# Land use change and the multifunctional role of agriculture: a spatial prediction model in an Italian rural area

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**Abstract:** Land use and cover change are very complex phenomena, based on relationships among environmental, social and economic factors. Moreover, its analysis could be highly valuable for predicting the effects of land use change and for planning a policy intervention able to steer agricultural activities towards sustainability.

We implemented a spatial prediction model of agricultural land use changes using a Bayesian-based procedure (Dempster-Shafer theory of evidence). This model focuses on the probability maps of changing in a Tuscan area, as derived from the land use change tendency shown in Corine Land Cover (CLC) 1990 and CLC 2000. The social characteristics of the farmer (age, educational level), farming system and farm structure characteristics based on past agricultural census data are taken into consideration. The multifunctional contribution each land covers option is then derived.

**Keywords:** corine land cover change; Dempster-Shafer theory; multi-functionality; rural abandonment.

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## 1 Introduction

Agriculture and related land use have been experiencing continuing transformations in response to the Common Agricultural Policy (CAP) reform and to the market competition forces. For these reasons, general awareness arises about the effects of the sector evolution. The agricultural sector development has embodied structural transformations of farms as well as Land Use and Land Cover Changes (LULCC) to satisfy the market requirements in terms of economic efficiency. These leading forces have trapped agricultural land between the phenomena of specialisation/intensification and abandonment of the higher cost, less competitive production areas. These two distinct phenomena are taking place on the basis of complex interaction between biophysical and socio-economic factors operating at various scales and driving land use pattern modifications with implications for the multi-functionality of agriculture.

We define multi-functionality as a characteristic feature of the agricultural sector involving agricultural activities and related land use as stated by FAO (1999). In fact, the FAO in its 'The Multifunctional Character of Agriculture and Land' (MFCAL) agrees that both agricultural activity and related land use may provide several functions beyond their primary goal of producing food (FAO, 1999). These functions are typical of agriculture and land and enable the sector to shape the landscape and environment, affecting social and cultural systems, and contributing to social/economic growth and rural development. Such a complex task is attained by agriculture and related land use through a variety of different functions ranging from environmental, to economic and social functions. In particular, we aim to consider the set of functions implied in rural sustainable development 'enhanced by achieving optimal diversity of economic activities in the rural communities' (Rizov, 2004). We apply the Rizov diversity concept to the landscape level since the land use diversity linked to the economic activities has a direct impact on the landscape aesthetic value; according to this concept, multi-functionality is intrinsically linked to agricultural activities and related land use, 'which helps to capture the complexity and continuing importance of the new agricultural pattern and land use systems'. The land use, as well as the multi-functional nature of agriculture, is thus the result of the intricate relationships between natural environment (in its physical and biological dimension) and local conditions (human capital, national and local institutions, policy environment, production processes characteristics and economic system) (FAO, 1999). Thus, land use and analysis and prediction of land cover changes are key elements in assessing and evaluating the risk of reduction of multi-functionality as it affects rural sustainable development and the diversity/complexity of the farming system and related landscape.

The aim of the present study is, therefore, to provide a non-deterministic land use, land cover change prediction model to assess the presence of arable crops under different natural and local conditions. The objective of this study is to determine the localisation of the LULCC within the arable crops areas. The model result based on the possibility map (expressed as Fuzzy logic) shows the possibility of a certain pixel to be involved in land use change phenomenon. The dimension and the pattern of such a change provide evidence about the evolution of the MFCAL in the area under consideration.

## 2 Case study

The study was carried out in areas of the County of Florence (Tuscany-Italy) with focus on arable crops land use. Arable crops are spread out over the County, covering around 50 546 ha. The structure of the local agricultural production system is highly diversified within the County. Agricultural activities show different pressure on the environment, mainly determined by farm types and related production systems. All these factors strongly affect the landscape characteristics and values as well as the land use and land cover pattern.

The economic role of the primary sector is locally very limited. In the last ten years, the utilised agricultural area decreased by around 16 000 ha, of which 6000 ha were used for arable crops. A relevant problem in the County of Florence is represented by agriculture profitability endorsing transformations and abandonment of farm activities, especially in those areas in which mainly extensive agriculture is characterised by low income.

At the same time, strong urban pressure often competes for agricultural land use causing the abandonment of agriculture and landscape transformation. The provincial data relative to population distribution shows that over 91% of the total population are located in the town centres (strongly urban areas) while 6% of the population occupy scattered houses, typical of rural areas.

Therefore in the County, there are rising concerns about the evolution of the rural community and agricultural sector in relation to the phenomena of land use transformation and abandonment, also considering the multi-functional role played by local agriculture and related land use.

The prediction model is applied to arable land in the County of Florence. The choice of arable crop is mainly due to diffusion and to feasibility in terms of data availability compared to other options. Moreover, arable crops have shown a real contraction in the last decade, commonly referred to as the structural and geographical condition of local agriculture (land morphology, low productivity, farm structure) (Pacciani *et al.*, 1998) allowing us to better understand the link between land use change and local conditions.

