A GIS-BASED MULTICRITERIA DECISION SUPPORT SYSTEM APPROACH TO MODELLING THE EFFECTS OF LAND USE CHANGES ON FARM INCOME AND LAND DEGRADATION AT WATERSHED LEVEL

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Abstract

The aim of this paper is to present the results of the MEDAFOR project (EC contract ENV4-CT97-0686). The overall objective was to develop and test a methodology (combining human and physical environmental dimensions) for assessing the impact that land use changes arising from European Union policies has had on socio-economics in forests and agriculture in Mediterranean areas.
A particular effort was made to include view-points of those involved (farmers, locals and EU decision makers) as "input" for the development of a MultiCriteria Spatial Decision Support System (MC-SDSS). This grants the public authority the means for carrying out an ex-ante evaluation of the potential effects of agro-environmental and forestry policies, and offers "output" in the form of information for decision makers to use when defining future strategies.
A modelling framework has been constructed where both environmental and socio-economic goals can be used to assess soil conservation strategies within an integrated land use context. In this way the study analyses the impact of different farming strategies on conflicting goals of both farmers and the public.

Keywords: Multicriteria Spatial Decision Support System; Geographic Information System; Land use change; Sustainable farming.

Introduction

The overall aim of the MEDAFOR project was to develop and test a methodology able to combine human and physical environmental dimensions to assess socio-economic and soil sustainability effects arising from land use changes due to EU agricultural and forestry policies.
The first paragraph of this paper identifies those involved. Their opinions regarding the soil erosion and land abandonment are examined by means of questionnaires distributed.
In the second paragraph an explanation of the methodology is provided, with particular regard to the definition of the MultiCriteria Spatial Decision Support System (MC-SDSS) and the description of the study-area.
In the third paragraph the case study is presented, along with the modelling framework, and the results shown. Starting from the present situation three scenarios have been considered simulating land use changes caused by the interaction of environmental and socio-economic variables and objectives.

1. Opinions of the Key Actors

The main task of the first part of the project was to identify those most involved, along with the study fields to be analysed. A socio-economic and environmental analysis was carried out on the whole province during the first year. Socio-economic indicators and other parameters such as accessibility, degree of vulnerability to erosion, land use and data availability have led to a final selection of two adjacent administration units, Fornovo and Medesano. Both the administration unit areas have a hillshape morphology with large badlands, and both are subject to local population abandonment phenomenons. Questionnaires were distributed to those most affected with the cooperation of the University of Aveiro (Pt), which permitted a colation of precise opinions regarding the issues at stake in the project.

1.1 Questionnaire survey to landowners

A questionnaire was given out to farmers in order to understand their opinions regarding the environment, and their future expectations concerning agricultural activity and common agricultural policy (Mancini, 2001).

A very narrow vision of the changes that had taken place in the environment in the course of the thirty-year period from 1960 to 1990 emerged from the first part of the questionnaire. In addition, limited interest was expressed in environmental phenomena directly influencing agricultural activity, such as the frequency of rain fall and the availability of water underground. The low percentage of answers given to the question regarding the changes in flora and fauna in the specified period of time, reveals the low interest in all activities not related to agriculture; conversely, the high percentage of answers to the questions on erosion proves that this phenomenon is present in the area and indeed represents a great worry to the farmers.

In this case, the fact that intensive practices and abandonment of lands were mentioned reveals a certain awareness of the causes for erosion, although other fundamental causes were not mentioned, such as the ploughing of gullies. It is possible to state, on the whole, that understanding of the agriculture-environment relationship is partial, if not in some cases tendentious, considering that only occasionally is agriculture cited as one of the causes of environmental degradation. Furthermore, the environmental state of the area where the farms are located does not constitute a primary preoccupation for the farmers, who on the contrary attribute the difficulties in managing their farms to financing policies chosen by the community.

