-off. However, this calculation requires numerous data inputs such as soil moisture retention characteristics, vegetation growth characteristics etc., therefore, the simple Bagnouls-Gaussen aridity index is used here. The Bagnouls-Gaussen aridity index (BGI) is defined as following:

$$BGI = \sum_{i=1}^{n} (2t_i - P_i) * k$$

Where: t_i is the mean temperature for month i; P_i is the total precipitation for month i; and ki represents the proportion of the month during which $2t_i - P_i > 0$. The Bagnouls-Gaussen bioclimatic index is classified into six classes as in Table 2.

Slope aspect is assumed to also influence microclimatic conditions. Slope aspect is divided into two classes: (a) NW and NE and (b) SW and SE, assigning the indices 1 and 2, respectively. Finally the climate quality index (CQI) assessed by the equation and Table 2:

$$CQI = (rainfall * aridity * aspect)^{1/3}$$

Vegetation quality is assessed in terms of: (a) fire risk and ability to recover, (b) erosion protection to the soils, (c) drought resistance, and (d) plant cover.

Fire risk and ability to recover

Forest fires are an important factor contributing to land degradation in the Mediterranean region. Fires have become very frequent especially in the pine dominated forests with dramatic consequences in soil erosion rates and biodiversity losses. The frequency of fire occurrence is lower in grasslands, and mixed Mediterranean macchia with evergreen forests. Also, Mediterranean pastures are frequently subjected to man-induced fires for regenerating higher annual grass production. The Mediterranean vegetation type is highly flammable and combustible due to the existing of species with high content of resins or essential oils. The dominant types of vegetation prevailing in the Mediterranean are grouped in four classes (Table 3).

Vegetation and land use are clearly important factors, controlling the intensity and the frequency of overland flow and erosion (Bryan and Campbell, 1986; Mitchell, 1990). Extensive areas cultivated with rainfed crops such as cereals, vines, almonds and olives are mainly confided to hilly lands with shallow soils very sensitive to erosion. These areas become vulnerable to erosion and desertification because of the decreased protection by vegetation cover in reducing rainfall intensity at the ground surface (Faulkner, 1990). Perennial crops such as almonds and olives have largely expanded in Mediterranean hilly areas, while vines have declined during the last decades (Grove, 1996). These crops require frequent removal of annual vegetation using pesticides. Actually, such soils remain almost bare during the whole year, creating favorable conditions for overland flow and soil erosion.The various types of vegetation are classified in five classes (Table 3) with respect to erosion protection to the soils.

The various ecosystems found in the Mediterranean region present a great capacity of adaptation and resistance to aridity because most of the species existing under Mediterranean climatic conditions have survived under long droughts and soil moisture contents below the theoretical wilting point for many months. The various types of vegetation prevailing in the Mediterranean are classified in four classes according to the drought resistance (Table 3).

Many authors have demonstrated that in a wide range of environments, both runoff and sediment loss decrease exponentially as the percentage of vegetation cover increases (Elwell and Stocking, 1976; Lee and Skogerboe, 1985; Francis and Thornes, 1990). A value of 40% vegetative cover is considered critical below which accelerated erosion dominates in a sloping land (Thornes, 1988). This threshold may be modified for different types of vegetation, rain intensity and land attributes. Plant cover for the various types of vegetation is classified into three classes (Table 3). The vegetation quality index (VQI) is assessed as the product of the above vegetation characteristics indices related to sensitivity to desertification as follows:

VQI = (fire risk * erosion protection * drought resistance * vegetation cover)$^{1/4}$

The vegetation quality index is classified in three levels with respect to desertification risk (Table 3). In order to facilitate reading and understanding of map and to demonstrate risk patterns not self-evident, an ES map was reclassified into an environmental degradation risk map depicting three categories of environmental degradation risk: low, high and severe risk (Fig. 3).