The first problem to be faced during the implementation of the model was due to the limited data availability at a small scale. The problem was partially overcome by using different scale data inputs adapted by fuzzy functions to a reduced common comparable level.

## 3 GIS and Land Use Land Cover Change (LULCC) Modellisation

The recent developments in the LULCC model simulation are closely linked to the extent use of Geographic Information Systems (GIS) (Shepherd and Bibby, 2000).

The various models for analysis, simulation and development of different thematic scenarios related to the LULCC have had to be compared to the necessity of representing the different results obtained through simulation in a spatial manner.

In this chapter, we are going to explore the principal models recently proposed through literature and show their strengths and weaknesses.

- Equation-based models

  Equation-based models are models of partial equilibrium closely linked to the economic theory and they are based on linear and non-linear planning. The most famous applicative cases are the Land Use Allocation Model (LUAM) (Jones *et al.*, 1995), and the General Optimal Allocation and Land (GOAL) use (Reinds *et al.*, 1992). Recently, some of these models have been formulated with spatially georeferenced data (Chuvieco, 1993; Cromley and Hanink, 1999). The main restriction of this approach is that the complexity of the equations does not allow sufficiently detailed spatial data.

- Statistical technique-based models

  Statistical techniques have been largely applied in the analyses of changes in land use. Generally, they are based on the regression technique (Ludeke *et al.*, 1990; Mertens and Lambin, 1997; Munroe *et al.*, 2001). The principal limitation of these techniques is that they are based on historical series data; therefore, they can explain possible future scenarios deriving from new occurrences of natural (*e.g.*, climate changes) or anthropic (*e.g.*, new economic policies) pressure.

- Cellular models

  This kind of model includes the Cellular Automata and Markov model. The Cellular model, until today, has been extensively applied within ecologic analysis of changes in land use (Li and Reynolds, 1997), within the analysis of vegetal succession (Silvertown *et al.*, 1992; Alonso and Sole, 2000; Cecchini and Viola, 1990) and climate changes (Gronewold and Sonnenschein, 1998). From the reported applications, it is evident that the major field of application of CM is the modelling of the LULCC ecological aspects. The frontier in this sector of research is represented by obtaining efficient modelling of the economical, social and political behaviour of the agents of the socio-economic system. An evolution in this sense is represented by the Multi-Agent Model, still an experimental model due to its complexity (Parker *et al.*, 2002).

- Knowledge-based model

  This kind of model combines empiric evaluation given by experts with parametric and non-parametric evaluations, such as logic-based approaches, ruled based systems, multiple criteria decision making (Bernetti and Fagarazzi, 2002; Bernetti *et al.*, 2003) and Dempster-Shaffer theory of evidence (Ollis, 1997). These models have also been applied in the analysis of changes in the land use of agricultural soil (Hubert-Moy *et al.*, 2001; Corgne *et al.*, 2004) and in the modelling of the behaviour of agricultural entrepreneurs (Bacon *et al.*, 2002). The principal strongpoint of knowledge-based models is the possibility of aggregating heterogeneous information in a correct mathematical and logical way, allowing us to consider qualitative and quantitative data coming from different sources. These characteristics make it possible to consider all driving forces that concur in the changes of land use: ecological, economic, individual behaviour, *etc*. The main restriction of these models is, however, their extreme empiricism, which sometimes needs to be used to build different hazy indicators.

The problem area involves complex phenomena requiring uncertainty to be introduced in the modelling approach. The Dempster-Shafer theory allows us to introduce uncertainty to the modelling approach through the expression of ignorance and through the assertion that the belief is not necessarily the complement of its opposite. We implemented a spatial prediction modelling approach of agricultural land use changes using a Bayesian-based procedure (Dempster-Shafer theory of evidence) in a case study located in the County of Florence (Tuscany-Italy).

### *The Dempster-Shafer theory of evidence*

An appropriate tool in a context like ours is the *Dempster-Shafer theory of evidence* (in what follows we refer to it more synthetically as *D-S theory or D-S*) (Shafer, 1976).

D-S theory, also known as *theory of the belief functions*, is a generalisation of the Bayesian theory of subjective probability. It allows us to manage data from different *lines of evidence*, thanks to a series of specific rules of combinations. Contrary to the Bayesian theory, the D-S theory does not require complete information about events and accepts that the belief in a hypothesis is not necessarily the complement of the belief in its negation.

Now we will summarise some basic aspects of the DS-theory (Le H'egarat-Mascle *et al.*, 2003).

Let $E = \{e_1,\ldots, e_N\}$ be the set of our elementary hypotheses (also called *frame of discernment*). The idea of the D-S theory is to distribute the total unitary mass of certainty over all the elements of:

$$\Omega = \{\{e_1\},\{e_2\},\{\ldots\},\{e_N\},\{e_1\}\cup\{e_2\},\{e_1\}\cup\{e_3\},\ldots,\{e_{N-1}\}\cup\ldots\cup\{e_N\},\ldots,E,\varnothing\}$$

(*i.e.*, the class of all the subsets of E). We must define a map *m* (called *mass function* or Basic Probabilistic Assignment – BPA) that assigns *evidence* (a number between 0 and 1) to (elementary and compounded) *hypotheses* (the elements of Ω). In particular, $m(\varnothing) = 0$ and $\sum_{A \in \Omega} m(A) = 1$.

