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# Ways of farming and ways of thinking: do farmers' mental models of the landscape relate to their land management practices?

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**ABSTRACT.** The efficiency of the European Union's Common Agricultural Policy in mitigating the negative effects of agricultural intensification on the landscape and biodiversity is increasingly being questioned. Enhancing a reciprocal understanding of various stakeholders' mental models of agro-social-ecosystems has been proposed to trigger changes in both policy design and farmers' behaviors. However, the relationship between farmers' mental models and practices is rarely considered. Here, we explore the relationship between farmers' individual mental models (IMMs) of the agricultural landscape and their land management practices. To do so, we developed a theoretical and methodological framework grounded in cognitive psychology and farming system research for eliciting and comparing IMMs and land management practices. We applied this framework in the Coteaux de Gascogne territory, a hilly crop-livestock region in southern France. We identified groups of farmers according to their cropland and semi-natural habitat management practices. The results of our quantitative and qualitative comparisons of mental models between farmer groups showed that the way of farming partly relates to farmers' ways of thinking about the landscape and highlighted the heterogeneity of IMMs between and within farmer groups. We found evidence that path-dependent factors that constrain farmers' practices can modify their mental models, e.g., the role of agricultural machinery. Our study illustrates how an interdisciplinary framework coupling mental models and farming systems approaches provides an opportunity to enhance our understanding of the relationships between farmers' world views and their practices. Moreover, our results challenge current ways of thinking and designing biodiversity conservation policies in farmed landscapes.

**Key Words:** *agricultural public policies; Common Agricultural Policy; farming systems; landscape management; social representations; social-ecological interdependencies*

## INTRODUCTION

European agricultural landscapes represent a classic example of social-ecological systems (SESs) that result from long-term interactions between humans, nonhumans, and their biophysical environment (Plieninger et al. 2015). A recent report shows that such landscapes represent > 45% of the European Union territory (EU 27; Henle et al. 2008). They have evolved rapidly during the second half of the 20th century, mainly because of agricultural intensification, which led to landscape simplification and biodiversity loss (Matson et al. 1997, Robinson and Sutherland 2002). Since 1999, the second pillar of the EU Common Agricultural Policy (CAP) and national public policies have been implemented to protect agricultural landscapes and the biodiversity they shelter (Henle et al. 2008). The efficiency of such conservation policies is, however, increasingly being questioned (Pe'er et al. 2014, Batáry et al. 2015). The way they are designed, through centrally defined management prescriptions, was suggested as a potential reason for their failure (e.g., Pinto-Correia et al. 2006, de Sainte Marie 2014). Pinto-Correia et al. (2006) and de Sainte Marie (2014) advocate for more contextual, results-based and place-related approaches to reconcile conservation goals with farmers' work and values. Such approaches require a better understanding of differences between representations of policy makers and representations of farmers who implement them (Wondolleck and Yaffee 2000 as cited in Biggs et al. 2011, Mathevet et al. 2014).

Mental models are cognitive constructs that people use as the basis for acting within the world around them (Jones et al. 2014).

They have recently been highlighted as a useful approach to study stakeholders' representations of complex SESs faced with "wicked" environmental problems (Özesmi and Özesmi 2004). Moreover, describing and sharing mental models among stakeholders has been suggested as a way to induce changes in their representations and therefore to improve policy efficiency (ComMod et al. 2003, Biggs et al. 2011). Indeed, mental models strongly influence people's perceptions of the world and therefore their practices (Grenier and Dudzinska-Przesmitzki 2015). For this reason, mental models have been increasingly studied in research on human-environment interactions (Lynam and Brown 2011). However, the assumed relationship between mental models and people's actions has rarely been investigated (for previous explorations see Ross 2002, Hoffman et al. 2014). A fortiori, despite a substantial literature on relationships between farmers' values, attitudes, and behavior (Ahnström et al. 2009), very few studies have addressed the relationship between farmers' mental models and their actual farming practices. Most studies used a priori dichotomous criteria to differentiate practices, e.g., organic vs. conventional farming (Michel-Guillou and Moser 2006, Kelemen et al. 2013), or either collective and direct or individual and indirect elicitation methods to assess mental models (Vanwindekens et al. 2014, Diniz et al. 2015). Because these methods do not rely on direct elicitation of individual mental models and farming practices, they are likely to underestimate the diversity in individual practices and mental models and may therefore produce misleading conclusions. We believe that the design of efficient, socially and ecologically sound policies for

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agricultural landscape management and biodiversity conservation requires understanding the diversity of relationships between the way of farming and the way of thinking of individual farmers.

The aims of our study were: (1) to develop a theoretical and methodological framework to assess and compare farmers' land management practices and their individual mental models (IMMs) of the landscape, and (2) to test this framework in a case-study area. We developed an interdisciplinary framework combining farming systems frameworks used in agricultural sciences to investigate farmers' land management practices (Errington et al. 1994, Gibon et al. 1999, Darnhofer et al. 2011) and mental models theory used in cognitive psychology to study farmers' IMMs of social and ecological interdependencies within agricultural landscapes (Lynam and Brown 2011). We tested the proposed framework in the Coteaux de Gascogne territory of France, one of eight regions studied in the BIODIVERSA European project FarmLand, which aims at assessing the relationships between crop heterogeneity, biodiversity, and ecosystem services at the landscape scale to provide guidelines for more efficient agricultural policies (<https://farmland-biodiversity.org/>).

## **THEORETICAL AND METHODOLOGICAL FRAMEWORK**

### **Understanding the complexity of agricultural practices: a farming systems approach**

Farming system research has highlighted the complexity of farmers' decision systems and shown that farmers' management practices vary greatly as a result of their own values, aims, knowledge, and projects, in addition to natural constraints, specific conditions of the farm enterprise, technology used, labor invested, and other factors (Errington et al. 1994, Gibon et al. 1999, Darnhofer et al. 2011). Consequently, raw classifications based on a priori dichotomous criteria such as organic farming vs. conventional farming or dairy cattle vs. nondairy cattle are likely to misrepresent the great variety of agricultural practices (Thenail 2002, Puech et al. 2013). In our research framework, we consider that investigating the link between practices and representations requires (1) conducting one-on-one socio-technical interviews (e.g., Landais 1998) to characterize the actual practices of individual farmers, and (2) building typologies by identifying distinct land management practices a posteriori to group farmers.

Farm management decisions and their logics can be best assessed using a modular analysis of farm subsystems (Gibon et al. 1999). In the literature on farming practices and their effects on biodiversity, practices that relate to cropped areas and semi-natural areas are often distinguished because they represent two subsystems of the land management system (e.g., Kremen and Miles 2012). In our research framework, we therefore propose to build two separate typologies of land management practices respectively for cropland and semi-natural areas. Practices can be characterized from face-to-face ethno-technical interviews combining semi-structured questionnaires and preprint maps of the farm as a medium for facilitating discussions (Gibon 1999, Mottet et al. 2006). Farmers' land management practices can then be categorized using a two-step statistical analysis commonly used in farming systems research (Mađry et al. 2013). First, a

multivariate analysis of farmers' land management practices is used to identify a limited number of composite variables called axes. Second, individual farmers are clustered into groups with similar scores along the first axes of the multivariate analysis (Appendix 1). This method allows identifying a limited number of groups of farmers with similar practices while acknowledging the underlying complexity of their practices.

### **Representations, mental models, and practices**

Until now, the link between people's representations and practices has mainly been investigated by social psychologists within a social representations framework (Flament 1987, Guimelli 1998, Abric 2011). Social representations are socially constructed representations of individuals that reflect common knowledge (Moscovici 1961). It has been shown that practices and social representations can reciprocally influence each other: When people have enough autonomy or a great affective load, representations tend to influence practices, whereas when people are in very materially or socially constrained contexts, practices may be in contradiction with representations and therefore lead to a change in representation (Flament and Rouquette 2001, Abric 2011). The link between social representations and practices has mainly been investigated at a coarse level, for example, by comparing groups associated with contrasting practice levels (e.g., frequent vs. no practice; Dany and Abric 2007). To investigate the relationship between representations and actions at a finer scale, i.e., between groups associated with a gradient of practices, we propose to use mental models.

The mental model construct was developed by cognitive psychologists to describe the way people organize and use their knowledge to reason and make inferences about the world before acting (Johnson-Laird 1980). IMMs are elaborated through experience and interactions with others (Johnson-Laird et al. 1998). In that respect, they are very similar to social representations (Mathevet et al. 2011) and are very relevant for exploring the relationship between representations and actions (Grenier and Dudzinska-Przesmitzki 2015). Indeed, IMMs are dynamic representations of how objects work and interact with other objects, i.e., a "small-scale" model of reality ( Craik 1943:61) used to try out alternative scenarios mentally (Carley and Palmquist 1992) before acting. According to Kearney and Kaplan (1997), IMMs act as a filter for new incoming information that determines whether this new information will be used for action. This makes IMMs appropriate for exploring cognition in complex and dynamic systems featuring interacting social and ecological processes (Jones et al. 2014). We therefore consider that IMMs are particularly relevant to describe farmers' representations of complex and dynamic agricultural landscapes and for exploring fine-scale relationships between farmers' representations and their land management practices.

Jones et al. (2014) and Grenier and Dudzinska-Przesmitzki (2015) reviewed advantages and drawbacks of diverse IMM elicitation methods. Building on their work, we propose a method in which IMMs are elicited graphically, individually, and directly. Our method follows Carley and Palmquist's (1992) theoretical assumptions that mental models are internal representations that can be represented linguistically as networks of concepts. Building on the work of Özesmi and Özesmi (2004) and Mathevet et al. (2011), the elicitation procedure is based on

an adaptation of the actors, resources, dynamics, and interactions (ARDI) method (Etienne et al. 2011) to face-to-face interview conditions. First, we used a free-association task to access farmers' latent knowledge (Dany et al. 2015), asking them to cite spontaneously concepts they associate with the landscape (actors, biophysical components, and drivers of change). Then, we invited each farmer to use these concepts to build a qualitative model, called an individual cognitive map (ICM). ICMs correspond to graphical representations of concepts interconnected by arrows associated with a verb (Crandell et al. 1996). ICMs allow the representation of farmers' understanding of the functioning of the agricultural landscape and therefore the assessment of farmers' IMM. It is important to note that individual elicitation minimizes the effects of power relationships and local social dynamics usually associated with collective elicitation. Moreover, direct elicitation helps respondents explore their cognition through the process of mapping, which overcomes the drawbacks of indirect elicitation, where ICMs are built a posteriori by researchers through content analysis. Indeed, mental models can contain deeply held beliefs that content analysis cannot capture (Kearney and Kaplan 1997). Our method combines computer-based and author-generated graphical elicitation methods. Each respondent gives instructions to the interviewer on how to link concepts by indicating the concepts to be linked and the link direction. The graphical result is displayed using a laptop with dedicated software. Respondents are required to specify the nature of the relationships between concepts by labeling the links they draw with a verb to form a proposition (Novak and Cañas 2008). This interview design minimizes the influence of the interviewer and ensures the interviewee's freedom to choose, define, and link concepts in a way that captures his or her own mental model. Further details on the IMM elicitation method used are provided in Appendix 2.