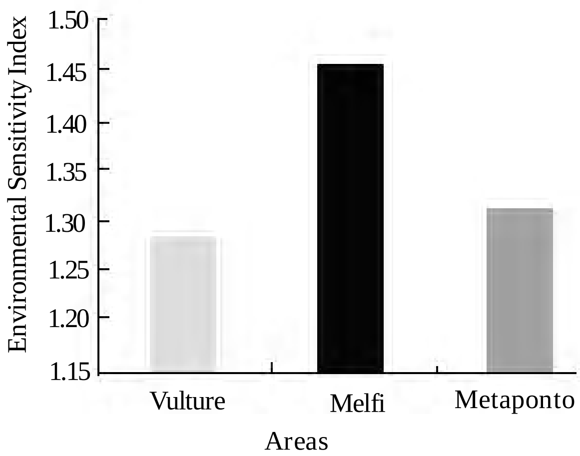

Fig. 3. Mean Environmental Sensitivity index (ES index) to land degradation for the Vulture, Melfi and Metaponto areas

Such classification was achieved grouping the ESI values into classes discriminated by natural breaks using Jenk's optimization formula that identified within the population of ESI values three breaks, thus identifying the three aforementioned risk classes. Jenk's formula minimized the sum of the variance within each of such classes, while maximizing the difference of values between classes.

As a result of such risk classification, it was apparent that ESI with respect to land degradation was affecting the three study areas exhibiting different intensities and spatial patterns. The Melfi area was the most affected, showing an ES index of around 1.45 followed by Metaponto and Vulture areas with an ESI of 1.3 and 1.28, respectively (Fig. 3). The Vulture area showed limited areas exposed to high and medium ES with the 3.9 and 6.7 %, respectively. Melfi area is exposed to high ESI for the 16.1% of its total area and it is exposed to medium ESI for the 10.6% of its area. On the other hand, Metaponto area is exposed to medium ESI for 26.6% of the total extent of its area and only 1.6% to high ESI.

RESULTS & DISCUSSION

Once areas subjected to different risk levels (low, medium and high) were identified, we proceeded with an analytical process to identify the main contributing factor (MCF) to the environmental sensitivity in space among the areas' landscape. The discrimination of the effect that each contributing factor may have on environmental rsik is an important aspect to consider for the decision making process in order to strategically address specific mitigation meaures towards specific factors.

Using well known raster analysis techniques, MCFs were identified at each location within each areas' landscape among the four quality layers (soil, vegetation, climate, management). Using the map calculator function featured in ArcGis, the environmental quality layers were processed applying a maximizing algorithm such as:

OUTPUT = MAX(GRID1, GRID2, GRID3, GRID4)

As a result, an output grid was obtained having the same cell size and extent of the input rasters, and having cell maximum values selected from the values of the correspondent cells contained in each of the four quality layers, at that same location. Such a grid was presented as a map depicting the dominance in space of one factor with respect to the other three.

The spatial distribution of the main contributing factors is depicted in the MCF map as shown in fig. 4. The map displays the 4 categorical classes of predominant quality layer. By means of spatial explorative analysis, it is possible to appreciate some similarity between the patterns of the ES and the MCF maps. A quantitative analysis of the landscape surface occupied by each MCF for each study area is showed in Figs 5a-c. For Melfi area management, soil and climate are the most frequtent MCFs among the landscape, contributing with 34.8, 27.3 and 24.2 %, respectively. In the Vulture area climate (49.1%), and soil (41%) are the two most frequent MFC (Fig. 5b), and in Metaponto area climate contributes to 40.5% of the total landscape while soil and vegetation followed with 26 and 29% of the total area, respectively (Fig. 5c).

Further analysis was carried out on each area included the identification of one or more factors for which mitigation measures should be taken in order to achieve improvements of environmental sensitivity to degradation, and optimizing costs/benefits. Therefore, once the specific role of each MCF is identified within