The second aspect- the farmers' expectations from their businesses - revealed on the whole, a certain preoccupation for the discrepancy between hill farming and plain farming which is becoming more accentuated because of various concurrent factors. The main reason for this detected decline is due, according to most of the younger interviewees, to the older age of the majority of the farmers, their unwillingness to invest in technologically advanced machinery and to use new cultivation methods. A fundamental difference between the farmers and institutions lay at the root of the farmers' lack of trust towards institutions and their role as an economic support for the rural population. Nevertheless, substantial contradictions emerge: although all the interviewees declared themselves dissatisfied with the financial support granted by the European Union, they also affirm that they would be forced to interrupt production or limit themselves to personal consumption farming if they did not receive this support.

Moreover, it is interesting to note that some of the interviewees disapproved of a few of the farmer's choices to leave soils in set-aside, being more economically convenient to that of cultivation, with the consequence of a desolate and abandoned landscape.

Under the current socio-political and environmental conditions, the scenarios that the farmers have forecast are two: total abandonment, or the continuation of agricultural activities carried out by larger farms that are able to earn incomes sufficient to continue their activity. The elements that emerged in this respect will therefore contribute to defining the future scenarios on the basis of specific socio-political assumptions.
According to this information the model only developed scenarios that maintain a comparable level of farm income (support included).

1.2 Policy makers

A questionnaire was given out to policy makers in order to understand their opinions regarding the environment and their future expectations concerning common agricultural policy. The local authority plays a key part in applying the Common Agricultural and Rural Policies objectives at regional and provincial level.
The policy aims at creating a consistent framework for guaranteeing the future of rural areas and promoting the maintenance and creation of rural employment. The main principles are the multifunctionality of agriculture, the role of which extends over and above the production of foodstuffs, implying the recognition and encouragement of the range of services provided by farmers; the multisector and integrated approach to the rural economy in order to diversify activities, creating new sources of income and employment and protecting the rural heritage; new aids framework for rural development, based on subsidiary elements; transparency in drawing up and managing programmes. Strength in the agricultural and forestry sector, the improvement of the competitiveness of rural areas and the preservation of the environment and rural heritage, are the main features of the new rural development policies.
According to the results of the survey, the model developed scenarios that maintain a comparable level of farm income (support included) with a reduction in soil erosion risk, and with a ceiling for total support.

1.3 The citizens: evaluation of the gully landscape

The overall evaluation (qualitative approach based on visual-aesthetic indices) of the rural landscape by the interviewees was not very positive. The evaluation (aesthetic) was probably negatively influenced by the time of the year when the pictures were taken, because all the vegetation of the area is deciduous and no leaves were present at the end of winter. The same was true for the fields that had yet not been seeded in that period and were totally devoid of vegetation. These elements were probably the most negative influence on the evaluation of the landscape. Furthermore, gullies, fields and woods proved to have a clearly positive influence on the landscape. For this reason, measures should be taken to preserve and protect these elements with the aim of maintaining the beauty of this agricultural landscape.
As regards anthropic elements, it was observed that those having a negative influence on the landscape, such as roads, high voltage lines or factories could reduce their negative impact if surrounded by vegetation. On a European scale, where agriculture is decidedly pursuing new environmental goals together with the traditional economic and productive ones, it is necessary for urban and agricultural policies to favour the safeguarding, restoration and enhancement of the rural landscape.
With regards to the primary sector, in particular the production of environmental and recreational services, attention paid to the agricultural landscape becomes more important in the areas that meet or may meet the growing demand for green spots and areas for leisure time.
The area under consideration has been playing these roles for many years: geographical location, uniqueness and variability of morphology, natural features, catering opportunities and, last but not least, the type of agricultural landscape present.

In the current situation, the abandonment of primary activities can strongly affect the existing landscape and therefore jeopardise the possible use of hilly areas for recreational purposes. Furthermore, the agricultural landscape, which is the historical expression of human activities and therefore the result of specific agricultural practices, is a basic resource for many types of tourist and recreational enhancement of rural areas. This applies in particular to those types of tourism that focus upon culture, memory of traditions, past civilisations, local folklore and identity. This becomes even more important considering the negative impact produced by uncultivated land, which can contain historical and cultural aspects.
For all these reasons, it is necessary to protect and improve this natural environment as much as possible and prevent its decay, especially bearing in mind that it played a key function for the society and therefore, losing it because of a mismanagement, would also mean losing a significant part of our heritage.