#### *Remark*

In the context of the D-S theory, a positive mass $m(\{e_1\}\cup\{e_3\})>0$ assigned to the compound hypothesis $\{e_1\}\cup\{e_3\}$, means that there is a degree of undecidibility between the two hypotheses $e_1$ and $e_3$ and it is clear that the term BPA does not refer to *probability* in the classical sense. BPA (*i.e.*, D-S *mass*) and any classical probability distribution P coincide at level of mass assignment to the singletons $\{e_1\}$, $\{e_2\}$, $\{\ldots\}$, $\{e_N\}$ only when the BPA of all the compounded objects in Ω is zero. Clearly, in that case we should have, for example, $m(\{e_{1,}e_3\}) = 0$ but $P(\{e_{1,}e_3\}) = P(\{e_1\}) + P(\{e_3\})>0$.

It is known that the practical definition of the BPA remains the main problem in applying the D-S theory. As for application to changes in land use, the problem of defining the map *m* will be addressed in Section 3.

Once BPA has been introduced, we are able to define *belief* (Bel) and *plausibility* (Pl) functions:

$$\mathrm{Bel(A)} = \sum\nolimits_{\mathrm{B} \in \Omega; \mathrm{A} \subseteq \mathrm{B}} m(\mathrm{B}) \geq 0$$

$$\mathrm{Pl(A)} = \sum\nolimits_{\mathrm{B} \in \Omega; \mathrm{A} \cap \mathrm{B} \neq \varnothing} m(\mathrm{B}) = 1 - \mathrm{Bel}(\underline{\mathrm{A}}) \leq 1$$

(where $\underline{\mathrm{A}} \cup \mathrm{A} = \mathrm{E}$). Hence, for each elementary or compounded hypotheses $\mathrm{A} \in \Omega$, we can compute the *belief interval* [Bel(A), Pl($\underline{\mathrm{A}}$)]. Any reasonable classical probability value P(A) must be included in the belief interval of *A* whose size can be regarded, in turn, as a measure of the uncertainty in assigning probability distribution.

Observe that an *information source* is fully described by the triad *E* (frame of discernment), Ω (set of elementary and compounded hypotheses) and *m* (basic probability assignment), called [E, Ω, m] in what follows.

The D-S theory also provides tools for the integration of two (or, actually, more) different information sources. For example, consider the two sources $[\mathrm{F} = \{\mathrm{f}_1,\ldots, \mathrm{f}_\mathrm{N}\}, \Omega_1, m_1]$ and $[\mathrm{G} = \{\mathrm{g}_1,\ldots, \mathrm{e}_\mathrm{M}\}, \Omega_2, m_2]$. We recall that, in our problem, behaviour of farmers (described over large pixels) had to be related to a very fine territorial database of land use. By means of Dempster's so-called *orthogonal rule,* we are able to produce a new aggregated mass distribution *m*, which incorporates the joint information from the two sources. The new distribution *m* assigns a value between 0 and 1 to each element of the product class Ω made by compounding the product singletons $\mathrm{E} = \{\mathrm{e}_1,\ldots, \mathrm{e}_\mathrm{R}\}$ (where $\mathrm{R} = \mathrm{N} \times \mathrm{M}$ and $\mathrm{e}_\mathrm{k} = \mathrm{f}_\mathrm{i} \cap \mathrm{g}_\mathrm{j}$ with $\mathrm{k} = \mathrm{i} + \mathrm{N(j–1)}$; i = 1,…,N and j = 1,…,M). The product distribution *m* is defined by means of the rule (*orthogonal sum*).

$$m(A) = (\sum\nolimits_{\mathrm{B} \cap C = \mathrm{A}} m_1(\mathrm{B}) m_2(C))(1 - \mathrm{K})^{-1}$$

with $\mathrm{K} = \sum_{\mathrm{B} \cap \mathrm{C} = \varnothing} m_1(\mathrm{B}) m_2(\mathrm{C})$ where $\mathrm{B} \in \Omega_1$ and $\mathrm{C} \in \Omega_2$. Since *K* is proportional to the mass assigned to the empty set, it can be interpreted as a measure of *conflict* between the two sources. In fact, for K = 1 we have a zero divisor and the orthogonal sum does not exist.

## 4 Model structure

The model is built up on a geographical basis to allow assessment of the specific localised geographical and socio-economical factors affecting LULCC at small scale (Figure 1).