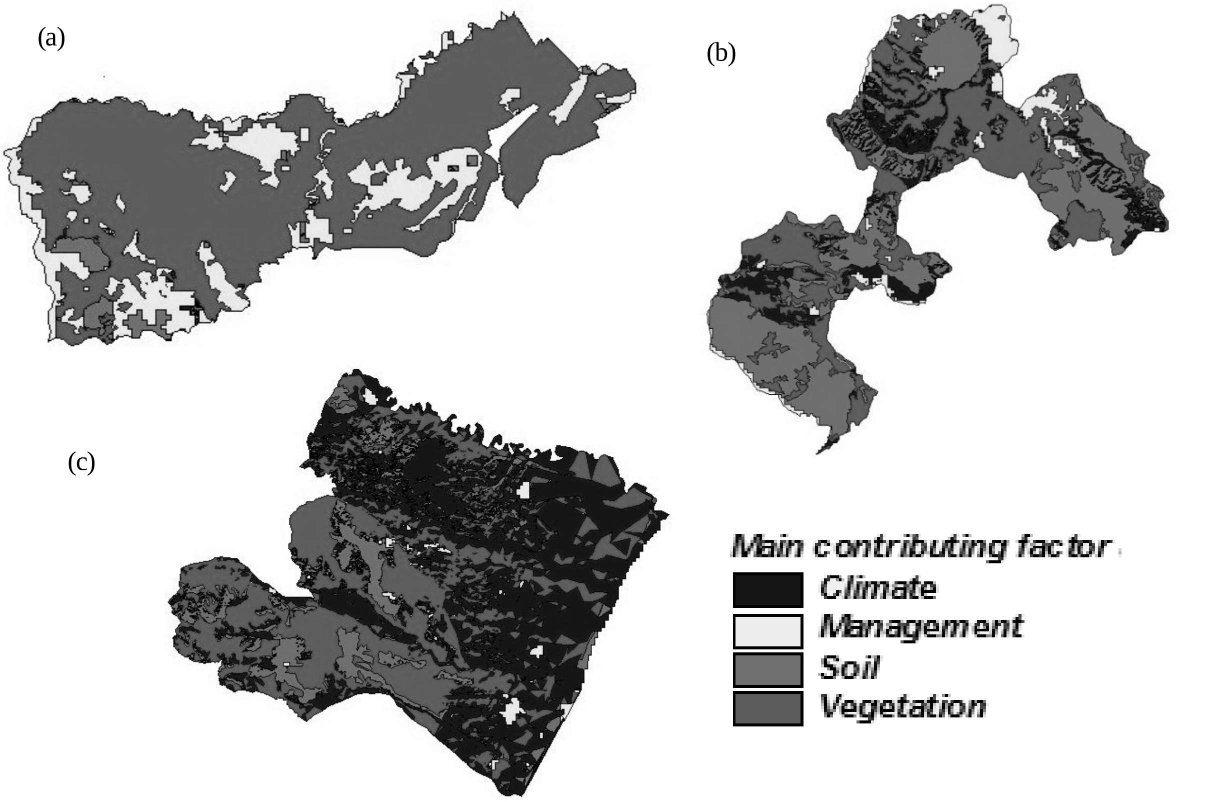

Fig. 4a-c. Map of the Main Contributing Factors (MCF) to desertification processes for the Melfi area (*a*); Map of the Main Contributing Factors (MCF) to desertification processes for the Vulture area (*b*); Map of the Main Contributing Factors (MCF) to desertification processes for the Metaponto area (*c*)