### Exploring links between farming practices and mental models of the landscape

Carley and Palmquist (1992:602) state, "the social meaning of a concept is not defined in a universal sense but rather through the intersection of individuals' mental models." Consequently, we propose a final step allowing us to compare mental models between groups of farmers with distinct practices based on the intersection of ICMs within each group of farmers. Each elicited ICM can be coded as an individual adjacency matrix as described by Özesmi and Özesmi (2004) and Vanwindekens et al. (2014). Individual adjacency matrices can then be summed within a group, and the resulting group adjacency matrix can be converted back to a group map (Özesmi and Özesmi 2004, Fairweather 2010, Vanwindekens et al. 2013). The weight of a link in a group map corresponds to the number of individuals in the group who cited this link (Vanwindekens et al. 2013, 2014). The great variety of concepts and links included in ICMs makes it necessary to regroup concepts that have similar meanings into broader categories to facilitate group map building and comparison (Özesmi and Özesmi 2003). This represents an a posteriori aggregation that is appropriate for mental model studies in which situated knowledge and context are important (Ostrom 2005). Details and examples of this process are given in Appendix 2.

To detect elements in each group map that are most likely to be related to farmers' land management practices type, we propose to consider the consensual part of each group map, i.e., to consider

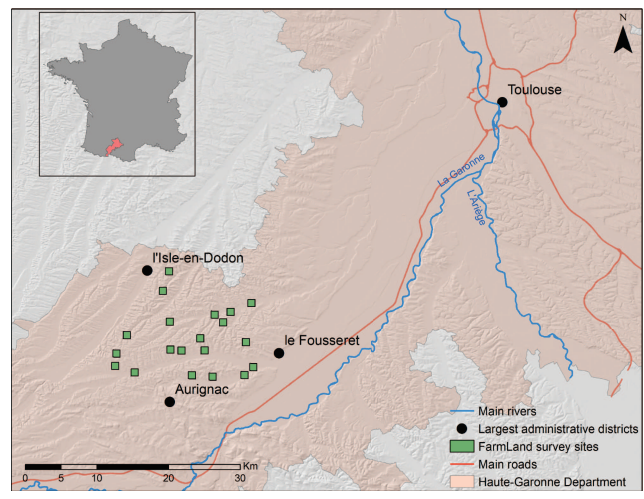
only concepts and links cited frequently (e.g., cited by > 30% of farmers) within a group, following Fairweather (2010). We then propose to conduct both a qualitative and a quantitative comparative analysis of group maps between farmer groups. The qualitative analysis involves analyzing differences and similarities between group maps, taking into account concepts, links, and verbs used by farmers within each group. The quantitative analysis aims to assess the statistical significance of differences in concept occurrence and link weights between groups. Unlike in previous studies, we propose to minimize false positive and false negative results arising from this multiple testing approach.

## CASE STUDY

### Study area

The study area is located 80 km southwest of Toulouse in southern France (Fig. 1). It encompasses three neighboring cantons (Aurignac, L'Isle-en-Dodon, and Le Fousseret) and covers a total area of approximately 400 km<sup>2</sup>. The regional landscape comprises steep hills and narrow valleys in a fine-scaled landscape mosaic of cropland, hedgerows, isolated trees, and small forests. Natural constraints and the peculiarity of the local house-based social system have slowed down agricultural intensification and farm enlargement in this region (Choisis et al. 2012). As a result, a mixed crop-livestock farming area still remains, although farms are increasingly specializing in either crops or cattle (Ryschawy et al. 2012).

Fig. 1. Location of the study area. Inset: France.



### Farmer sampling

Our sampling design aimed to encompass a large range of landscape and farm types occurring in the study area. Our sample of farmers was therefore based on the overall sampling design of the FarmLand project, which aimed at selecting landscapes along a wide range of crop composition (crop type diversity) and crop configuration (mean field size; see detailed protocol in Calatayud et al. 2012 and Pasher et al. 2013). Within each landscape, four fields with contrasting crop types were then selected to conduct a biodiversity survey after obtaining the agreement of the farmers managing the fields. To guarantee maximum overlap between

different work packages within the FarmLand project, we contacted the same pool of farmers by phone (60 farmers). We obtained a sample of 30 farmers due to a 57% positive response rate. This purposive sample accurately represented the local range of agricultural landscapes and farming systems. Of the 30 farmers, 16 had a mixed crop-beef cattle system typical of the region, 7 were specialized in cash crops, 3 were dairy farmers (3 with cows and 1 with goats), and 1 had a sheep farm for meat production. Farm acreages were very diverse, with a mean utilized agricultural area of  $131 \pm 65$  ha (mean  $\pm$  SE). In beef cattle farms, herd sizes ranged from 40 to 160 livestock units (LU), with a mean of  $93 \pm 39$  LU. Farmers were between 22 and 64 years old. All were men with an education level from middle of high school to bachelor degree equivalent.

### Surveys

We conducted two separate face-to-face interviews with each farmer to elicit IMM and to assess land management practices, respectively. The IMM elicitation interviews took place in September and November 2013, and the land management practices interviews took place in April 2014. For IMM interviews, we used Cmap Tool software (Florida Institute for Human and Machine Cognition, <http://cmap.ihmc.us/>). Each type of interview was conducted by a single observer (N. C. for land management practices, C. V. for IMM). Some farmers interviewed for the IMM elicitation could not make themselves available at the time of the land management practices interview (3 of 30). One incomplete ICM was removed from analyses. As a result, the final sample included 26 farmers.

### Methods

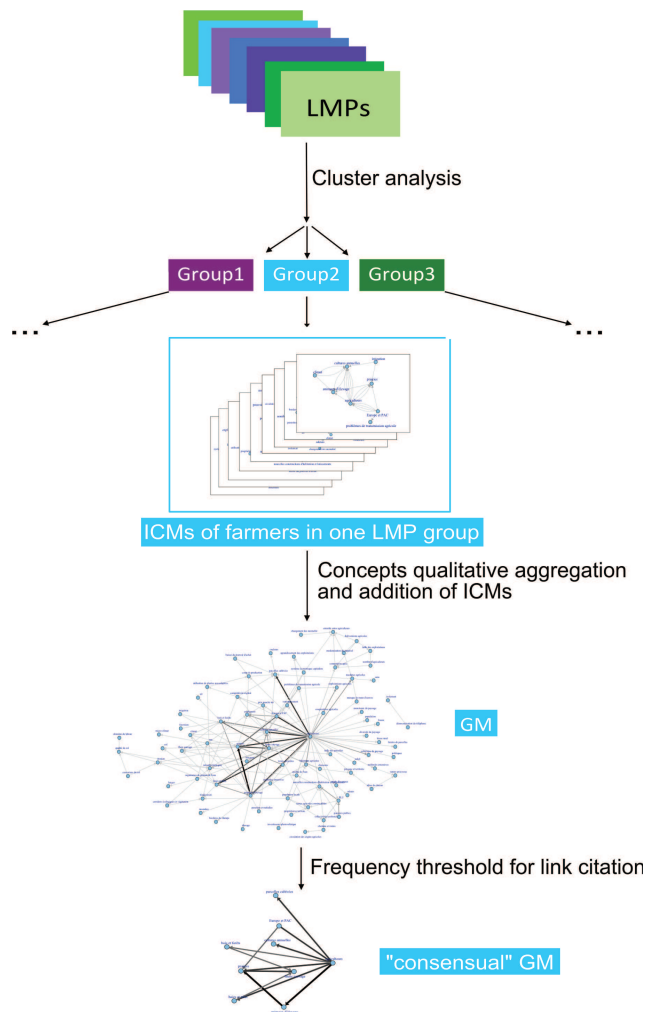
#### Land management practices groups

We selected 12 indicators of cropland management practices to build typology 1 (Table 1): 6 indicators on cropping area heterogeneity, and 6 on crop management intensification level. We chose wheat as a reference crop for the field scale because it was the only crop cultivated by all interviewed farmers. We selected seven indicators of semi-natural areas management practices for building typology 2 (Table 1). We used a generalization of the principal component analysis for mixed quantitative variables and factors (Kiers 1991) using the `dudi.mix` function in the `ade4` package in R (Dray et al. 2007). Then, we performed an agglomerative hierarchical clustering on the scores of individuals on the first axes using Euclidian distance and Ward's aggregation criterion to identify groups. We observed high levels of inter-individual heterogeneity in farmers' practices, both for crop management and semi-natural areas management. As a result, we selected three groups for each typology to maximize both intragroup homogeneity and intergroup dissimilarities (Köbrich et al. 2003).

#### Group maps per land management practice group

We observed high levels of interindividual heterogeneity in farmers' ICMs. This heterogeneity was partly due to specificities of words used by different farmers. We condensed the 394 words uttered into 152 broader categories. This reduced the number of links from 716 to 431. Levels of interindividual heterogeneity in farmers' ICMs remained high even after this aggregation process. We discarded links whose weight was below a 30% threshold to build consensual group maps (see Fig. 2).

**Fig. 2.** Conceptual framework developed to compare individual mental models (IMMs) and land management practices (LMPs) illustrating the main steps of the approach used to generate a "shared" group map (GM) for a group of farmers with similar LMPs. Darker and wider arrows have higher weight, i.e., higher frequency of citation by farmers in that group. Individual multiple links made by farmers between two concepts are merged when these links have the same direction (but different verbs are maintained). ICM = individual conceptual model.