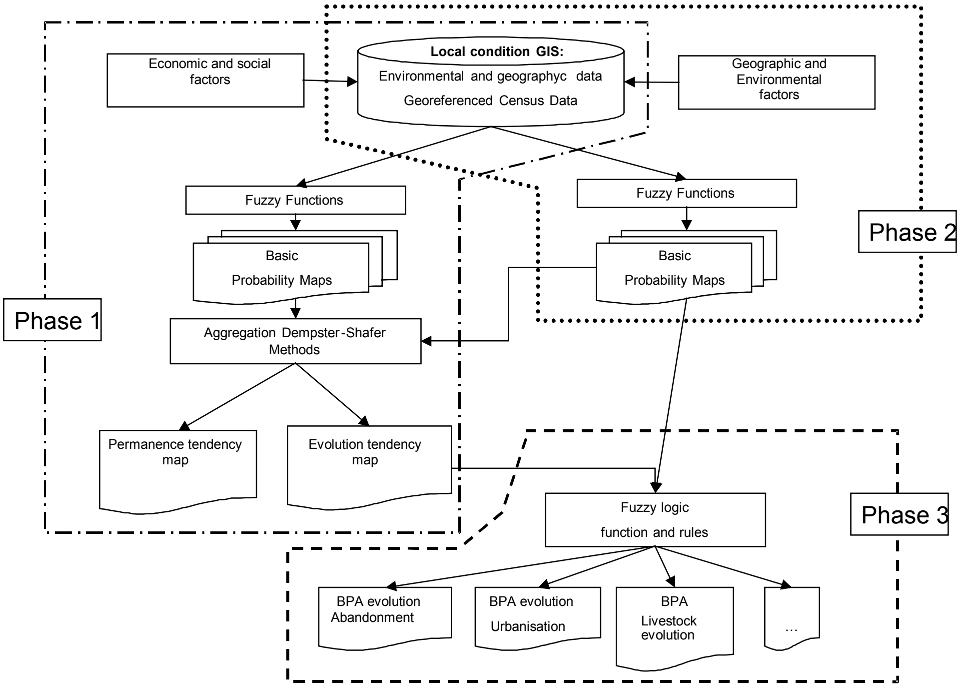
The lines of evidence we adopt in this study are as follows: 'arable crops permanence' and 'arable crops change'. The belief, plausibility and belief interval maps show the different degree to which the lines of evidence identify the proposition of permanence or otherwise of change of the land use, under consideration.

The structure of the model is then developed following three main phases by which it becomes possible to encounter local conditions (socio-economic, environmental, geographic) affecting land use according to data availability and scale.

The first two phases of the model end with the D-S outputs, then we pass to the third phase in which one of the D-S outputs (the arable crop change maps) become one of the inputs of the third phase in which we aim to predict the new land use, referring to the arable crop change maps.

For arable crop change we define an indicator list based both on physical site specificity and on the socio-economical characteristics of the farm holder. Both the indicator sets are used to evaluate economic conditions in term of competitiveness of the farms.

**Figure 1** Approach flow-chart



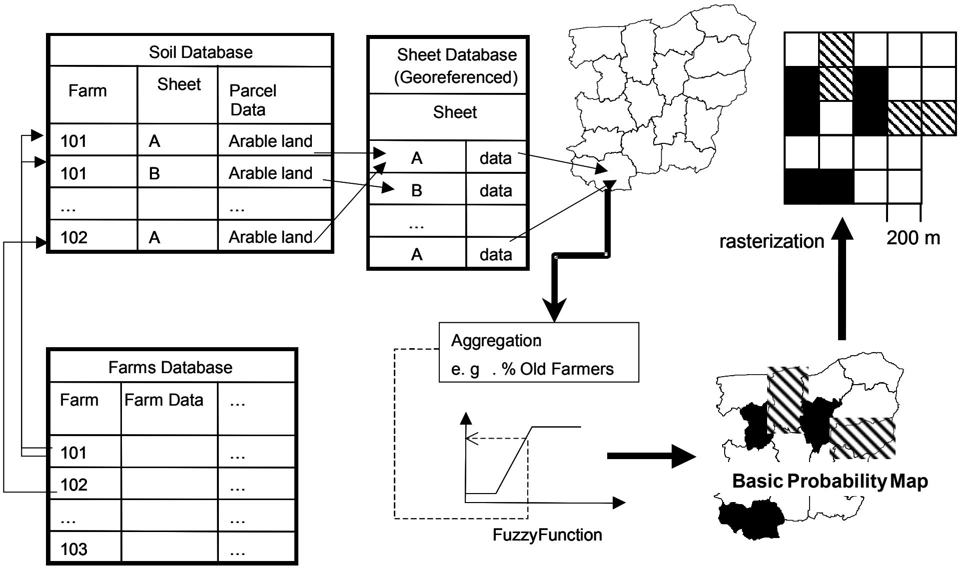

## 4.1 *First phase*

In this phase, the National Agricultural Data Census is georeferred in order to define fuzzy indicators to be used in the construction of the Basic Probability Map (BPM) (Figure 2).