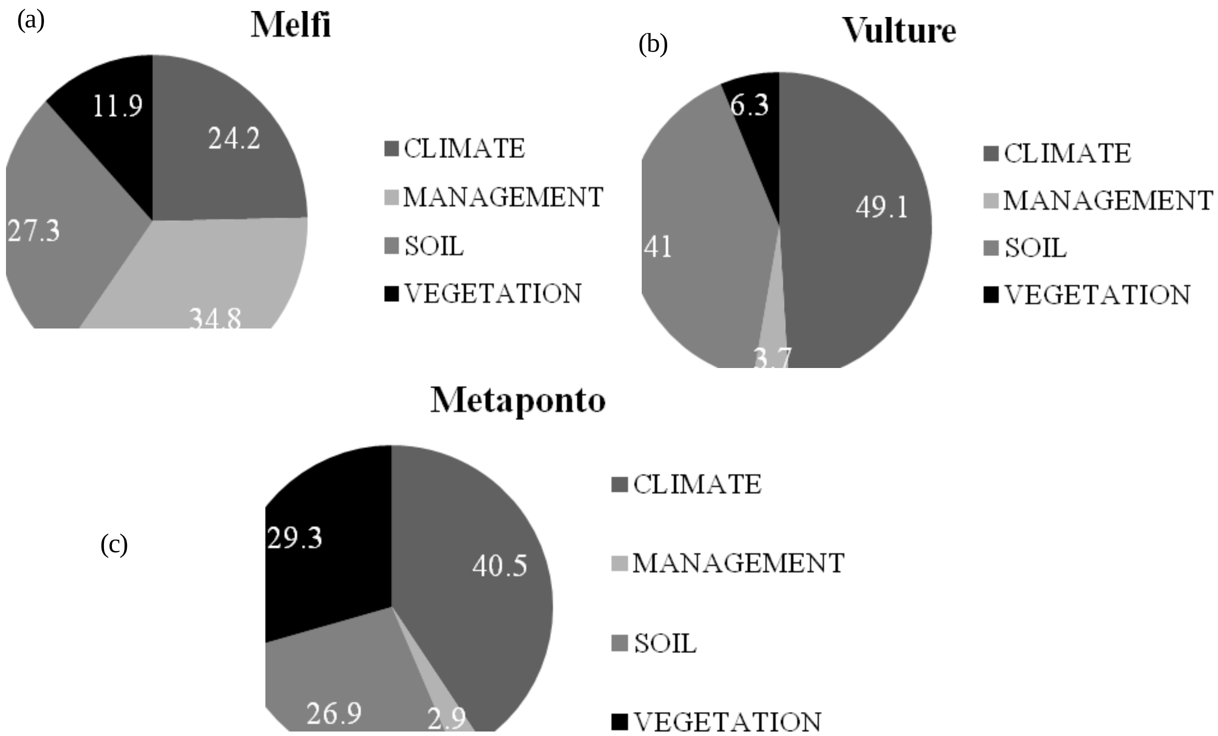

Fig. 5a-c. Pie chart of the percentage of Melfi area occupied by each Main Contributing Factor (MCF) (*a*); pie chart of the percentage of Vulture area occupied by each MCF (*b*); pie chart of the percentage of Metaponto area occupied by each MCF (*c*)

each area at high and medium ESI, those areas will be targeted with specific mitigation measures. As a consequence, MCF counts (number of pixels belonging to each factor class) were summarized within ESI cateories (Low, Medium, High) by cross-tabulating the ESI map and the MCF maps in ArcGis. Results showed that Melfi area, which is the most sensitive area among the one studied here, the main contributing factor to the medium and high risk zones is the soil, while climate contributes to the low sensitivity zones (Fig. 6a). In the Vulture area vegetation and management are the main contributing factors in the medium and high risk ESI and in the Metaponto area climate is the main contributing factor in areas at medium and high ESI (Fig. 6b-c).

The simulation of mitigation measures was carried out using the SALUS (System Approach to Land Use Sustainability) model (Basso *et al.*, 2005; Basso and Ritchie, 2005; Senthilkumar *et al.*, 2009) The SALUS model is designed to simulate continuous crop, soil, water, and nutrient conditions under different management strategies for multiple years. These strategies may have various crop rotations, planting dates, plant populations, irrigation and fertilizer applications, and tillage practices. The program simulates plant growth and soil conditions every day (during growing seasons and fallow periods) for any time period when weather sequences are available. For any simulation run, a number of different management strategies (conventional, conservation, low N input etc) can be run simultaneously. By running the different strategies at the same time we can compare this effect on crops and soil under the same weather sequences. This also provides a framework whereby the interaction between different areas under different management practices (tillage, fertilization etc) can be easily compared. Every day, and for each management strategy being run, all major components of the crop-soil-water model are executed. These components are management practices, water balance, soil organic matter, nitrogen and phosphorous dynamics, heat balance, plant growth and plant development. The water balance considers surface runoff, infiltration, surface evaporation, saturated and unsaturated soil water flow, drainage, root water uptake, soil evaporation and transpiration. The soil organic matter and nutrient model simulates organic matter decomposition, N mineralization and formation of ammonium and nitrate, N immobilization, gaseous N losses and three pools of phosphorous. The development and growth of plants uses temperature and light to calculate the potential rates of growth for the plant. This growth is then reduced based on water and nitrogen limitations.