#### Comparison of group maps between land management practice groups

We qualitatively compared group maps between land management practice groups by comparing link and verb occurrence frequencies between group maps. We used Fisher's exact tests to compare concept occurrence frequencies and link weights between groups. We chose a risk of  $\alpha = 10\%$  because of the qualitative and very diverse nature of our data and our relatively small sample size. We controlled for false positive and false negative detection rates using the Benjamini-Hochberg

**Table 1.** Land management practices indicators.

| Type of indicator                        | Measure   | Code                          | Unit or modality   |
|--|---|-------------------------------|--|
| Cropping area heterogeneity              | Median size of wheat fields   | SIZE                          | ha   |
|  | Total number of different crops in the cropping plan  | CROPDIV                       | Number of crops  |
|  | Share of annual crops in the cropland area  | ANNU                          | %  |
|  | Simpson's diversity index (Simpson 1949) of cultivated plant families (Graminaceae, Brassicaceae, Fabaceae, Asteraceae) | SDI                           | $0 < SDI < 1$  |
|  | Number of different crop rotations used on the farm   | ROT_nb                        | Number of rotations  |
|  | Length of the longest rotation  | ROT_L                         | Yr   |
| Intensification level of crop management | Annual proportion of cropland area fertilized with manure   | ORGAF                         | %  |
|  | Mineral nitrogen fertilization of wheat   | NFW                           | N units/ha   |
|  | Mineral nitrogen fertilization of temporary grassland   | NFG                           | N units/ha   |
|  | Intensity of pesticide use on wheat fields  | PHYTO                         | Number of sprays/yr  |
|  | Type of use of crop protection products   | SYST<br>INTEG                 | Systematic and preventive<br>Integrated treatments or crop monitored to adjust treatments                    |
|  | Type of tillage   | NO P<br>DEEP<br>SHALL<br>NO T | No pesticides<br>Deep tillage<br>Shallow tillage<br>No tillage   |
| Semi-natural areas management practices  | Share of permanent natural grassland  | GRASS                         | %  |
|  | Farmland hedge density  | HEDGE_D                       | m of hedges/ha of arable land area   |
|  | Type of hedge planting and removal practices  | RECENT_R<br>OLD_R<br>PLANT    | Removed within the past 5 years<br>removed before the past 5 yr<br>Planting and no removal                   |
|  | Type of grass strips management   | UNDIF<br>EXTENS               | Undifferentiated management from the neighboring crop<br>Extensive uptake distinct from the neighboring crop |
|  | Frequency of hedges upkeep  | NO GS<br>FREQ<br>RARE         | No grass strips<br>Frequent<br>Rare  |
|  | Type of hedges upkeep practices   | CHEMI<br>MECHA                | Chemical upkeep<br>Mechanical upkeep   |

adjustment technique for  $P$  values (Benjamini and Hochberg 1995). All analyses were performed with R (R Core Team 2014).

## RESULTS

### Identification of farmers' land management practices

In the first typology on cropland management practices (Table 2), the group CROP1 includes large farms specialized in cash crops (five farms) or associating them with beef production (two farms). These farms have the largest fields and lowest crop diversity. The farms comprise intensive cereal production, high chemical fertilizer inputs, and use of pesticides in a preventive and systematic way. The group CROP2 includes large farms with diversified integrated crop-livestock systems with beef or dairy cattle (seven and two farms, respectively). They have high crop diversity and benefit from crop and livestock complementarities (e.g., fewer chemical inputs and more manure used as fertilizers). On these farms, pesticide use is adapted to the needs of the crops. The group CROP3 includes medium and small farms with integrated crop-livestock systems with an extensive beef or goat and sheep production (six and two farms, respectively) and one

medium-sized crop farm. They have low crop diversity, mainly due to a high share of grasslands and small wheat plots, and manage their crops using few or no chemical fertilizers or pesticides.

In the second typology on semi-natural area management practices (Table 3), the group SN1 gathers six large farms specialized in beef cattle and four specialized in cash crops. They have few semi-natural grasslands, medium hedge density, and irregular and mainly chemical hedge maintenance. Eight farmers in this group had recently removed some hedgerows. The group SN2 gathers mixed crop-livestock farms (with beef, dairy cattle, or sheep) of variable sizes. They have many permanent grasslands but the lowest hedge density. They maintain hedgerows regularly and chemically. Most of these farmers removed some hedgerows a long time ago. The group SN3 gathers medium and large farms with a mixed crop-livestock system with beef cattle (four farms) or specializing in cash crops (two farms). They have the highest hedge density and a medium share of permanent grassland. They regularly maintain hedgerows without chemicals and have a differentiated management of field margins (reduced chemical

**Table 2.** Descriptive statistics for the three types of cropland management practices identified for typology 1 (mean  $\pm$  SD). See Table 1 for definitions of variable codes.

| Land management practices group | Number of individuals | SIZE          | CROPDIV       | ANNU        | SDI           | ROT_nb        | ROT_L         | ORGAF       | NFW          | PHYTO         |
|---------------------------------|-----------------------|---------------|---------------|-------------|---------------|---------------|---------------|-------------|--------------|---------------|
| CROP 1                          | 9                     | 4.1 $\pm$ 3.3 | 6.1 $\pm$ 1.9 | 87 $\pm$ 15 | 1.8 $\pm$ 0.6 | 2.4 $\pm$ 1.7 | 4.4 $\pm$ 1.7 | 18 $\pm$ 22 | 144 $\pm$ 56 | 3.8 $\pm$ 0.7 |
| CROP 2                          | 8                     | 3.7 $\pm$ 2.0 | 6.7 $\pm$ 1.5 | 55 $\pm$ 20 | 2.6 $\pm$ 0.9 | 2.0 $\pm$ 0.5 | 8.1 $\pm$ 1.4 | 72 $\pm$ 30 | 147 $\pm$ 28 | 2.5 $\pm$ 1.3 |
| CROP 3                          | 9                     | 3.9 $\pm$ 1.5 | 5.2 $\pm$ 2.1 | 47 $\pm$ 33 | 1.5 $\pm$ 0.4 | 1.6 $\pm$ 0.5 | 5.8 $\pm$ 2.3 | 63 $\pm$ 33 | 74 $\pm$ 52  | 1.1 $\pm$ 1.0 |

**Table 3.** Descriptive statistics for the three types of semi-natural areas management practices identified for typology 2 (mean  $\pm$  SD for GRASS and HEDGE\_D; % of farmers in each group with the identified practice for the other indicators). See Table 1 for definitions of variable codes.

| Land management practices group | Number of individuals | GRASS       | HEDGE_D     | RECENT_R | PLANT | EXTENS | FREQ | CHEMI |
|---------------------------------|-----------------------|-------------|-------------|----------|-------|--------|------|-------|
| SN 1                            | 10                    | 12 $\pm$ 9  | 79 $\pm$ 20 | 70       | 0     | 50     | 60   | 20    |
| SN 2                            | 10                    | 38 $\pm$ 26 | 68 $\pm$ 21 | 30       | 0     | 0      | 100  | 70    |
| SN 3                            | 6                     | 14 $\pm$ 11 | 94 $\pm$ 22 | 0        | 83    | 83     | 100  | 50    |

input and tillage; grass strips). Most of them had never removed hedgerows and had even planted some on their farms.

### Comparison of mental models between land management practices groups

#### *Mental models and cropland management practices*

We observed several qualitative differences in the frequency of concepts used in different cropland management practice groups (Fig. 3), although differences were not significant (Tables 4 and 5). CROP1 farmers (i.e., with more intensive practices) highlighted the strong effects of world market prices and agricultural marketing cooperatives on farmers' incomes using verbs such as "ruin", "make us leave", "impact the income", and "remunerate". Most of CROP1 farmers (78%) mentioned the economic role of woodlots ("make profit from", "exploit", and "cut for heating") vs. 13% and 33%, respectively, for CROP2 and CROP3 farmers. Many verbs used by CROP1 farmers referred to economics (12 verbs) vs. only three in CROP2 and two in CROP3 farmers. CROP 2 and CROP3 farmers emphasized the influence of the EU's CAP. Half of the verbs used by CROP2 farmers to describe the influence of the CAP were negative ("impose", "control") and half were positive or neutral ("guide", "sustain"), whereas those used by CROP3 farmers were mostly positive or neutral ("encourage", "support", "make them work", "oxygenate", "subsidize", "keep", "impact"). Half of CROP2 farmers (i.e., with diversified production and integrated practices) highlighted the link between farmers and chemical inputs (vs. 11% in CROP1 and 22% in CROP3 groups). CROP2 farmers also used many verbs related to their knowhow and love of the profession such as "care for", "work on", "be passionate about", and "integrated use of". A majority (56%) of CROP3 farmers (i.e., with extensive practices) mentioned wild fauna vs. 22% in CROP1

**Table 4.** Concepts tested during the comparative analysis of farmer groups based on types of cropland management practices (typology 1).

| Concept category  | CROP1 | CROP2 | CROP3 | <i>P</i> (Fisher's exact test) | Adjusted <i>P</i> |
|---|-------|-------|-------|--------------------------------|-------------------|
| Woods and forests   | 0.889 | 0.125 | 0.444 | 0.0071**                       | 0.206             |
| Farming advisers, farmers' association, and agricultural unions | 0.333 | 0.500 | 0     | 0.061†                         | 0.645             |
| Agricultural production   | 0.333 | 0     | 0     | 0.086†                         | 0.645             |
| Directives and norms  | 0.111 | 0.375 | 0     | 0.089†                         | 0.645             |
| Agricultural holdings   | 0     | 0.375 | 0.222 | 0.150                          | 0.725             |
| New housing developments  | 0.333 | 0     | 0.333 | 0.210                          | 0.725             |
| World market prices   | 0.556 | 0.125 | 0.444 | 0.210                          | 0.725             |
| Investor in photovoltaic energy                                 | 0.333 | 0     | 0.111 | 0.280                          | 0.725             |
| Local urban planning scheme                                     | 0.111 | 0     | 0.333 | 0.280                          | 0.725             |
| Local authorities   | 0.444 | 0.625 | 0.222 | 0.290                          | 0.725             |
| Hedgerows   | 0.222 | 0.625 | 0.444 | 0.290                          | 0.725             |
| Local people  | 0.667 | 0.250 | 0.444 | 0.300                          | 0.725             |
| Upgrading of farm equipment                                     | 0.111 | 0.375 | 0.111 | 0.380                          | 0.768             |
| Wild fauna  | 0.222 | 0.250 | 0.556 | 0.390                          | 0.768             |
| Cultivated plots  | 0.444 | 0.750 | 0.444 | 0.420                          | 0.768             |
| Farm buildings  | 0.444 | 0.125 | 0.333 | 0.440                          | 0.768             |
| Public authorities  | 0.111 | 0.375 | 0.222 | 0.450                          | 0.768             |
| Chemical inputs   | 0.222 | 0.500 | 0.222 | 0.490                          | 0.782             |
| Field paths and roads   | 0.333 | 0.375 | 0.111 | 0.550                          | 0.782             |
| Climate   | 0.111 | 0.125 | 0.333 | 0.570                          | 0.782             |
| Agricultural marketing cooperatives                             | 0.333 | 0.125 | 0.111 | 0.570                          | 0.782             |
| Water   | 0.444 | 0.500 | 0.222 | 0.600                          | 0.782             |
| Common Agricultural Policy and Europe                           | 0.333 | 0.625 | 0.556 | 0.620                          | 0.782             |
| Handover of agricultural holdings issues                        | 0.222 | 0.375 | 0.444 | 0.680                          | 0.822             |
| Grasslands  | 0.889 | 0.750 | 0.778 | 0.840                          | 0.970             |
| Agricultural machines   | 0.333 | 0.375 | 0.222 | 0.870                          | 0.970             |
| Livestock   | 0.667 | 0.625 | 0.667 | 1.000                          | 1.000             |
| Annual crops  | 0.667 | 0.625 | 0.667 | 1.000                          | 1.000             |
| Slopes  | 0.444 | 0.375 | 0.333 | 1.000                          | 1.000             |

\*\**P* < 0.01, \**P* < 0.05, †*P* < 0.10.

and 25% in CROP2 farmers. CROP3 farmers emphasized the role of hedgerows, woodlots, and grasslands in sheltering and feeding wild fauna and highlighted more links between biophysical components than did farmers in the other groups (Fig. 3).