2. The case study: methodology

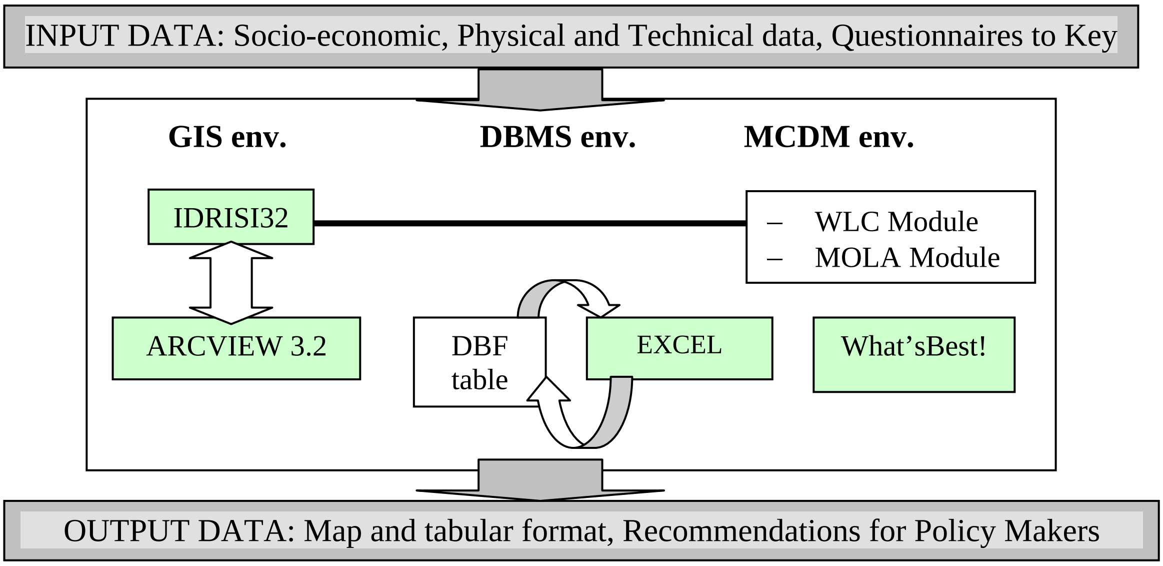
The second part of the project involved the identification of a Multicriteria Spatial Decision Support System (MC-SDSS) in order to enable the public authority to evaluate, from an ex-ante point of view, the potential effects of the agro-environmental and forestry policies. Consequently it is able to offer the decision maker an integral approach in defining the future strategies (Mora C. et al., 2001).
A modelling framework has been constructed in which both environmental and socio-economic goals are incorporated to deal with the assessment of soil conservation strategy under an integrated land use context. The Goal Programming (GP) method was applied to analyse the impact of different farming strategies in conjunction with conflicting household and public goals, in a watershed of the hilly Parma Province.

2.1 Research methods: identification of the MC-SDSS

MC-SDSS (Multicriteria Spatial Decision Support System) can be viewed as a part of a broader field of the spatial decision support system (SDSS). It involves the integration between the SDSS concept and the Multi-Criteria Decision Making (MCDM) techniques. On the one hand, the GIS allows the storage, management and analysis of spatial data; on the other hand, using a wide range of related methodologies, such as multiobjective or multiattribute decision making, a rich collection of techniques and procedures to reveal decision makers' preferences is offered (Malczewski, 1999).
A small MC-SDSS can be built using a spreadsheet or DBMS package, MCDM software and a GIS, in less time than it would take to fully evaluate methods of constructing the MC-SDSS. This leads us to the issue of coupling GIS with the decision modelling system. With coupling, we can measure the degree to which functions in one software package can be controlled directly from another. It refers to the physical and logical connection between software packages and the system in which it is implemented. In general we can distinguish two categories: loose coupling and tight coupling.
The tight coupling approach is based on a single data or model manager and a common user interface. Depending on the way in which one of the two components is dominant software, one can distinguish between the GIS and MCDM dominant integration strategies. The loose coupling approach facilitates the integration of GIS and MCDM techniques using a file exchange mechanism. It involves running MCDM models outside a GIS, using the latter as a source of data and a means of displaying the results. The data interchange standards are important for spatial decision making because they provide means for an efficient and effective integration of input data to be used in the decision-making process. They can bridge the gap between GIS and MCDM software.