The SALUS biophysical model is composed of three main structural components: i) a set of crop growth modules; ii) a soil organic matter and nutrient cycling module and; iii) a soil water balance and temperature module. SALUS was run with the objective of identifying the best management practice that would improve soil quality, and consequently result in improved soil water infiltration, thus reducing runoff and soil evaporation. We did not attempt to modify the vegetation and climate component. SALUS model results showed that the best management practices were found to be the one that minimizes soil disturbance and increased soil organic carbon. From the SALUS simulated results, due to the versatile nature of the model and the setup information system, it is possible to hypothesize alternative scenarios of environmental sensitivity to degradation. For each area the model was run to mitigate the factors causing higher ES values, the ES was then recalculated and the results are shown in Figs 7a-c. Once total surfaces exposed at different risk levels were assessed, and once the spatial distribution of dominating factors among such zones was quantified, a simulation was performed in order to evaluate how ameliorating one or more quality factors together would impact the extent and severity of the final environmental sensitivity of the three areas. Such a simulation can result useful in the evaluation of effectiveness of mitigation measures. For each scenario, the original ES model was re-run after that the specific quality layer/s was/were manipulated. Simulated results were compared with the environmental sensitivity originally calculated.For the Melfi area an improved quality of the soil layer has been considered and a simulation has been carried out in order to quantify the resulting ES after such modification. For the Vulture area the simulation was carried out to mitigate for management quality while in the Metaponto was simulated to decrease the ES index for the climate quality (Fig. 7b-c).

The emphasis of this paper has been on a static system; however, degradation, sensitivity, and management are all dynamic entities. Considerable attention is currently being paid to developing the system as a continuous monitoring system in which data can be updated and compared over a range of time scales. To this extent, some layers can be considered static, whose environmental parameters change slowly, or rarely, if at all, and by their nature are infrequently measured or mapped e.g., soil type, while others are more dynamic e.g., vegetation biomass. Some data are essentially cost free and their use depends on their utility and availability e.g., gauges station data, while others might be highly desirable but their cost precludes frequent updating. In any event, the aim of such a monitoring system is to define and predict trends and changes in the Environmental Sensitivity of a defined environment so as to promote efficient and optimal management.