#### *Mental models and semi-natural areas management practices*

SN1 farmers (i.e., intensively maintaining very few semi-natural areas) put significantly more emphasis on the effects of agricultural machinery on the landscape: 70% stressed the effects of machine modernization on agricultural landscape functioning, using verbs highlighting the ever-growing size and power of machinery ("enlarge", "equip", "increase"), whereas none mentioned it in SN2



**Table 5.** Links tested during comparative analysis of farmer groups based on types of cropland management practices (typology 1).

| Link direction                        |                       | CROP1 | CROP2 | CROP3 | <i>P</i> (Fisher's exact test) | Adjusted <i>P</i> |
|---------------------------------------|-----------------------|-------|-------|-------|--------------------------------|-------------------|
| From                                  | To                    |       |       |       |                                |                   |
| Wild fauna                            | Grasslands            | 0     | 0     | 0.444 | 0.022*                         | 0.219             |
| Farmers                               | Woods and forests     | 0.778 | 0.125 | 0.333 | 0.023*                         | 0.219             |
| World market prices                   | Farmers               | 0.444 | 0     | 0.111 | 0.089†                         | 0.501             |
| Farmers                               | Agricultural holdings | 0     | 0.375 | 0.222 | 0.15                           | 0.501             |
| Local people                          | Farmers               | 0.333 | 0.125 | 0     | 0.18                           | 0.501             |
| Farmers                               | Chemical inputs       | 0.111 | 0.5   | 0.222 | 0.21                           | 0.501             |
| Farmers                               | Grasslands            | 0.778 | 0.375 | 0.444 | 0.24                           | 0.501             |
| Woods and forests                     | Wild fauna            | 0.111 | 0     | 0.333 | 0.28                           | 0.501             |
| Agricultural marketing cooperatives   | Farmers               | 0.333 | 0     | 0.111 | 0.28                           | 0.501             |
| Common Agricultural Policy and Europe | Grasslands            | 0.111 | 0     | 0.333 | 0.28                           | 0.501             |
| Common Agricultural Policy and Europe | Farmers               | 0.222 | 0.625 | 0.444 | 0.29                           | 0.501             |
| Farmers                               | Farm buildings        | 0.444 | 0.125 | 0.222 | 0.42                           | 0.665             |
| Farmers                               | Cultivated plots      | 0.333 | 0.625 | 0.444 | 0.55                           | 0.76              |
| Hedgerows                             | Wild fauna            | 0.111 | 0.125 | 0.333 | 0.57                           | 0.76              |
| Farmers                               | Hedgerows             | 0.222 | 0.5   | 0.444 | 0.6                            | 0.76              |
| Farmers                               | Agricultural machines | 0.333 | 0.125 | 0.222 | 0.84                           | 0.998             |
| Livestock                             | Grasslands            | 0.556 | 0.5   | 0.556 | 1                              | 1                 |
| Farmers                               | Livestock             | 0.444 | 0.5   | 0.556 | 1                              | 1                 |
| Farmers                               | Annual crops          | 0.556 | 0.5   | 0.444 | 1                              | 1                 |

\*\**P* < 0.01, \**P* < 0.05, †*P* < 0.10.

and 20% in SN3 groups (Tables 6 and 7). Several other concepts and links differed between SN groups, although not significantly (Fig. 4). SN1 farmers were the only group to mention grass strips (implemented through CAP incentives), although they did not acknowledge any role of hedgerows or grasslands on the landscape. SN1 farmers also omitted wild fauna, whereas SN2 (i.e., with high density of semi-natural grasslands) and SN3 farmers (i.e., with environmentally friendly management of semi-natural areas) mentioned wild fauna (Table 6). SN2 farmers often mentioned hedgerows, woodlots, and grasslands, with several links flowing through these concepts, using verbs evoking their role on the landscape (i.e., ecosystem services) such as “heat”, “shelter”, “pollinate”. They also stressed the effect of economic factors (e.g., world market prices) on cropping plans and the role played by topographic constraints (“slopes”) in the local persistence of grasslands and livestock. SN3 farmers cited “soil quality”, “erosion”, “biodiversity”, and “water quality” more often. They referred to the role of hedgerows for protecting wild fauna and stressed the role of grasslands for preventing soil erosion. They were the only group to mention negative effects of chemical inputs on soil and water quality and on wild fauna. In addition, SN3 farmers emphasized more their cooperation or the need for better cooperation with other users of the territory (“local people”) through verbs such as “talk with” and “do not talk enough with”.

## DISCUSSION

### Constraints influencing practices and mental models

Our results show that farmers with distinct practices highlight economic, regulatory, technical, or biophysical constraints differently. This result is consistent with previous studies in which very constrained contexts have been shown to induce a change in representation (Flament and Rouquette 2001). Farmers with intensive specialized crop farms (CROP1) highlighted economic constraints (market prices), whereas farmers with integrated and extensive mixed crop-livestock farms (CROP2 and CROP3) tended to emphasize regulatory constraints (EU's CAP). Indeed,

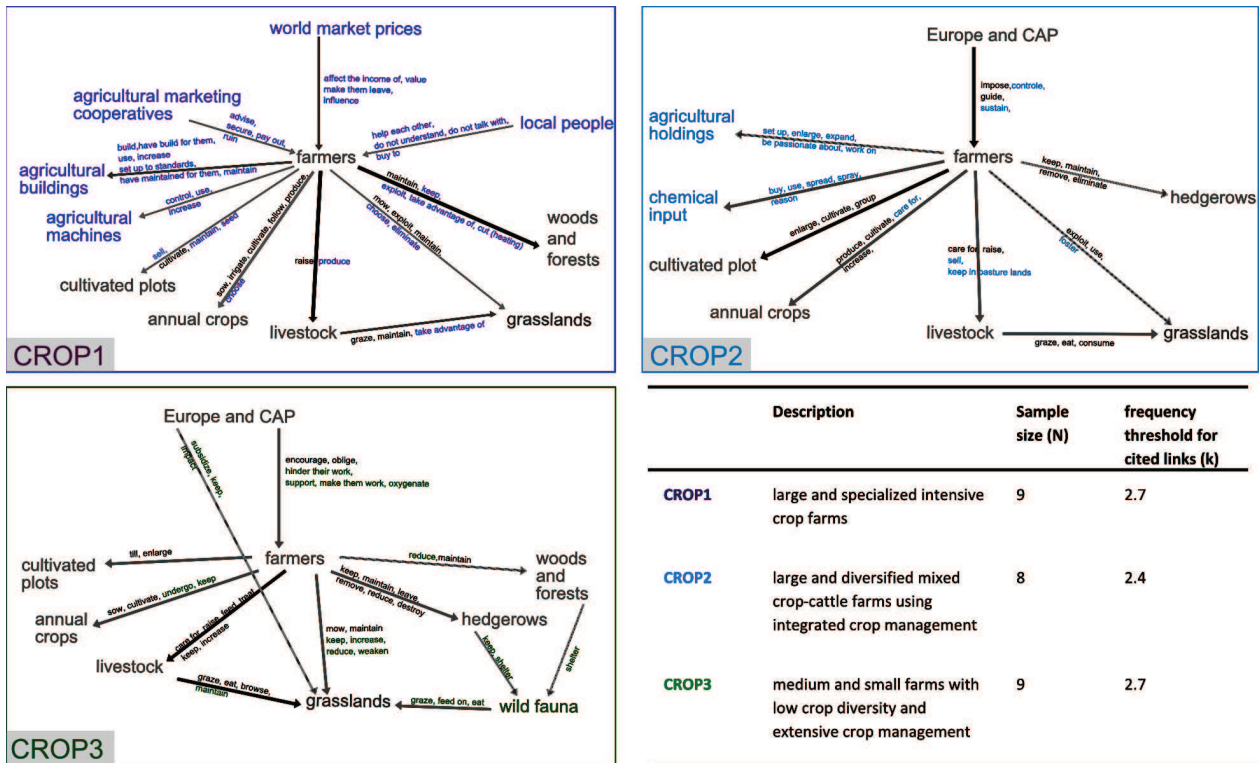
**Table 6.** Concepts tested during the comparative analysis of farmer groups based on types of semi-natural areas management practices (typology 2).

| Concept category   | SN1  | SN2  | SN3  | <i>P</i> (Fisher's exact test) | Adjusted <i>P</i> |
|--|------|------|------|--------------------------------|-------------------|
| Agricultural machines  | 0.70 | 0    | 0.17 | 0.002**                        | 0.060†            |
| Soil quality   | 0    | 0    | 0.50 | 0.008**                        | 0.110             |
| Woods and forests  | 0.50 | 0.80 | 0    | 0.011*                         | 0.110             |
| Slopes   | 0.10 | 0.70 | 0.33 | 0.023*                         | 0.168             |
| Erosion  | 0.10 | 0    | 0.50 | 0.028*                         | 0.168             |
| Biodiversity   | 0    | 0    | 0.33 | 0.046*                         | 0.168             |
| Water quality  | 0    | 0    | 0.33 | 0.046*                         | 0.168             |
| Soil   | 0    | 0    | 0.33 | 0.046*                         | 0.168             |
| Cropping plan  | 0    | 0.40 | 0    | 0.056†                         | 0.168             |
| Grass strips   | 0.40 | 0    | 0    | 0.056†                         | 0.168             |
| Agricultural marketing cooperatives                              | 0    | 0.40 | 0.17 | 0.078†                         | 0.213             |
| Wild fauna   | 0.10 | 0.50 | 0.50 | 0.110                          | 0.275             |
| Chemical inputs  | 0.20 | 0.20 | 0.67 | 0.130                          | 0.300             |
| Annual crops   | 0.40 | 0.80 | 0.83 | 0.180                          | 0.386             |
| Field paths and roads  | 0.30 | 0.10 | 0.50 | 0.220                          | 0.424             |
| Agricultural holdings  | 0.40 | 0.10 | 0    | 0.230                          | 0.424             |
| Livestock  | 0.70 | 0.80 | 0.33 | 0.240                          | 0.424             |
| Cultivated plots   | 0.70 | 0.40 | 0.50 | 0.480                          | 0.789             |
| Directives and norms   | 0.10 | 0.10 | 0.33 | 0.500                          | 0.789             |
| Handover of agricultural holdings issues                         | 0.20 | 0.40 | 0.50 | 0.580                          | 0.809             |
| Climate  | 0.10 | 0.20 | 0.33 | 0.600                          | 0.809             |
| Grasslands   | 0.80 | 0.90 | 0.67 | 0.600                          | 0.809             |
| Farming advisers, farmers' associations, and agricultural unions | 0.40 | 0.20 | 0.17 | 0.620                          | 0.809             |
| Water  | 0.50 | 0.30 | 0.33 | 0.690                          | 0.819             |
| World market prices  | 0.30 | 0.50 | 0.33 | 0.690                          | 0.819             |
| Common Agricultural Policy and Europe                            | 0.40 | 0.50 | 0.67 | 0.710                          | 0.819             |
| Farm buildings   | 0.40 | 0.30 | 0.17 | 0.860                          | 0.956             |
| Local authorities  | 0.40 | 0.40 | 0.50 | 1.000                          | 1.000             |
| Hedgerows  | 0.40 | 0.40 | 0.50 | 1.000                          | 1.000             |
| Local people   | 0.40 | 0.50 | 0.50 | 1.000                          | 1.000             |