The example proposed to structure an MC-SDSS system allows integrating GIS functions, such as data acquisition, storage and management of spatial data, analysis processes and representation in map format, and multi-objective methodologies, formulated and processed both in a spreadsheet environment and in a GIS environment.
As figure 1 shows, the proposed MC-SDSS is divided into three operating ambits, where four different software packages are used. In the first study environment, two different GIS softwares, IDRISI and ArcView v.3.2, work closely connected by an effective bridge of data transfer utilities. The database environment is strictly related to the GIS environment since for any map created or imported in ArcView GIS software, there is a related table of attributes, stored in DBF format. MS-Excel spreadsheet formats are used as a file interchange approach between GIS and MCDM software. Then, What'sBest! (a spreadsheet interface to the LINDO optimiser) can perfectly amalgamate spreadsheet style modelling with mathematical programming capability. Thus, the GIS data can be imported to What'sBest!, the multi-objective problem can be solved in the spreadsheet, and the results can be transferred back to the GIS system. The application of the SQL (Structured Query Language) connection allows an immediate visualisation of the results.

Figure 1: Structure of the proposed MC-SDSS.



2.2 The decision rule

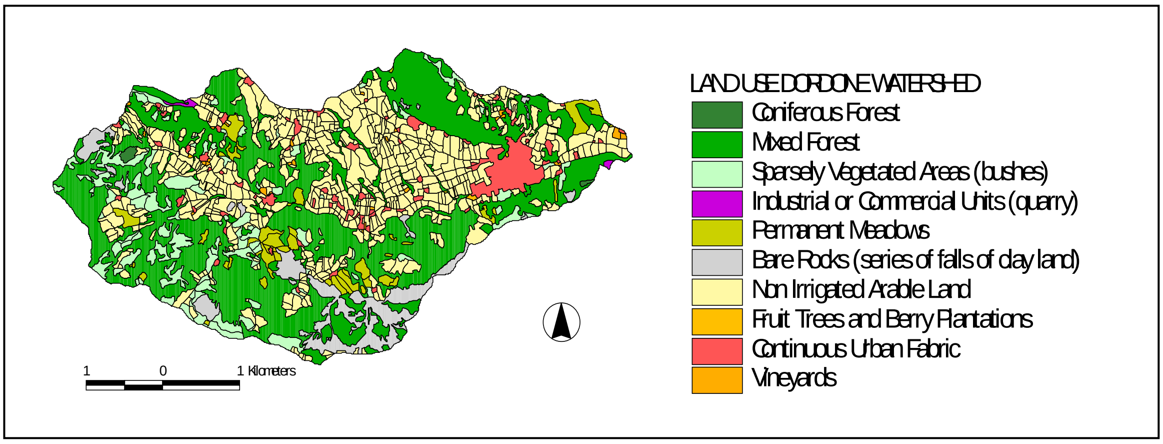
The decision rule applied to simulate changes in land use, considering conflicting objective is Goal Programming (GP). This method allows for consideration of multiple goals (evaluation criteria). GP determines the point that best satisfies the set of goals in the decision-problem (Rehman, Romero, 1989).
Although there are different methods to solve a goal programming problem (Rehman, Romero, 1989, p. 31), in the case study the Weighted Goal Programming (WGP) method is proposed. The WGP method considers all goals simultaneously in a composite objective function that minimises the sum of all deviations between the goals and their aspiration levels. The output of the model is a binary matrix (1-0 values) representing the distribution of land use types across the watershed land parcels, which attempts to achieve the objectives, subject to the physical and technical constraints imposed.

2.3 The study area

The proposed MC-SDSS has been applied to the Dordone watershed, a 17 Km.sq area in southern Parma Province. This hilly area is particularly affected by land degradation

phenomena, like soil erosion and landslides. At the same time, however the presence of farmers in the hills surrounding Parma is threatened by the progressive abandonment of the marginal lands by the native populations. The decision maker's interest in guaranteeing maintenance of an acceptable level of farm income is combined with the necessity to stimulate the application of environmentally friendly agricultural practices, in order to control the soil erosion process.
Using an integrated GIS and multi-objective approach the analyst has the possibility to generate a series of different alternatives, paying particular attention to the trade-offs amongst objectives, while the decision maker makes a value judgement about the relative significance of the alternatives proposed. To this end the Dordone watershed current land use map has been represented (figure 2) on the basis of field surveys and aerial ortophotos (scale 1:10.000), referred to the year 1999.