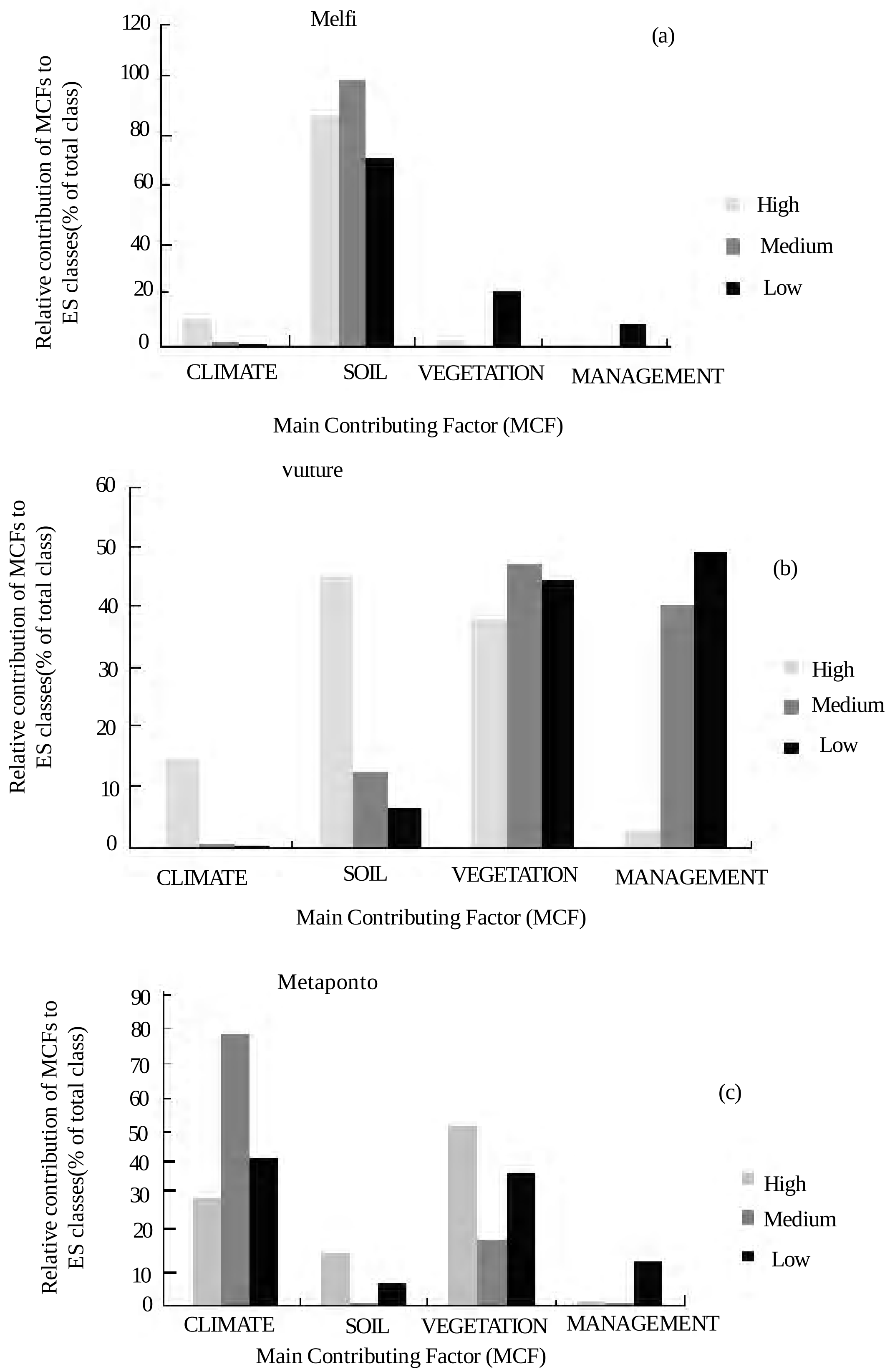

Fig. 6a-c. Influence of the Main Contributing Factors (MCF) within each Environmental Sensitive (ES) class in Melfi area (*a*); Influence of the MCFs within each ES class in Vulture area (*b*); Influence of the MCFs within each ES class in Vulture area (*c*)