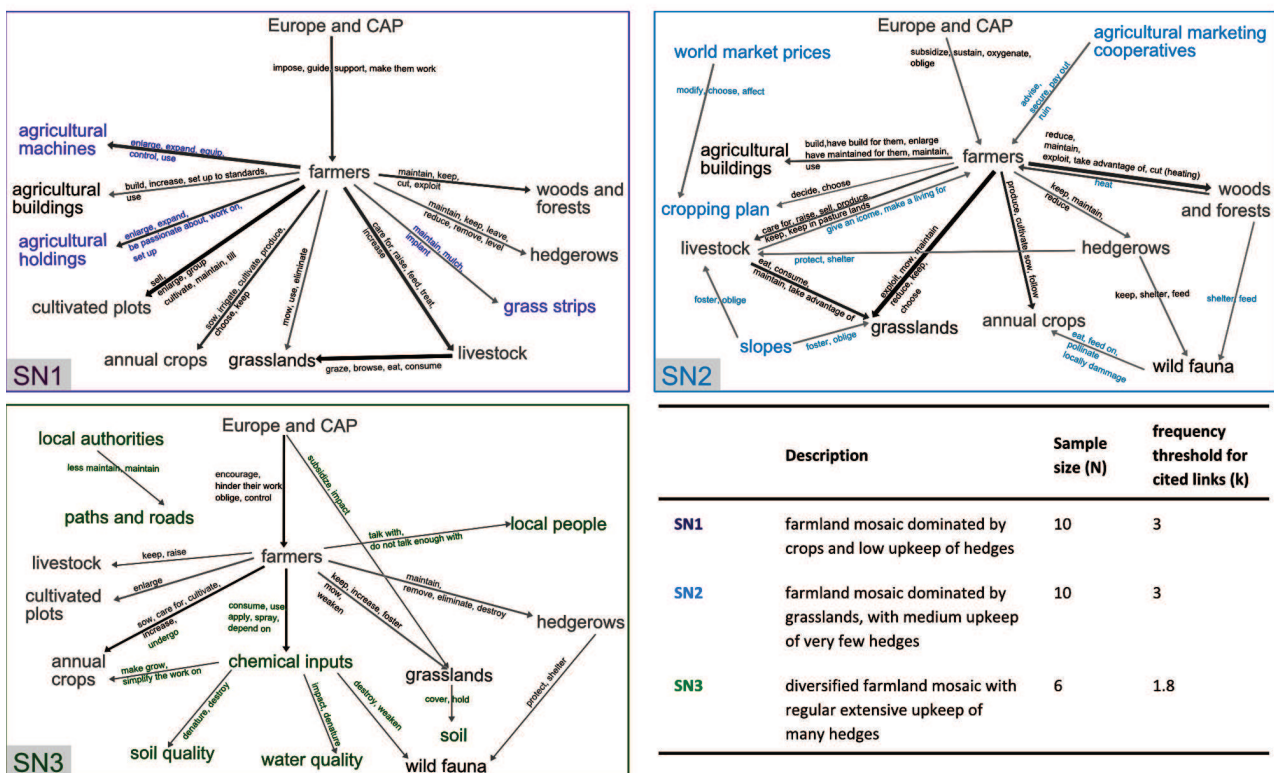
\*\**P* < 0.01, \**P* < 0.05, †*P* < 0.10.

farmers who specialize on few crops are likely to be highly dependent on rather volatile world grain markets, which might have affected their practices and therefore their mental models more deeply than those of farmers with more diversified mixed

**Fig. 3.** Group maps for farmers with distinct cropland management (frequency threshold for links = 0.3). Concepts and links that were frequently cited in only one of the three groups appear in color code for that group (i.e., CROP1, 2, or 3).



**Fig. 4.** Group maps for farmers with distinct management practices for semi-natural areas (frequency threshold for links = 0.3). Concepts and links that were frequently cited in only one of the three groups appear in color code for that group (i.e., SN1, 2, or 3).



**Table 7.** Links tested during the comparative analysis of farmer groups based on types of semi-natural areas management practices (typology 2).

| Link direction                        |                       | SN1 | SN2 | SN3   | P (Fisher's exact test) | Adjusted P |
|---------------------------------------|-----------------------|-----|-----|-------|-------------------------|------------|
| From                                  | To                    |     |     |       |                         |            |
| Farmers                               | Agricultural machines | 0.6 | 0   | 0     | 0.002**                 | 0.0529†    |
| Farmers                               | Woods and forests     | 0.4 | 0.7 | 0     | 0.026*                  | 0.129      |
| Grasslands                            | Soil                  | 0   | 0   | 0.333 | 0.046*                  | 0.129      |
| Chemical inputs                       | Water quality         | 0   | 0   | 0.333 | 0.046*                  | 0.129      |
| Chemical inputs                       | Soil quality          | 0   | 0   | 0.333 | 0.046*                  | 0.129      |
| Chemical inputs                       | Annual crops          | 0   | 0   | 0.333 | 0.046*                  | 0.129      |
| Chemical inputs                       | Wild fauna            | 0   | 0   | 0.333 | 0.046*                  | 0.129      |
| Farmers                               | Farmers               | 0   | 0   | 0.333 | 0.046*                  | 0.129      |
| Woods and forests                     | Farmers               | 0   | 0.4 | 0     | 0.056†                  | 0.129      |
| Farmers                               | Cropping plan         | 0   | 0.4 | 0     | 0.056†                  | 0.129      |
| Farmers                               | Chemical inputs       | 0.2 | 0.1 | 0.667 | 0.063†                  | 0.132      |
| Farmers                               | Cultivated plots      | 0.7 | 0.2 | 0.5   | 0.076†                  | 0.134      |
| Farmers                               | Grasslands            | 0.3 | 0.8 | 0.5   | 0.076†                  | 0.134      |
| Hedgerows                             | Wild fauna            | 0   | 0.3 | 0.333 | 0.13                    | 0.214      |
| Common Agricultural Policy and Europe | Grasslands            | 0   | 0.2 | 0.333 | 0.15                    | 0.23       |
| Livestock                             | Grasslands            | 0.7 | 0.6 | 0.167 | 0.17                    | 0.244      |
| Farmers                               | Local people          | 0.1 | 0   | 0.333 | 0.22                    | 0.294      |
| Farmers                               | Agricultural holdings | 0.4 | 0.1 | 0     | 0.23                    | 0.294      |
| Common Agricultural Policy and Europe | Farmers               | 0.4 | 0.3 | 0.667 | 0.47                    | 0.569      |
| Local authorities                     | Field paths and roads | 0.1 | 0.1 | 0.333 | 0.5                     | 0.575      |
| Farmers                               | Livestock             | 0.6 | 0.5 | 0.333 | 0.71                    | 0.742      |
| Farmers                               | Annual crops          | 0.4 | 0.5 | 0.667 | 0.71                    | 0.742      |
| Farmers                               | Hedgerows             | 0.4 | 0.3 | 0.5   | 0.88                    | 0.88       |

\*\* $P < 0.01$ , \* $P < 0.05$ , † $P < 0.10$ .

crop-livestock farms. The evolution of agricultural machinery driven by farmer training and policy associated with agricultural intensification is often identified as a driver of hedge and field border destruction (Thenail 2002). In our study, farmers who removed hedgerows and did not regularly maintain them (SN1) perceived machinery as an intermediary object between farmers and the landscape. SN1 farmers' emphasis on machinery might therefore represent an a posteriori justification of practices durably affected by path-dependent constraints (Sutherland et al. 2012). Indeed, investing in a new and powerful tractor involves long-term technical and economic constraints. Farmers with the highest proportion of grasslands (SN2) highlighted the role of topographic constraints on the landscape (i.e., a local natural determinism). In our study area, farmers located on steep areas where large machinery cannot operate may have been constrained to maintain permanent grasslands, therefore impairing the intensification of production systems (Choisis et al. 2012). Such constrained practices are likely to have influenced their mental models.

#### Perception of social-ecological interdependencies influencing practices

Our results show that farmers with distinct practices perceive interactions between landscape components and the effect of farmers on agroecosystems differently. Farmers with extensive cropland management practices (CROP3) were the only group aware of ecological cascading effects, i.e., the effect of farmers on landscape components that influence wild fauna, and the effect of wild fauna on agricultural habitats. Farmers with high densities of semi-natural grasslands (SN2) perceived semi-natural components as a source of potential services or disservices for agricultural production. These results are in line with previous studies showing that attachment to anthropocentric values (e.g.,

ecosystem services) can trigger environmentally friendly behavior (Stern 2000). Finally, farmers with the most environmentally friendly management of semi-natural areas (SN3) showed concerns for the potential effects of farmers' actions on nonagricultural components of the landscape, and the cooperation or lack of cooperation with local people, suggesting that they are more aware of social-ecological interdependencies than are the other groups. Farmers with integrated crop-livestock farming systems and cautious use of chemical inputs (CROP2) highlighted farmers' know-how and their role as "stewards" of the agricultural landscape by "caring for" landscape components. This result is consistent with the fact that farmers' representation of their profession is likely to influence their practices (Weiss et al. 2006).

These results are generally consistent with the hypothesis that perception of social-ecological interdependencies is likely to influence farmers' practices and cooperation (Leeuwis and Van den Ban 2004). However, the differences we observed were mostly nonsignificant, which may suggest, as already advocated by Michel-Guillou and Moser (2006), that differences in representations of the environment lie in less consensual parts of individual representations. This hypothesis is also consistent with Abric (2011), who states that less consensual elements are more likely to justify contrasted commitment to different behaviors despite common belief about more consensual knowledge.