Then, BPM are set up to define the lines of evidence of the permanence of arable crops or else the line of evidence of arable crop land use change. It follows the data fusion of both lines through the D-S model resulting in areas where arable crops are permanent and areas where there is an evolution of arable crops towards different land uses.

The line of evidence of arable crop permanence is based on indicators including farm type, socio-economic characteristics of holder and characteristics of the production processes.

**Figure 2** Georeferencing procedure of national agricultural data census




The farm type derives from FADN classifications with specific focus on farm involvement in extension programmes for management support and product market valorisations.

The holder characteristics refer to the age and specific skills of farmers, gained from university degrees or special professional courses.

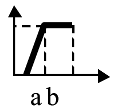
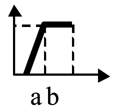
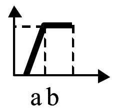
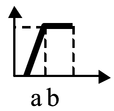
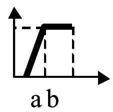
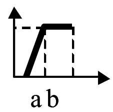
The characterisation of the farm production process is based on indicators concerning the adoption of organic production techniques and on production of high-quality cereals.

The physical indicators refer to land morphology (altitude and slope) since this affects crop productivity and cost levels. The socio-economical indicators are based on the farm holder's age and educational level.

We selected a specific set of indicators for each line of evidence based on the Farm Accountancy Data Network (FADN) and on National Agricultural Census. The latest version of the National Agricultural Census makes available the geographical location of individual farm data at the minimum territorial scale of the cadastral sheet (around 150 ha in size).

In order to realise the BPM images, it is possible to utilise the concept of fuzzy set. In this context, each component contributing to the hypothesis (or to its complement) is represented through a map of continuous values from 0 – minimal probability that the factor will contribute to the event to 1 – maximum probability. For example, an average age of entrepreneurs above 60 could give the maximum contribution to abandonment of arable crops (value 1), while an age equal to or below 35 could represent the minimal contribution (value 0). Intermediate average ages are assigned proportionally within such an interval. Identification of the parameters of the fuzzy function can be carried out through the generalisation of previous studies, on the basis of indications provided by operators in the sector or through empirical observation of the territory.[1]

**Figure 3** Fuzzy function parameters

| Function | Input data | *m*(.) | Control point | |
|---|---|---|---|---|
| | | | a | b |
| Age of farm holder | Percentage of land owned by entrepreneur over 65 years old |  | 30% | 60% |
| Management assistance and product valorisation | Percentage of land possessed by entrepreneur that joined to specific programmes |  | 0 | 30% |
| Highly qualified entrepreneurs | Percentage of land possessed by entrepreneurs with high education diploma |  | 20% | 60% |
| Crops of farms with organic productions or producing high quality cereals | Percentage of land possessed by entrepreneur that joined biological protocol or realised high quality products |  | 0% | 60% |
| Altitude | Metre |  | 0 | 600 m |
| Slope | Percent |  | 0 | 10% |

The most widely used fuzzy functions are the so-called 'J-shaped' linear functions. They are defined by two 'control points' *a* and *b*. Point *a* is the point of 'minimum probability' conditions of the component at hand, while point *b* corresponds to 'maximum probability'.

Elaborations are realised utilising the following indicators:

1 Land use change (LUC):

   a characteristics of the farmer

   - fuzzy probability map of arable crops in farms with entrepreneurs over 65

   b productivity/costs

   - altitude fuzzy probability map
   - slope fuzzy probability map

2 Permanence:

   c type of farm

   - fuzzy probability map (possibility) of arable crops belonging to farms involving bodies of management assistance and product valorisation d characteristics of the entrepreneur

- fuzzy probability map of arable crops of farms managed by highly qualified entrepreneurs (university degrees, specialisation courses)

e presence of complementary productive activities

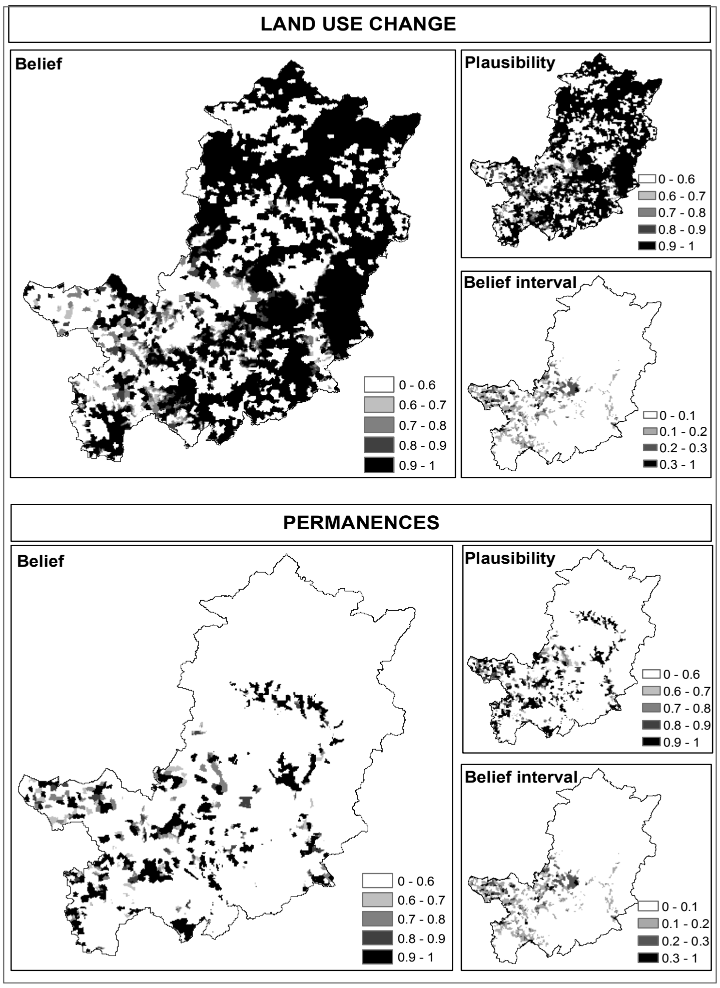
- probability map of arable crops of farms with organic products or producing high-quality cereals.