Figure 2: Dordone basin current land use map (year 1999).



3.The case study: modelling land use scenarios

3.1 Environmental and socio-economic goals

The study attempts to explore the interaction between conflicting environmental and socio-economic objectives, using an ex-ante assessment approach that permits generation of alternative scenarios. Three objectives are considered: one environmental (soil erosion) and two socio-economic (farmers' gross margin and public expenditure).
Soil erosion is one of the most important processes determining soil degradation in the Dordone watershed environment. The adoption of a policy for soil erosion reduction should also take into account socio-economic factors, and will require preliminary analysis to be carried out on a territorial scale.
The estimation of soil erosion in the Dordone watershed is assessed using the Stehlìk method (Zachar, 1982). This method uses a linear equation, combining six environmental and land use weighted factors (i.e. climatic, petrological, pedological, slope, slope length and land cover factor). The land cover factor (called "O factor") joins the environmental and socio-economic dimensions of the problem. The output is an estimate of the mean annual soil loss (mmy-1). In order to calculate the soil erosion value, it is necessary to transform the mm into tons (here an average value of 1.3 t/m3 soil density was assumed).
In the considered socio-economic model, it is assumed that the whole basin acts as a single farm. This assumption might seem very rigid; however, we found from direct surveys, that farmers in the Dordone catchment have very few exchange relations with farms outside the

basin, while they are open for exchanges within the basin (mainly hay and fodder exchanges). Moreover the milk produced by the dairy farms within the basin is sold to the same cheese dairy. The economic performance of farms in the analysis is calculated taking into account the total gross margin. This can be defined as the difference between farm total revenue and farm variable costs. The most important element of farm revenue is the market value of produce (e.g. milk, wheat, corn) including the value of produce retained as input in the farm, and the direct payments for cereals.

Gross margin is not a profit figure. Gross margin is the farm's contribution to fixed costs and profit, once the variable costs have been paid. In the short run, to maximise the gross margin is equal to maximise profits, since the fixed costs are assumed to be constant (Kay, Edwards, 1992, p. 175).

In order to obtain the total gross margin it is necessary to estimate the likely yields for each crop enterprise, varying across slope and aspect, and the crop variable costs, depending principally on slope and soil type. The breeding livestock gross margin is calculated assuming that any forage produced in the basin which exceeds the requirement for existing cattle, is sold; that the entire cereal production of the "Dordone" farm is sold; and that flour and vegetable feed, needed for feeding cattle, are purchased outside the farm. These hypotheses are also confirmed by the information collected through direct interviews with basin farmers.

Finally, public expenditure is defined by the need for the local administration to limit the amount of public support offered to farmers. The total amount of support comprises direct payments for cereals and subsidies for agro-environmental and afforestation measures.

3.2 Results from the present situation

All the calculations needed to evaluate the environmental and socio-economic performances of the present situation are processed in the GIS environment (IDRISI), and the results expressed in map and tabular format.

According to the current land use and crop distribution, the calculated total soil erosion loss for the basin is equal to 295,335 tons per year, with a mean value of 169.68 tons/ha/year.

For the socio-economic model, the present situation refers to the basic rotation applied inside the basin, which consists of 5 years of alfalfa, followed by one year of wheat and one year of barley. The crop gross margin amounts to approximately Euro 30,000. Based on the number of working days per hectare (Emilia-Romagna Region, 2000), it is possible to determine the global number of working days for the basin, with the crops indicated. The total number amounts to about 4,500 working days per year, corresponding to more than 16 working units (a working unit consisting of family workers and permanently hired staff of 2200 hour per year or, considering a working day of 8 hours, 275 days per year). By adding the crop gross margin to the breeding margin we obtain the total gross margin for the "Dordone" farm, which has been estimated to be approximately Euro 520,750 per year. The total number of working units in the basin amounts to 26.7, if we also consider the working days required for the breeding livestock (Emilia-Romagna Region, 2000).