#### Implications for further development of our conceptual and mixed methods framework

Our theoretical and methodological framework allowed us to highlight complex relationships between mental models and practices. Moreover, our results revealed high interindividual heterogeneity in both land management practices and individual cognitive maps, even after the aggregation process. These

interindividual differences may have been overlooked in studies using either more indirect elicitation techniques through researchers' coding of semi-structured interviews, direct drawing with pre-defined concepts, collective elicitation via focus groups, or simple a priori dichotomous criteria to differentiate practices. Our results therefore confirm the value of our interdisciplinary methodological framework compared to these other methods. Grenier and Dudzinska-Przesmitzki (2015) have also highlighted drawbacks of existing methods and proposed a multi-method mental model elicitation that consists of three consecutive elicitation techniques. However, those authors did not discuss the potential drawbacks of such a method on sample size. Our study suggests that sample size is likely to be a critical issue when dealing with high interindividual heterogeneity. We therefore believe that simple methods such as the one developed in our framework should be favored to obtain a pertinent sample size.

Our methodological framework relies heavily on the aggregation process, which is obviously influenced by researchers' subjectivity. Fairweather (2010) suggested that using a list of predefined concepts before building the cognitive maps avoids the qualitative aggregation process that relies too much on the ability of the researcher to match the respondents' meanings. However, providing a list of factors implicitly influences and constrains what farmers can possibly express and strongly depends on researchers' appreciation of the topic as well (selection of concepts, level of precision chosen for concepts, etc.). Hence, both approaches depend on the interpretation made by researchers. However, the aggregation we propose maximizes transparency of the researchers' interpretation throughout the process, therefore allowing an evaluation of the quality of the interpretation, and ultimately, a better understanding of the influence of the aggregation process on mental models and how to take into account "situated knowledge" (Ostrom 2005). In our study, we conducted the aggregation process for concepts. However, the same process could be applied to verbs used by farmers to qualify links between concepts. We think that the conceptual framework we propose offers several avenues for improvement and represents a valuable first step toward a more robust theory linking farmers' mental models and their practices.

#### **Implications for future agricultural policy**

Our results suggest that relationships between mental models and practices are two-way relationships: constrained practices can influence mental models, and awareness of social-ecological interdependencies in mental models can in turn influence less constrained practices. This finding highlights the importance of taking both relationships into account when designing agricultural policies.

One consideration is that policies should aim at increasing social-ecological interdependencies awareness. Our results are in line with Stern and colleagues' theory (Stern and Dietz 1994, Stern 2000), which states that anthropocentric values such as ecosystem services and specific knowledge about the consequences of one's actions on the environment are both likely to enhance environmentally friendly behavior. Furthermore, our results suggest that farmers that are most aware of social-ecological interdependencies and consequences of farming on the environment have more "biodiversity friendly" practices than those who perceive the utilitarian properties of semi-natural

landscape components (ecosystem services). They also seem more concerned by cooperation with other stakeholders of the landscape. These results suggest, as already highlighted by Leeuwis and Van den Ban (2004), that increasing social-ecological interdependencies awareness is likely to have a positive influence on farmers' behavior. Consequently, sharing different stakeholders' knowledge of the various social-ecological interdependencies and promoting environmental pragmatism such as an ecological solidarity framework (Mathevet et al. 2016) rather than solely focusing on an ecosystem services utilitarian construct could lead to more efficient agricultural policies.

In addition, future policy should take into account the complex role of various constraints in farmers' mental models and consider alleviating them. For instance, technological factors that frame farmers' actions on the environment often create path dependencies that impair the resilience of SESs such as agricultural landscapes (Santos 1997). When promoting technological change, public policy can make technological means become ends in themselves (Ellul et al. 1964), which strongly frame landscape transformations. The technological regime fostered by the first CAP and more recently by the liberalization of agricultural markets and international competition may have created the conditions that abolish the local control of landscape evolution. In light of our results, it is possible that recent agri-environmental policy guidelines for EU farming systems that are mostly based on an ecological point of view, and which do not fully integrate the social, economic, and cultural dimensions of land-use change (e.g., Pe'er et al. 2014), will contribute to increase farmers' feelings of a lack of control of their actions by applying top-down compulsory choices designed by the technological and scientific spheres.

#### **CONCLUSION**

We propose a novel interdisciplinary framework grounded in mental models and farming system theories to explore the relationship between farmers' mental models and their land management practices that takes into account the diversity of farmers' ways of thinking and ways of farming. Our results suggest that such a conceptual and methodological framework could greatly contribute to a better understanding of SES complexities. It also highlights the need for further improvements and, more particularly, the need to identify optimal trade-offs between detailed qualitative analyses of interindividual heterogeneity and quantitative analysis of general patterns. Our case study suggests that farmers' ways of thinking and ways of farming are linked. Farmers' representations of the complexity of agricultural landscape functioning seem to influence their ways of farming. However, practices that are under strong constraints are also likely to influence farmers' representations. Our study therefore suggests that increasing farmers' awareness of social-ecological interdependencies may not be sufficient to induce a change in practices or increase their acceptance of top-down landscape management prescriptions. Indeed, increasing the efficiency of agricultural public policies will only be achieved by taking into account path-dependency processes and reducing distal technological-economical obstacles to biodiversity friendly landscape management. This will require changing our own ways of thinking about agricultural policies by developing bottom-up processes for policy design which truly integrate farmers' representations.

Responses to this article can be read online at:  
<http://www.ecologyandsociety.org/issues/responses.php/8281>

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#### LITERATURE CITED

Abric, J.-C. 2011. *Pratiques sociales et représentations*. Presses Universitaires de France, Paris, France.

Ahnström, J., J. Höckert, H. L. Bergeå, C. A. Francis, P. Skelton, and L. Hallgren. 2009. Farmers and nature conservation: What is known about attitudes, context factors and actions affecting conservation? *Renewable Agriculture and Food Systems* 24 (1):38-47. <http://dx.doi.org/10.1017/S1742170508002391>

Batáry, P., L. V. Dicks, D. Kleijn, and W. J. Sutherland. 2015. The role of agri-environment schemes in conservation and environmental management. *Conservation Biology* 29(4):1006-1016. <http://dx.doi.org/10.1111/cobi.12536>

Benjamini, Y., and Y. Hochberg. 1995. Controlling the false discovery rate: a practical and powerful approach to multiple testing. *Journal of the Royal Statistical Society: Series B (Methodological)* 57(1):289-300. <http://www.jstor.org/stable/2346101>

Biggs, D., N. Abel, A. T. Knight, A. Leitch, A. Langston, and N. C. Ban. 2011. The implementation crisis in conservation planning: could “mental models” help? *Conservation Letters* 4(3):169-183. <http://dx.doi.org/10.1111/j.1755-263X.2011.00170.x>

Calatayud, F., S. Ladet, G. Balent, and L. Fahrig. 2012. A mapping method of crop composition and configuration to study their effect on biodiversity of European agricultural landscapes. Pages 308-311 in J. Gensel, D. Josselin, and D. Vandenbroucke, editors. *Proceedings of the AGILE'2012 International Conference on Geographic Information Science*. AGILE, Avignon, France.

Carley, K., and M. Palmquist. 1992. Extracting, representing, and analyzing mental models. *Social Forces* 70(3):601-636. <http://dx.doi.org/10.1093/sf/70.3.601>

Choisis, J.P., C. Thévenet, and A. Gibon. 2012. Analyzing farming systems diversity: a case study in south-western France. *Spanish Journal of Agricultural Research* 10(3):605-618. <http://dx.doi.org/10.5424/sjar/2012103-533-11>

ComMod, O. Barreteau, M. Antona, P. D'Aquino, S. Aubert, S. Boissau, F. Bousquet, W. Dare, M. Etienne, C. L. Page, R. Mathevet, G. Trebail, and J. Weber. 2003. Our companion

modelling approach. *Journal of Artificial Societies and Social Simulation* 6(2):1. [online] URL: <http://jasss.soc.surrey.ac.uk/6/2/1.html>

Craik, K. 1943. *The nature of explanation*. Cambridge University Press, London, UK.

Crandell, T. L., N. A. Kleid, and C. Soderston. 1996. Empirical evaluation of concept mapping: a job performance aid for writers. *Technical Communication* 43(2):157-163.

Dany, L., and J.-C. Abric. 2007. Distance à l'objet et représentations du cannabis. [Distance to the object and representations of cannabis]. *Revue Internationale de Psychologie Sociale* 20(3):77-104.

Dany, L., I. Urdapilleta, and G. L. Monaco. 2015. Free associations and social representations: some reflections on rank-frequency and importance-frequency methods. *Quality and Quantity* 49(2):489-507. <http://dx.doi.org/10.1007/s11135-014-0005-z>

Darnhofer, I., S. Bellon, B. Dedieu, and R. Milestad. 2011. Adaptiveness to enhance the sustainability of farming systems. Pages 45-58 in E. Lichtfouse, M. Hamelin, M. Navarrete, and P. Debaeke, editors. *Sustainable agriculture volume 2*. Springer, Dordrecht, The Netherlands. [http://dx.doi.org/10.1007/978-94-007-0394-0\\_4](http://dx.doi.org/10.1007/978-94-007-0394-0_4)

de Sainte Marie, C. 2014. Rethinking agri-environmental schemes. A result-oriented approach to the management of species-rich grasslands in France. *Journal of Environmental Planning and Management* 57(5):704-719. <http://dx.doi.org/10.1080/09640568.2013.763772>

Diniz, F. H., K. Kok, M. A. Hoogstra-Klein, and B. Arts. 2015. Mapping future changes in livelihood security and environmental sustainability based on perceptions of small farmers in the Brazilian Amazon. *Ecology and Society* 20(2):26. <http://dx.doi.org/10.5751/es-07286-200226>

Dray, S., A. B. Dufour, and D. Chessel. 2007. The ade4 package — II: two-table and K-table methods. *R News* 7(2):47-52. [online] URL: <http://pbil.univ-lyon1.fr/ade4/article/rnews2/rnews2.pdf>

Ellul, J., J. Wilkinson, and R. K. Merton. 1964. *The technological society*. Vintage, New York, New York, USA.

Errington, A. J., R. Gasson, and J. B. Dent. 1994. Farming systems and the farm family business. Pages 181-192 in M. J. McGregor and J. B. Dent, editors. *Rural and farming systems analysis: European perspectives*. CABI, Wallingford, UK.