The fuzzy functions we use for the construction of BPM are described in Figure 3.

All the information is reduced to raster format on a 200 metres-sided square grid (four hectares pixel). In this way, the BPMs related to geographical data (altitude and slope) are consistent with those related to georeferred socio-economic conditions. This type of grid is regarded as appropriate in consideration of the scale of analysis and of the geographical data inputs definition degree.

The data fusion of the two BPMs produced is carried out by the 'Belief' module of IDRISI software. The Dempster-Shafer model in IDRISI provides three outputs: belief, plausibility and interval belief maps.

**Figure 4** Belief, plausibility and belief interval maps



As shown in Figure 4 the higher tendency towards land use change of arable crops is registered both in mountainous areas and in less-specialised agricultural areas. The prediction of permanence phenomenon shows consistency with this hypothesis. The belief interval seems to be of particular interest since it shows the areas in which the model assesses simultaneous conditions for both lines of evidence: permanence and land use change affecting arable crops. These areas seem particularly susceptible to policy actions since there is an opportunity to address land use change by adopting adequate policy design in order to attract farm holder decision towards the preferred options.

### *4.2 Second phase*

The analysis was carried out through two main steps: an initial analytical step and a second step in which we created the BPM.

In the first step we analysed the qualitative and quantitative changes of arable crops in the last ten years. In particular, we identified arable lands in which changes had occurred and concentrated the study on these areas for definition of the evolution rules. We identified three main transformation directions: the transition from crops to urban areas, the transition from crops to livestock farms and the abandonment of agricultural areas (no cultivation). The transition rules are implemented by the temporal analysis of the land use changes in the last ten years. They are calibrated using observed and historical data. Subsequently, we modelled land use behaviours through algorithms allowing us to reproduce, in the short-term, the trend of land use through fuzzy logic.

Using fuzzy logic, we transform each cell transition probability into new BPA maps, which determine whether it is likely that a transition will take place. In particular, concerning the exchange *crops-urban area*, we built probability maps based on the reproduction of the behaviour of the urban areas in the decade 1990–2000 compared to the arable crops, using fuzzy functions. The indicator used to define the BPA is the distance factor. From the comparison between Corine Land Cover (CLC) 90 and CLC 2000, it has been possible to individuate the thresholds of minimum and maximum probability for land use change, or rather the inclination to change from arable crops to urban area. In this domain, the distance of arable lands (present in 2000) from urban areas is represented by a map of continuous values from 0 – minimal probability of the factor to contribute to the occurrence of the event, to 1 – maximum probability. This map represents the BPA for the transformation of arable crops compared to urban areas.

### *4.3 Third phase: construction of transformation maps*

Starting from the general BPA, we defined two Boolean maps, one able to represent a high tendency to overbuilding, and another, able to represent a low propensity to change from arable crops to urban area,[2] through identification of the factor critical level.

| *Distance* | *MAPs* |
|---|---|
| 0–900 | High probability to urbanisation |
| 900–1500 | Low probability to urbanisation |
| 1500 | No probability to change of land use into urbanised |

Concerning the substitution *arable crops-livestock use*, the study concentrated on the presence of livestock farms within the cadastral sheet in the year 2000. In particular we considered two elements: the area occupied by livestock farms compared to the area occupied by agricultural farms and the number of livestock farms compared to the number of the total agricultural farms. These two indicators have been aggregated in a compensatory way (rule of the sum).

Successively, this data has been attributed to each cell belonging to the cadastral sheet itself. The transition rule has been defined on the basis of the aggregate indicator according to which rule the increase in the value of the indicator corresponds to a proportional increase in the probability of change in land use towards livestock.[3]

| *Density* | *MAPs* |
|---|---|
| 60% | High probability to zootechnical |
| 40%–60% | Low probability to zootechnical |
| 40% | No probability to change of land use into zootechnical |

The rules identifying the non-transformation of arable crops, persistence and abandonment with no substitutive crop, have not been defined. This derives indirectly from the previous rules. The no-transition rules are defined when and where low livestock and urbanised transition probabilities occur.