The total public expenditure is calculated as Euro 51,571. The support dependence rate, calculated as the percentage of public expenditure for direct support out of the total gross margin, is around 10%. This is a measure of the extent to which farmers' incomes are dependent on public support.

3.3 Simulating land use scenarios

The simulations are limited to those parcels whose land use is supposed to be variable in the short run. Therefore forested lands, bushes, urban areas and industrial zones are excluded from the analysis. For the purpose of the model, rotations represent the possible land use types in each parcel. This system allows us to consider a more realistic period of time with respect to the farmers' choice. Six possible land use types (table 1) are defined: base rotation, intensive rotation, extensive rotation, grassland, integrated production methods and afforestation. The fractions in brackets refer to rotation periods; all the land use types must be related to the same year period.

Table 1: Land use types (crop rotations).

N.	Land use type description (period)	Crops for each land use type
1	Base Rotation (7 years)	Alfalfa (5/7) + Barley (1/7) + Soft Wheat (1/7)
2	Intensive Rotation (6 years)	Alfalfa (1/2) + Soft Wheat (1/3) + Barley (1/6)
3	Extensive Rotation (8 years)	Alfalfa (7/8) + Soft Wheat (1/8)
4	Grassland (10 years agreement)	None
5	Integrated Production Method Rotation (7 years)	Alfalfa LI (5/7) + Barley LI (1/7) + Soft Wheat LI (1/7)
6	Afforestation (20 years agreement)	None

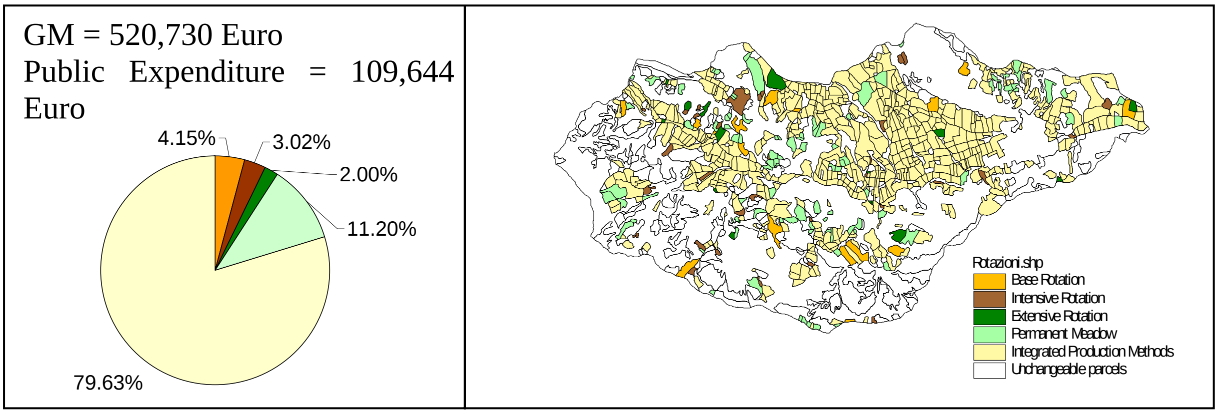
An estimate of the objective functions of the model (soil erosion, gross margin and public expenditure) is calculated considering all the land use types that can be adopted according to the economic model and the expectations of land owners. A set of six hypothetical maps for each objective (each one calculated assuming a homogeneous land use for every land use type considered) is built up. This huge amount of raster data is summarised in a vector-table format. The application of the Weighted Goal Programming model, with 3 goals (soil erosion, gross margin and public expenditure) and 5 constraints, allows us to produce a set of scenarios, obtained by varying the weights attached to each decision variable and the target values imposed at the objectives. The results of three simulations are reported in table 2, along with the performances from the present situation.

Table 2: Total Gross Margin (Euro), Mean Soil Erosion (t/ha/year), Total Working Units, Public Expenditure (Euro) and Support Dependence Rate (%).