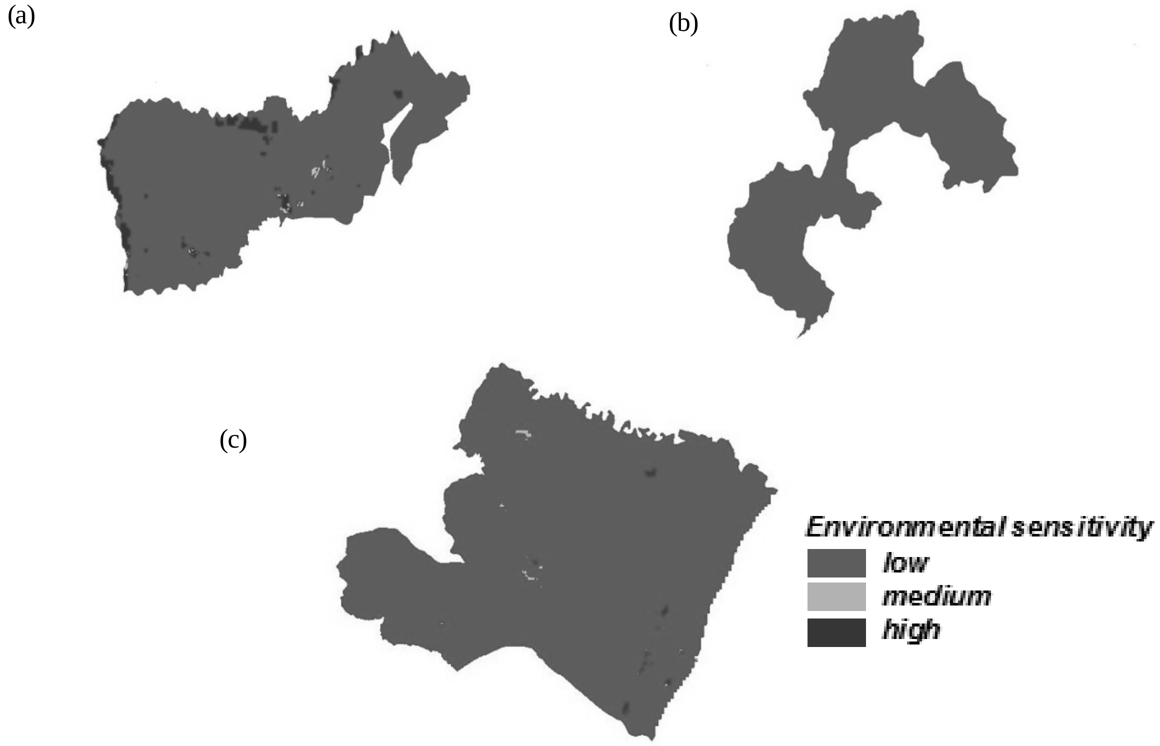

Fig. 7a-c. Simulated Environmental Sensitivity (ES) after mitigation of soil quality in Melfi area (*a*); simulated ES after mitigation of management quality in Vulture area (*b*); simulated ES after mitigation of climate quality in Metaponto area (*c*)

CONCLUSION

The result of this study showed that through the integration of GIS and soil-plant-atmosphere system model like SALUS, it is possible to identify strategies that could potentially mitigate degradation processes. The factors responsible for land degradation processes in the three regions were identified using a GIS algorithm that allowed assessing the weight of each factor within the environmental risk classes that were identified. The SALUS model was exectuted to identify the practices and the areas where the soil could have been improved. The best management practices were found to be the one that minimized soil disturbance and increased soil organic carbon. Two alternative scenarios with improved soil quality and subsequently improving soil water holding capacity were used as mitigation measures. The new ESA showed a significant reduction in the ES, with shifts from high to medium and low level risk classes.

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REFERENCES

Basso, B., Ritchie, J. T., Grace, P. R. and Sartori L. (2006). Simulating tillage impacts on soil biophysical proprerties using the SALUS model. Ital. Jour. Agron., **3**, 1-10.

Basso, B. and Ritchie, J. T. (2005). Impact of animal manure, compost and inorganic fertilizer on nitrate leaching and yield in a six-year maize-alfalfa rotation. Agriculture Ecosystem and Environment, **108**, 329-241.

Basso, B., Cammarano, D., Troccoli, A., Chen, D. and Ritchie, J. T. (2010). Long-term wheat response to nitrogen in a rainfed Mediterranean environment: Field data and simulation analysis. Eur. J. Agron., **33**, 132–138.

Basso, F., Bellotti, A., De Natale, F., Ferrara, A. and Pisante, M. (1997). Analisi del rischio di degradazione del suolo in aree agricole della Basilicata: una proposta metodologica. Rivista di Agronomia, **3**, 864-871.

Basso, F., Bove, E., Dumontet, S., Ferrara, A., Pisante, M., Quaranta, G. and Taberner, M. (2000). Evaluating Environmental Sensitivity at the basin scale through the use of Geographic Information Systems and Remote Sensed data: an example covering the Agri basin southern Italy. Catena, **40**, 19–35.

Basso, F., Bellotti, A., Bove, E., Faretta, S., Ferrara, A., Mancino, G., Pisante, M., Quaranta, G. and Taberner, M. (1998). Degradation processes in the Agri Basin: evaluating environmental sensitivity to desertification at basin scale.

International Seminar on 'Indicator for Assessing Desertification in the Mediterranean, Porto Torres, Italy.

Bryan, R. B. and Campbell, I. A. (1986). Runoff and sediment discharge in a semi-arid drainage basin. Zeit fuer Geomorph., **58**, 121-143.

Danalatos, N. G., Kosmas, C. S., Moustakas N. S. and Yassoglou, N. (1995). Rock fragments II. Their impact on soil physical properties and biomass production under Mediterranean conditions. Soil Use and Management, **11**, 120-125.