**Table 1** Boolean maps

| *Continuous maps* | *Bound* | *Boolean maps* |
|---|---|---|
| Urbanised BPA values | >0.7 | High Urbanised Transformation (HUT) |
| Urbanised BPA values | <0.3 | Low Urbanised Transformation (LUT) |
| Zootechnical BPA values | >0.7 | High Zootechnical Transformation (HZT) |
| Zootechnical BPA values | <0.3 | Low Zootechnical Transformation (LZT) |
| Belief map values | >0.7 | High Abandonment Probability (HAP) |
| Belief map values | <0.3 | Low Abandonment Probability (LAP) |

Once the belief map for abandonment was defined, we proceeded to define the potential scenarios of change in land use in order to identify the new land use that might occur within the analysed area for the arable crops.

Therefore, we aggregated each BPA relative to the change in land use with the belief map relative to the propensity for abandonment and resistance of arable crops.

In order to carry out this operation, we utilised the logical operator AND on the $BPA_i$[4] and the belief maps, re-classified according to the criteria as shown below in the table.

*Transition rules*

HZT and HAP

HZT and LAP

HUT and HAP

HUT and LAP

LUT and LZT and HAP

LUT and LZT and LAP

Through the aggregation rules indicated in table below, we obtained probability maps concerning the transformation of arable crops according to the main trends:

- The first transition rule corresponds to the definition of areas with a high propensity to livestock associated with a high risk of abandonment.
- The second transition rule corresponds to the definition of areas with a high propensity to zootechnics associated with a high possibility of persistency.
- The third transition rule corresponds to the definition of areas with a high risk of overbuilding associated with a high probability of abandonment.
- The fourth transition rule corresponds to the definition of areas with a high risk of overbuilding associated with a high propensity to persistence.
- The fifth transition rule corresponds to the definition of areas with a high propensity for pure abandonment.
- The sixth transition rule corresponds to the definition of areas with a high propensity for no-food.

The behaviour of agents and territory may be represented by the territorial probabilistic model taking into account the time series of land use and defining, through these, possible behaviour directions.