Scenario	Total GM	Mean Soil Erosion	Public Expenditure	Working Units	PE / GM
Present Situation	520,750.00	169.7	51,571.00	26.7	9.9
Scenario 1	520,730.00	150.0	109,644.00	25.3	21.1
Scenario 2	520,745.00	150.0	88,533.00	25.2	17.0
Scenario 3	482,338.00	145.0	80,000.00	24.3	16.6

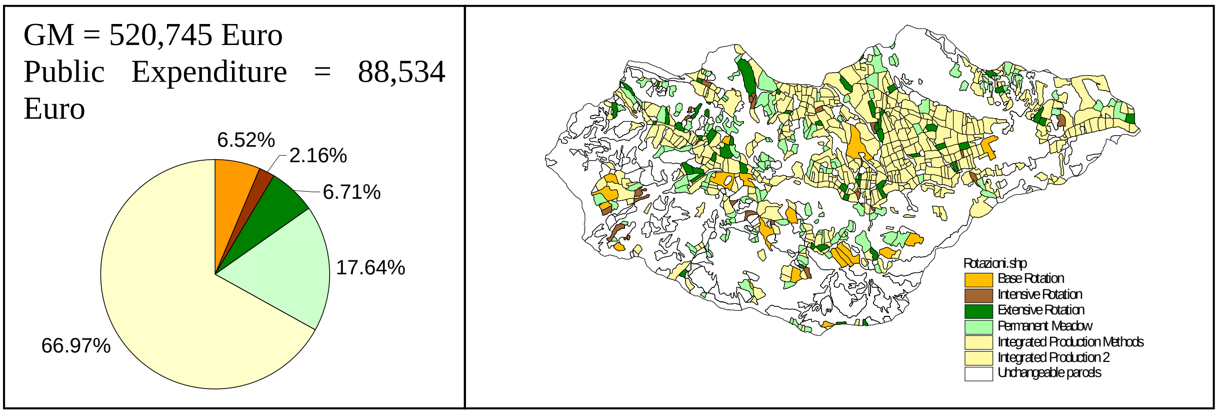
In the first scenario the objectives are gross margin (set equal to that of the present situation) and soil erosion (20% less than the present situation). Results for each objective are displayed below by means of a pie chart: it also shows the land use distribution inside the basin, and the percentage of each land use type out of the total number of the modelled plots. The results show a widespread application of integrated production methods. This is also confirmed by the (negative) performance of the public expenditure, doubled compared to the present situation.

Figure 3: Scenario 1 - Goals of soil erosion (150 t/ha/year) and gross margin (520,750 Euro).



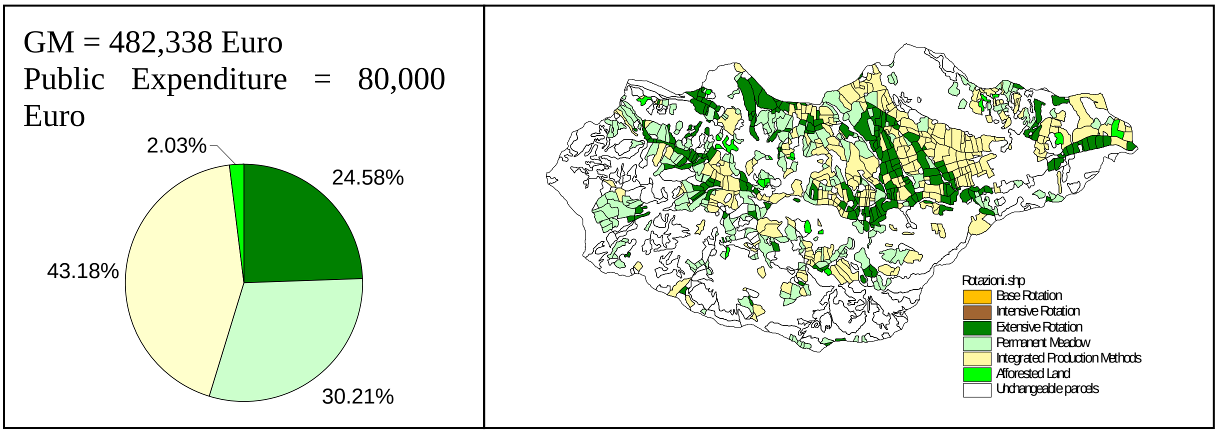
The support dependence rate amounts to 21%, therefore the decision maker might be interested in controlling the amount of direct support offered to farmers. Thus a second scenario has been modelled considering a 15% reduction in the direct support related to integrated production methods (IPM), while maintaining the target values for the two other objectives equal to those of the previous scenario. In the second scenario we allow the number of cattle to vary within a range of 40 units. This is a value which does not affect the structure of the existing stables in the basin. The results of the second scenario are shown in figure 4. The global expenditure decreases in this scenario compared to the other, whereas it is still higher than that of the present situation. In this case, the farmers are willing to compensate the drop in gross margin due to the subsidy reduction, with an increase in the number of cattle (420).