Etienne, M., D. R. Du Toit, and S. Pollard. 2011. ARDI: a co-construction method for participatory modeling in natural resources management. *Ecology and Society* 16(1):44. [online] URL: <http://www.ecologyandsociety.org/vol16/iss1/art44/>

Fairweather, J. 2010. Farmer models of socio-ecologic systems: application of causal mapping across multiple locations. *Ecological Modelling* 221(3):555-562. <http://dx.doi.org/10.1016/j.ecolmodel.2009.10.026>

Flament, C. 1987. Pratiques et représentations sociales. Pages 143-150 in J.-L. Beauvois, R.-V. Joule, and J.-M. Monteil, editors. *Perspectives cognitives et conduites sociales: théories implicites et conflits cognitifs*. Delval, Fribourg, Switzerland.

- Flament, C., and M.-L. Rouquette. 2001. Pratiques sociales et dynamique des représentations. [Social practices and dynamics of representations]. Pages 43-58 in P. Moliner, editor. *La dynamique des représentations sociales*. Presses Universitaires de Grenoble, Grenoble, France.
- Gibon, A. 1999. Etudier la diversité des exploitations agricoles pour appréhender les transformations locales de l'utilisation de l'espace: l'exemple d'une vallée du versant Nord des Pyrénées centrales. *Options Méditerranéennes B* 27:197-215.
- Gibon, A., A. R. Sibbald, J. C. Flamant, P. Lhoste, R. Revilla, R. Rubino, and J. T. Sørensen. 1999. Livestock farming systems research in Europe and its potential contribution for managing towards sustainability in livestock farming. *Livestock Production Science* 61(2-3):121-137. [http://dx.doi.org/10.1016/s0301-6226\(99\)00062-7](http://dx.doi.org/10.1016/s0301-6226(99)00062-7)
- Grenier, R. S., and D. Dudzinska-Przesmitzki. 2015. A conceptual model for eliciting mental models using a composite methodology. *Human Resource Development Review* 14 (2):163-184. <http://dx.doi.org/10.1177/1534484315575966>
- Guimelli, C. 1998. *Chasse et nature en Languedoc: étude de la dynamique d'une représentation sociale chez des chasseurs languedociens*. L'Harmattan, Paris, France.
- Henle, K., D. Alard, J. Clitherow, P. Cobb, L. Firbank, T. Kull, D. McCracken, R. F. A. Moritz, J. Niemelä, M. Rebane, D. Wascher, A. Watt, and J. Young. 2008. Identifying and managing the conflicts between agriculture and biodiversity conservation in Europe—a review. *Agriculture, Ecosystems and Environment* 124 (1-2):60-71. <http://dx.doi.org/10.1016/j.agee.2007.09.005>
- Hoffman, M., M. Lubell, and V. Hillis. 2014. Linking knowledge and action through mental models of sustainable agriculture. *Proceedings of the National Academy of Sciences* 111 (36):13016-13021. <http://dx.doi.org/10.1073/pnas.1400435111>
- Johnson-Laird, P. N. 1980. Mental models in cognitive science. *Cognitive Science* 4(1):71-115. [http://dx.doi.org/10.1207/s15516709cog0401\\_4](http://dx.doi.org/10.1207/s15516709cog0401_4)
- Johnson-Laird, P. N., V. Girotto, and P. Legrenzi. 1998. Mental models: a gentle guide for outsiders. *Sistemi Intelligenti* 9(68):33.
- Jones, N. A., H. Ross, T. Lynam, and P. Perez. 2014. Eliciting mental models: a comparison of interview procedures in the context of natural resource management. *Ecology and Society* 19 (1):13. <http://dx.doi.org/10.5751/es-06248-190113>
- Kearney, A. R., and S. Kaplan. 1997. Toward a methodology for the measurement of knowledge structures of ordinary people: the conceptual content cognitive map (3CM). *Environment and Behavior* 29(5):579-617. <http://dx.doi.org/10.1177/0013916597295001>
- Kelemen, E., G. Nguyen, T. Gomiero, E. Kovács, J.-P. Choisis, N. Choisis, M. G. Paoletti, L. Podmaniczky, J. Ryschawy, J.-P. Sarthou, F. Herzog, P. Dennis, and K. Balázs. 2013. Farmers' perceptions of biodiversity: lessons from a discourse-based deliberative valuation study. *Land Use Policy* 35:318-328. <http://dx.doi.org/10.1016/j.landusepol.2013.06.005>
- Kiers, H. A. L. 1991. Simple structure in component analysis techniques for mixtures of qualitative and quantitative variables. *Psychometrika* 56(2):197-212. <http://dx.doi.org/10.1007/bf02294458>
- Köbrich, C., T. Rehman, and M. Khan. 2003. Typification of farming systems for constructing representative farm models: two illustrations of the application of multi-variate analyses in Chile and Pakistan. *Agricultural Systems* 76(1):141-157. [http://dx.doi.org/10.1016/s0308-521x\(02\)00013-6](http://dx.doi.org/10.1016/s0308-521x(02)00013-6)
- Kremen, C., and A. Miles. 2012. Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. *Ecology and Society* 17 (4):40. <http://dx.doi.org/10.5751/ES-05035-170440>
- Landais, E. 1998. Modelling farm diversity: new approaches to typology building in France. *Agricultural Systems* 58(4):505-527. [http://dx.doi.org/10.1016/s0308-521x\(98\)00065-1](http://dx.doi.org/10.1016/s0308-521x(98)00065-1)
- Leeuwis, C., and A. Van den Ban. 2004. *Communication for rural innovation: rethinking agricultural extension*. Third edition. Blackwell, Oxford, UK. <http://dx.doi.org/10.1002/9780470995235>
- Lynam, T., and K. Brown. 2011. Mental models in human-environment interactions: theory, policy implications, and methodological explorations. *Ecology and Society* 17(3):24. <http://dx.doi.org/10.5751/es-04257-170324>
- Mądry, W., Y. Mena, B. Roszkowska-Mądra, D. Gozdowski, R. Hryniewski, and J. M. Castel. 2013. An overview of farming system typology methodologies and its use in the study of pasture-based farming system: a review. *Spanish Journal of Agricultural Research* 11(2):316-326. <http://dx.doi.org/10.5424/sjar/2013112-3295>
- Mathevet, R., M. Etienne, T. Lynam, and C. Calvet. 2011. Water management in the Camargue Biosphere Reserve: insights from comparative mental models analysis. *Ecology and Society* 16 (1):43. [online] URL: <http://www.ecologyandsociety.org/vol16/iss1/art43/>
- Mathevet, R., J. D. Thompson, C. Folke, and F. S. Chapin III. 2016. Protected areas and their surrounding territory: socioecological systems in the context of ecological solidarity. *Ecological Applications* 26(1):5-16. <http://dx.doi.org/10.1890/14-0421>
- Mathevet, R., C. Vuillot, and C. Sirami. 2014. Effective nature conservation on farmland: Can we change our own models, not just the farmers? *Conservation Letters* 7(6):575-576. <http://dx.doi.org/10.1111/conl.12064>
- Matson, P. A., W. J. Parton, A. G. Power, and M. J. Swift. 1997. Agricultural intensification and ecosystem properties. *Science* 277 (5325):504-509. <http://dx.doi.org/10.1126/science.277.5325.504>
- Michel-Guillou, E., and G. Moser. 2006. Commitment of farmers to environmental protection: from social pressure to environmental conscience. *Journal of Environmental Psychology* 26(3):227-235. <http://dx.doi.org/10.1016/j.jenvp.2006.07.004>
- Moscovici, S. 1961. *La psychanalyse, son image et son public: étude sur la représentation sociale de la psychanalyse*. Presses Universitaires de France, Paris, France.
- Mottet, A., S. Ladet, N. Coqué, and A. Gibon. 2006. Agricultural land-use change and its drivers in mountain landscapes: a case study in the Pyrenees. *Agriculture, Ecosystems and Environment* 114(2-4):296-310. <http://dx.doi.org/10.1016/j.agee.2005.11.017>
- Novak, J. D., and A. J. Cañas. 2008. *The theory underlying concept maps and how to construct and use them*. Technical Report IHMC