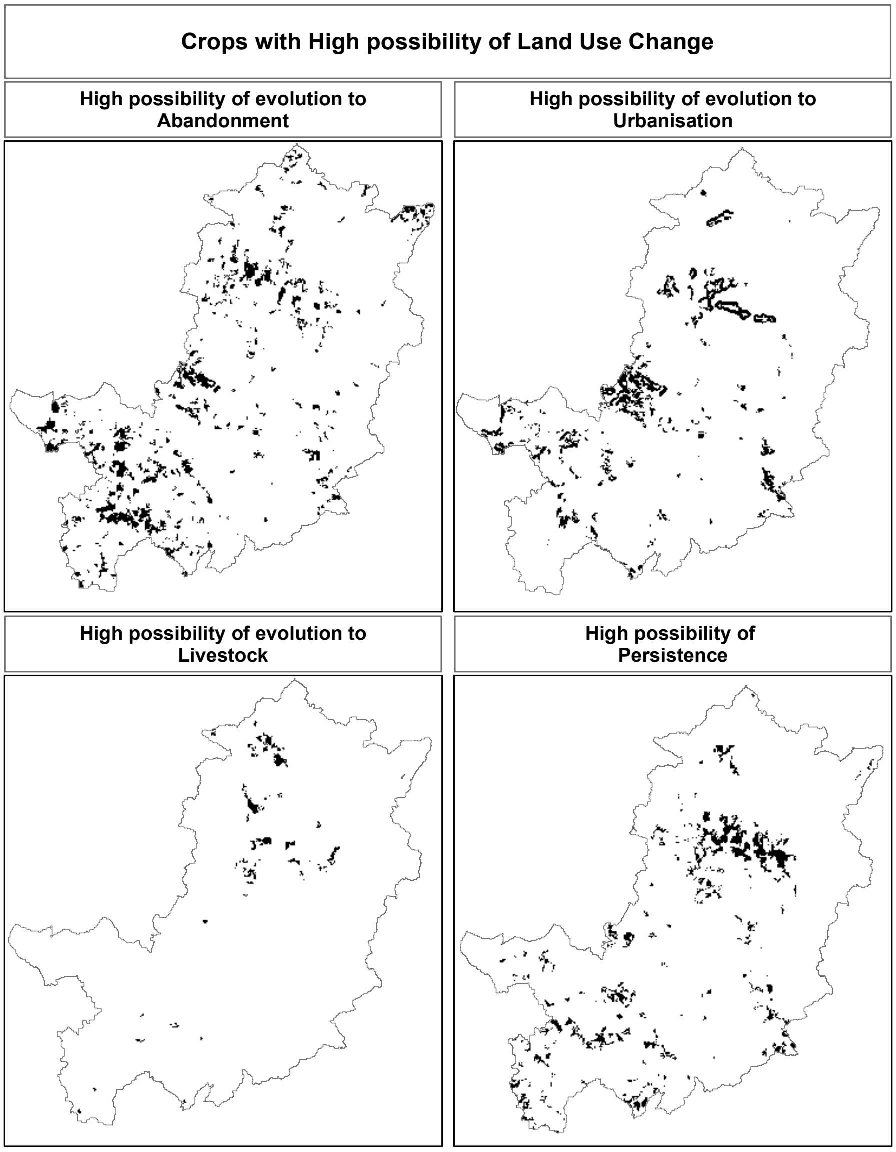
## 5 Results

The model allows us to identify areas in which uncertainty in the change of land destination is very low. These represent around 88% of total arable lands. The areas where uncertainty is very high cover around 6500 ha, representing nearly 12% of the total.

Through the model it has been possible, in a first phase, to identify the areas with a high propensity to arable crops land use change: these represent nearly 60% of the total areas presently cultivated with arable crops, corresponding to around 44 000 ha. They are mainly located in the Mugello and Chianti areas. In particular, areas with the highest propensity to arable crop land use change are located in Chianti, the lowest propensity are located in the Mugello area.

For 90% of the arable crops land use change areas, the model is able to define that precisely 67% (corresponding to around 20 000 ha) has a high propensity towards the urban area, while 18% has a propensity towards pure abandonment (Figure 5). Only 10% of this class has a poorly defined propensity for urban areas, livestock and abandonment. In these areas, arable crops play an important role in shaping landscape and in enhancing rural development (Rizov, 2004), since they are a fundamental part of the agricultural patchwork of the region contributing towards diversifying local products.

**Figure 5** Land use change maps of county of Florence




The propensity permanence of arable crops, whose trend is well-defined at around 83% by the model, occurs in around 18 000 ha while 27% is under uncertainty.

The arable crop permanence areas are mainly located in the south-western municipality of Florence in the west of the Chianti region. More specifically, they cover the areas between the municipalities of Fucecchio and Montespertoli, as well as the lower Mugello areas (San Piero, Borgo, Pontassieve).

These first results show how the model is able to broadly identify both arable crop permanence and the evolution trends of arable crops towards other land uses addressing the phenomenon of change towards urban areas.

The agricultural transformation and abandonment phenomena are the sector's response to market requirements for producing efficiently and they are linked both to natural and socio-economic conditions. At the same time, agricultural transformation and abandonment have profound effects on the environment and on local society with implications for multi-functionality. At a local level there is competition between agricultural and non-agricultural use of the land. The effect of such dynamics is a different pattern of land use with different impact on the agricultural sector and its multifunctional role. The localisation of abandonment coincides with the less favoured areas of the region in which agriculture plays a multifunctional role towards local community and landscape with implications for sustainability and rural development. According to MacDonald *et al*. (2000) the impacts of abandonment could be placed in three main categories: 'these are impacts on biodiversity (including habitats), landscape and soils'. The decline in arable crops could implicate some loss of local environmental and social values.

> "The additional consequence of these changes was loss of open space, either in terms of lost agricultural ground, or more usually, as a loss of landscape heterogeneity and mosaic features, which in many cases, represented a loss of cultural landscape." (MacDonald *et al*., 2000)

## 6 Conclusion

The Dempster-Shafer belief method is a flexible tool allowing uncertainty in the data and showing adequate performance for the LUCLCC prediction. The arable land evolution hypothesis emerging from the model implementation shows a high feasibility. So the D-S theory could be a useful model for assessing land use change, mostly in consideration of limitations on available data and on their poor quality at small area level. The present study showed the potential of such a model as well as the need for more accuracy in the indicator selection that surely needs to be improved. Moreover, the model results show consistency with the geographic distribution of social economic disadvantage and with adverse physical local conditions.

The model could be helpful in defining areas where the policy makers' role could focus on the prevention of abandonment or on the management of this trend based on social and environmental results of the change. In the former case, the policy maker could encourage land use change by managing the transformation; in the latter, she/he would prevent them by adopting agri-environmental policies.

And even though the model shows some simplifications and uncertainties that need to be erased, its significance deals with this new theoretic approach. It consists in combining agent behaviour with land use, aiming to analyse all the complex factors that affect corine land use change.

By using and improving this model, it may be possible to predict the further consequences of different agricultural policies on the abandonment of crops or other areas.

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## Notes

1 For example, the contribution of altitude to the probability of abandonment can be investigated analysing the percentage of agricultural lands abandoned on the Corine Land Cover land use map as the altitude increases.

2 For the construction of the first map the minimum discriminant level was established at 0.7, while in the case of the second map the maximum level corresponds to 0.3.

3 In this case the minimum discriminant level for the BPA relative to high propensity towards zootechnics was established at 0.7, while in the case of the second map the maximum level was fixed at 0.3.

4 Where 'i' represents each line of transformation.