Figure 4: Scenario 2 - Same goals as scenario 1; 15% reduction in IPM subsidies from the present situation.



Finally, with the introduction of an afforestation option, a more optimistic goal for average yearly erosion has been considered (145 tons/ha/year). The previous scenario target for gross margin is maintained, while public expenditure goal is set at 80,000 Euros. In this case, it has been necessary to assign different weighting for the three objective functions, respectively 0.2 for soil erosion, 0.3 for gross margin and 0.5 for public expenditure. We thus considered the point of view of public administrations whose aim is to keep expenditure within acceptable limits, without reducing the income of farmers and at the same time pursuing environmental objectives. The results, represented in figure 5, show that two of the three goals can be successfully achieved (soil erosion and public expenditure). However the goal of maintaining the gross margin inside the basin is underachieved by 7%, compared to the present situation.

Figure 5: Scenario 3 - Goals of soil erosion (145 t/ha/year), public expenditure (80,000 Euros) and gross margin (520,750 Euros).



Conclusions

Conclusions concern both methodology and empirical implementation. From the methodological point of view, the proposed MultiCriteria Spatial Decision Support System (MC-SDSS), permits exploration of the interaction between conflicting environmental and socio-economic objectives, using an ex-ante planning approach capable of generating different alternative scenarios. This framework is innovative if compared with the literature consulted during the research. Moreover, in view of the large number of available MCDM techniques and the possible ways of employing the information yielded by the various models, our technique does not offer itself as an exhaustive answer with regard to its concrete exploitation. In the immediate future, the main objective will be to evaluate answers in terms of results and information by way of alternative MCDM techniques. From the point of view of implementation, tools now used for supporting decision-making processes require high levels of competence in data management and elaboration, as well as in the drawing up of multi-objective analysis models. Future research seems to point towards an improvement in the ways in which such instruments may be employed through the creation of a user interface.

Moreover, the introduction of the ceiling of public expenditure as a third objective is a key issue. Indeed, this topic will increasingly assert itself as one of the main issues in future political debates as, with limited funding, the Common Agriculture Policy will be more and more called upon to reach specific aims of environmental conservation and the preservation of rural populations. Legislators will therefore need instruments which enable them to direct subsidies to those areas where they may be most useful for environmental protection and production methods that best adapt the farmer’s income objectives and the containment of public expenditure.

Thus the tools examined above may be usefully employed at a provincial level, or at the level of specific programme areas (such as protected areas or parks) for an identification of the objectives of the key protagonists, and a visual, cartographic representation of those preferential areas where public subsidies are to be directed in order to reach prefixed objectives-targets with the utmost degree of efficiency and effectiveness.

However two kinds of limits in the application of MC-SDSS should be mentioned.

The first one is specific to the proposed MC-SDSS, and concerns the quality of the available data and models applied. The application of the Stehlìk method, compared to the collected field data, seemed to overestimate the magnitude of soil erosion in the basin. Moreover a more exhaustive socio-economic model, also including fixed costs, should be applied.
The second, common to most simulating tools, entails the strong assumptions underlying the substantial rationality paradigm, according to which as soon as an optimal solution exists, the farmer should logically accept it (Attonay et al., 1999). It seems that farmers' objectives cannot just be expressed in simplified terms of maximising income, but also depend upon preferences that are less valuable in economic terms. For these reasons, these decision support tools might be intended to increase farmers' understanding of possible solutions, and their interactive application with consultants (extension services) might expand farmers' project perspectives.

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