Elwell, H. A. and Stocking, M. A. (1976). Vegetal cover to estimate soil erosion hazard in Rhodesia. Geoderma, **15**, 61-70.

Faulkner, H. (1990). Vegetation cover density variations and infiltration patterns on piped alkali sodic soils: Implications for the modelling of overland flow in semi-arid areas. In: J.B. Thornes (editor), Vegetation and Erosion, Processes and Environments. J. Wiley & Sons, Chichester, pp. 317-346.

Ferrara, A., Bellotti, A., Faretta, S., Mancino, G., Baffari, P., D'Ottavio, A. and Trivigno, V. (2005). Carta delle aree sensibili alla desertificazione della Regione Basilicata. Forest, **2**, 66-73.

Francis, C. F. and Thornes, J. B. (1990). Runoff hydrographs from three Mediterranean vegetation cover types. In: J.B. Thornes (editor), Vegetation and Erosion, Processes and Environments. J. Wiley & Sons, Chichester, 363-384.

Grove, A. T. (1996). Physical, biological and human aspects of environmental change. In: MEDALUS II Project 3, Managing desertification. EV5V-CT92-0165, pp. 39-64.

Kosmas, C. S., Danalatos, N., Moustakas, N., Tsatiris, B., Kallianou, Ch. and Yassoglou, N. (1993). The impacts of parent material and landscape position on drought and biomass production of wheat under semi-arid conditions. Soil Technology, **6**, 337-349.

Kosmas, C. S., Moustakas, N., Danalatos, N. G. and Yassoglou, N. (1995). The effect of land land use change on soil properties and erosion along a catena. In: J. Thornes and J. Brandt (Editors), Mediterranean Desertification and Land Use. J. Wiley and Sons, Chichester, 207-227.

Kosmas, C. S., Danalatos, N., Cammeraat, L. H., Chabart, M., Diamantopoulos, J., Farand, R., Gutierrez, L., Jacob, A., Marques, H., Martinez-Fernandez, J., Mizara, A., Moustakas, N., Nicolau, J. M. Oliveros, C., Pinna, G., Puddu, R., Puigdefabregas, J., Roxo, M., Simao, A., Stamou, G., Tomasi, N., Usai, D. and Vacca, A. (1997). The effect of land use on runoff and soil erosion rates under Mediterranean conditions. Catena, **29**, 45-59.

Kosmas, C. S., Danalatos, N. and Gerontidis, S. (1998). The effect of land parameters on vegetation performance and degree of erosion under Mediterranean climatic conditions. Catena, **40**, 3–17.

Lee, C. R. and Skogerboe, J. G. (1985). Quantification of erosion control by vegetation on problem soils. In: Al Swaify, W. C. Moldenhauer and A. Lo (editors), Soil Erosion and Conservation. Soil Conservation Soc. of America, 437-444.

Marotta, G. and Quaranta, G. (1996). L'applicazione in Italia delle politiche strutturali, Working Paper no. 5, Istituto Universitario Navale, Facolta di Economia. Universita di Napoli, 41 pp.

Mitchell, D. J. (1990). The use of vegetation and land use parameters in modelling catchment sediment yields. In: J.B. Thornes (editor), Vegetation and Erosion, Processes and Environments. J. Wiley & Sons, Chichester, pp. 289-314.

Moustakas, N. C., Kosmas, C. S., Danalatos, N. G. and Yassoglou, N. (1995). Rock fragments I. Thei effect on runoff, erosion and soil properties under field conditions. Soil Use and Management, **11**, 115-120.

Thornes, J. B. (1988). Erosional equilibria under grazing. In J. Bintliff, D. Davidson and E. Grant (eds.) Conceptual Issues in Environmental Archaeology, Edinburgh University Press, pp. 193-210.

Senthilkumar, S., Basso, B., Kravchenko, A. N. and Robertson, G. P. (2009). Contemporary Evidence of Soil Carbon Loss in the U.S. Corn Belt. Soil Sci. Soc. Amer. J., **73**, 2078-2086.