- CmapTools 2006-01 revision 01-2008. Institute for Human and Machine Cognition (IHMC), Pensacola, Florida. [online] URL: <http://cmap.ihmc.us/docs/theory-of-concept-maps>
- Ostrom, E. 2005. *Understanding institutional diversity*. Princeton University Press, Princeton, New Jersey, USA.
- Özesmi, U., and S. Özesmi. 2003. A participatory approach to ecosystem conservation: fuzzy cognitive maps and stakeholder group analysis in Uluabat Lake, Turkey. *Environmental Management* 31(4):518-531. <http://dx.doi.org/10.1007/s00267-002-2841-1>
- Özesmi, U., and S. L. Özesmi. 2004. Ecological models based on people's knowledge: a multi-step fuzzy cognitive mapping approach. *Ecological Modelling* 176(1-2):43-64. <http://dx.doi.org/10.1016/j.ecolmodel.2003.10.027>
- Pasher, J., S. W. Mitchell, D. J. King, L. Fahrig, A. C. Smith, and K. E. Lindsay. 2013. Optimizing landscape selection for estimating relative effects of landscape variables on ecological responses. *Landscape Ecology* 28(3):371-383. <http://dx.doi.org/10.1007/s10980-013-9852-6>
- Pe'er, G., L. V. Dicks, P. Visconti, R. Arlettaz, A. Báldi, T. G. Benton, S. Collins, M. Dieterich, R. D. Gregory, F. Hartig, K. Henle, P. R. Hobson, D. Kleijn, R. K. Neumann, T. Robijns, J. Schmidt, A. Shwartz, W. J. Sutherland, A. Turbé, F. Wulf, and A. V. Scott. 2014. EU agricultural reform fails on biodiversity. *Science* 344(6188):1090-1092. <http://dx.doi.org/10.1126/science.1253425>
- Pinto-Correia, T., R. Gustavsson, and J. Pirnat. 2006. Bridging the gap between centrally defined policies and local decisions – towards more sensitive and creative rural landscape management. *Landscape Ecology* 21(3):333-346. <http://dx.doi.org/10.1007/s10980-005-4720-7>
- Plieninger, T., T. Kizos, C. Bieling, L. Le Dü-Blayo, M.-A. Budniok, M. Bürgi, C. L. Crumley, G. Girod, P. Howard, J. Kolen, T. Kuemmerle, G. Milcinski, H. Palang, K. Trommler, and P. H. Verburg. 2015. Exploring ecosystem-change and society through a landscape lens: recent progress in European landscape research. *Ecology and Society* 20(2):5. <http://dx.doi.org/10.5751/es-07443-200205>
- Puech, C., J. Baudry, and S. Aviron. 2013. Effet des pratiques biologiques et conventionnelles sur les communautés d'insectes auxiliaires dans les paysages agricoles. [Effect of organic and conventional practices on the insects natural enemies communities in agricultural landscapes.] *Innovations Agronomiques* 32:401-412. [online] URL: [http://www6.inra.fr/ciag/content/download/5158/40490/file/Vol32\\_Puech%20et%20al.pdf](http://www6.inra.fr/ciag/content/download/5158/40490/file/Vol32_Puech%20et%20al.pdf)
- R Core Team. 2014. *R: a language and environment for statistical computing*. R Foundation for Statistical Computing, Vienna, Austria.
- Robinson, R. A., and W. J. Sutherland. 2002. Post-war changes in arable farming and biodiversity in Great Britain. *Journal of Applied Ecology* 39(1):157-176. <http://dx.doi.org/10.1046/j.1365-2664.2002.00695.x>
- Ross, N. 2002. Cognitive aspects of intergenerational change: mental models, cultural change, and environmental behavior among the Lacandon Maya of southern Mexico. *Human Organization* 61(2):125-138. <http://dx.doi.org/10.17730/humo.61.2.9bhqghxvpth2qebc>
- Ryschawy, J., N. Choisis, J. P. Choisis, A. Joannon, and A. Gibon. 2012. Mixed crop-livestock systems: an economic and environmental-friendly way of farming? *Animal* 6(10):1722-1730. <http://dx.doi.org/10.1017/S1751731112000675>
- Santos, M. 1997. *La nature de l'espace: technique et temps, raison et émotion*. M.-H. Tiercelin, translator. L'Harmattan, Paris, France.
- Simpson, E. H. 1949. Measurement of diversity. *Nature* 163:688. <http://dx.doi.org/10.1038/163688a0>
- Stern, P. C. 2000. New environmental theories: toward a coherent theory of environmentally significant behavior. *Journal of Social Issues* 56(3):407-424. <http://dx.doi.org/10.1111/0022-4537.00175>
- Stern, P. C., and T. Dietz. 1994. The value basis of environmental concern. *Journal of Social Issues* 50(3):65-84. <http://dx.doi.org/10.1111/j.1540-4560.1994.tb02420.x>
- Sutherland, L.-A., R. J. F. Burton, J. Ingram, K. Blackstock, B. Slee, and N. Gotts. 2012. Triggering change: towards a conceptualisation of major change processes in farm decision-making. *Journal of Environmental Management* 104:142-151. <http://dx.doi.org/10.1016/j.jenvman.2012.03.013>
- Thenail, C. 2002. Relationships between farm characteristics and the variation of the density of hedgerows at the level of a micro-region of bocage landscape. Study case in Brittany, France. *Agricultural Systems* 71(3):207-230. [http://dx.doi.org/10.1016/S0308-521X\(01\)00048-8](http://dx.doi.org/10.1016/S0308-521X(01)00048-8)
- Vanwindekens, F. M., P. V. Baret, and D. Stilmant. 2014. A new approach for comparing and categorizing farmers' systems of practice based on cognitive mapping and graph theory indicators. *Ecological Modelling* 274:1-11. <http://dx.doi.org/10.1016/j.ecolmodel.2013.11.026>
- Vanwindekens, F. M., D. Stilmant, and P. V. Baret. 2013. Development of a broadened cognitive mapping approach for analysing systems of practices in social-ecological systems. *Ecological Modelling* 250:352-362. <http://dx.doi.org/10.1016/j.ecolmodel.2012.11.023>
- Weiss, K., G. Moser, and C. Germann. 2006. Perception de l'environnement, conceptions du métier et pratiques culturelles des agriculteurs face au développement durable. [Perception of the environment, professional conceptions and cultural behaviours of farmers in favor of sustainable development.] *Revue Européenne de Psychologie Appliquée/European Review of Applied Psychology* 56(2):73-81. <http://dx.doi.org/10.1016/j.erap.2005.04.003>

## **Appendix 1.** Land management practices methods and results

### ETHNO-TECHNICAL SURVEY ON FARMERS' LAND-MANAGEMENT PRACTICES

Interviews took place in farmers' house. They lasted between 1 and 3 hours. Maps showing the respondent's plots in the landscape were created from the CAP land unit data base and printed beforehand. They were used during the interview as a facilitator in the discussion about land management practices. The following topics were addressed:

- (1) General information : legal status, condition when setting-up, education, number of workers, cooperation with other farmers and agricultural advisers;
- (2) Main productions and side-productions (product transformation and hosting on the farm) and recent history of changes in productions;
- (3) Land management at the farm level: UAA, irrigation and drainage systems, sloppy areas, soil type, far-off lands management, wooded areas ;
- (4) Crops and grasslands management : type, number, areas, crop rotations as well as history of changes and choices rationale ;
- (5) Livestock systems management : type of production , size, variety, animal husbandry, type of feed ;
- (6) Land management at the plot level: type of tillage, fertilization (mineral and organic), use of plant health products (including information on expenditures) ;
- (7) Field borders management: frequency, type of management, planting and removal, rationale of choice and type of subsidies received (if applicable) ;
- (8) CAP subsidies and participation to Agri-Environmental Scheme;
- (9) Future project for the farmer and the farm.

Besides, the density of hedges and slopes (>30%) amongst each farmer's lands was evaluated through a GIS by FC.

### TYOLOGY METHODS

Groups were identified using a partition of the dendrogram from the AHC (Agglomerative Hierarchical Clustering). We observed high levels of inter-individual heterogeneity in farmers' practices, both for crop management and semi-natural areas management. As a result, we selected three groups for each typology to maximize both intra-group homogeneity and inter-group dissimilarities (Köbrich et al. 2003).

Details of the multivariate analysis outputs for each typology (crop and semi-natural areas management) are provided below.

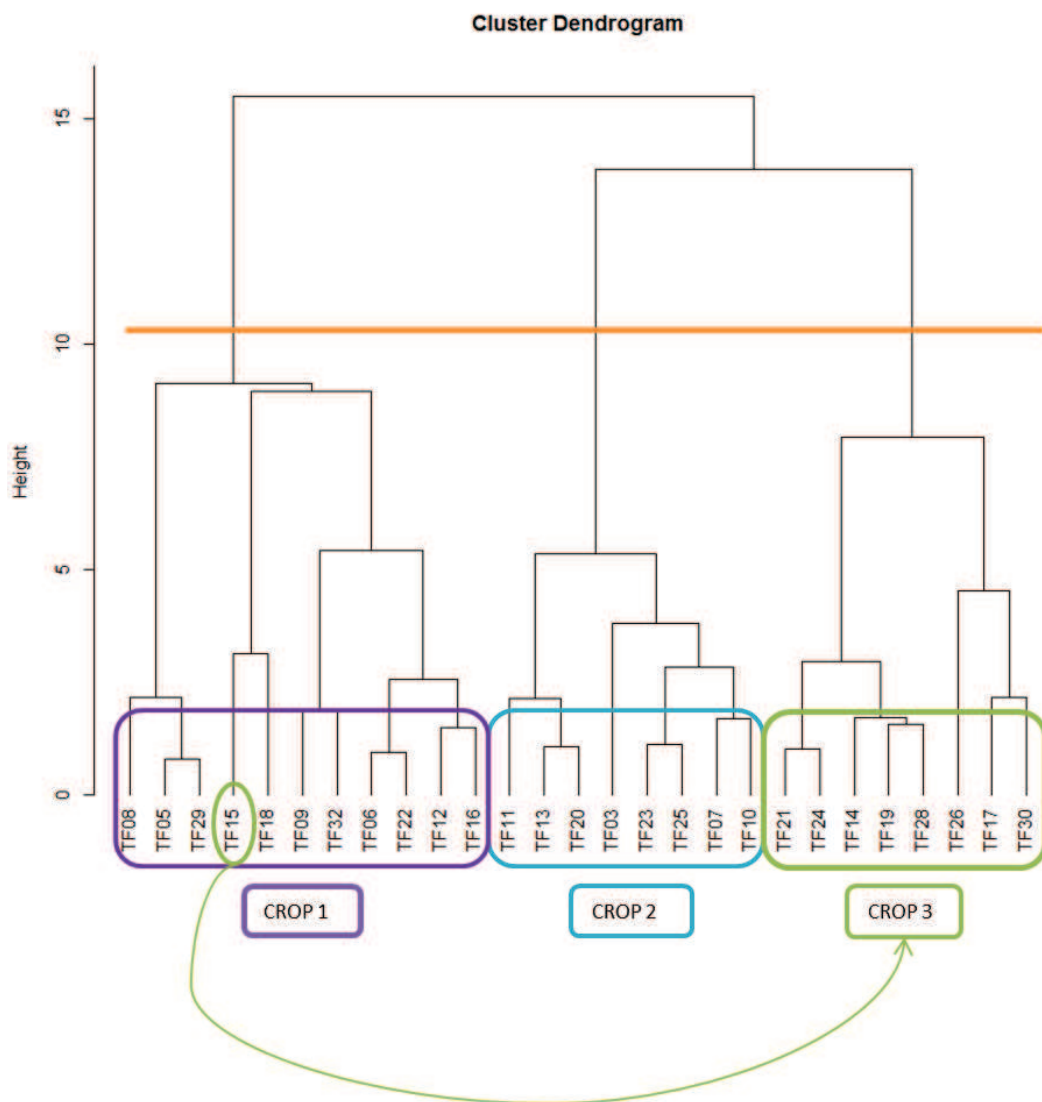
#### **Typology 1: Crop management practices**

We selected 4 axes that represented 69% of the total inertia.



**Table A1.1 Contribution of the indicators used for Typology 1 on the 4 axes (see Table 1 in the main text for the meaning of indicators' codes)**

| INDICATORS | AXE 1 | AXE 2 | AXE 3 | AXE 4 |
|------------|-------|-------|-------|-------|
| SIZE       | 92    | 87    | 2197  | 734   |
| CROPDIV    | 8     | 2378  | 74    | 88    |
| SDI        | 148   | 1283  | 764   | 2318  |
| ROT_L      | 844   | 1566  | 2     | 597   |
| ROT_nb     | 195   | 491   | 1630  | 123   |
| ANNU       | 2485  | 12    | 323   | 274   |
| SHALL      | 14    | 1189  | 626   | 1206  |
| NO T       | 4     | 340   | 179   | 345   |
| ORGAF      | 1565  | 65    | 127   | 835   |
| NFW        | 751   | 81    | 590   | 2808  |
| NFG        | 23    | 42    | 2874  | 19    |
| PHYTO      | 2129  | 359   | 291   | 35    |
| SYST       | 344   | 1102  | 10    | 25    |
| INTEG      | 3     | 963   | 92    | 44    |
| NO P       | 1395  | 41    | 220   | 551   |



**Figure A1.1 Cluster Dendrogram obtained from the AHC on the scores of farmers on the axes of the multivariate analysis on cropland management practices**

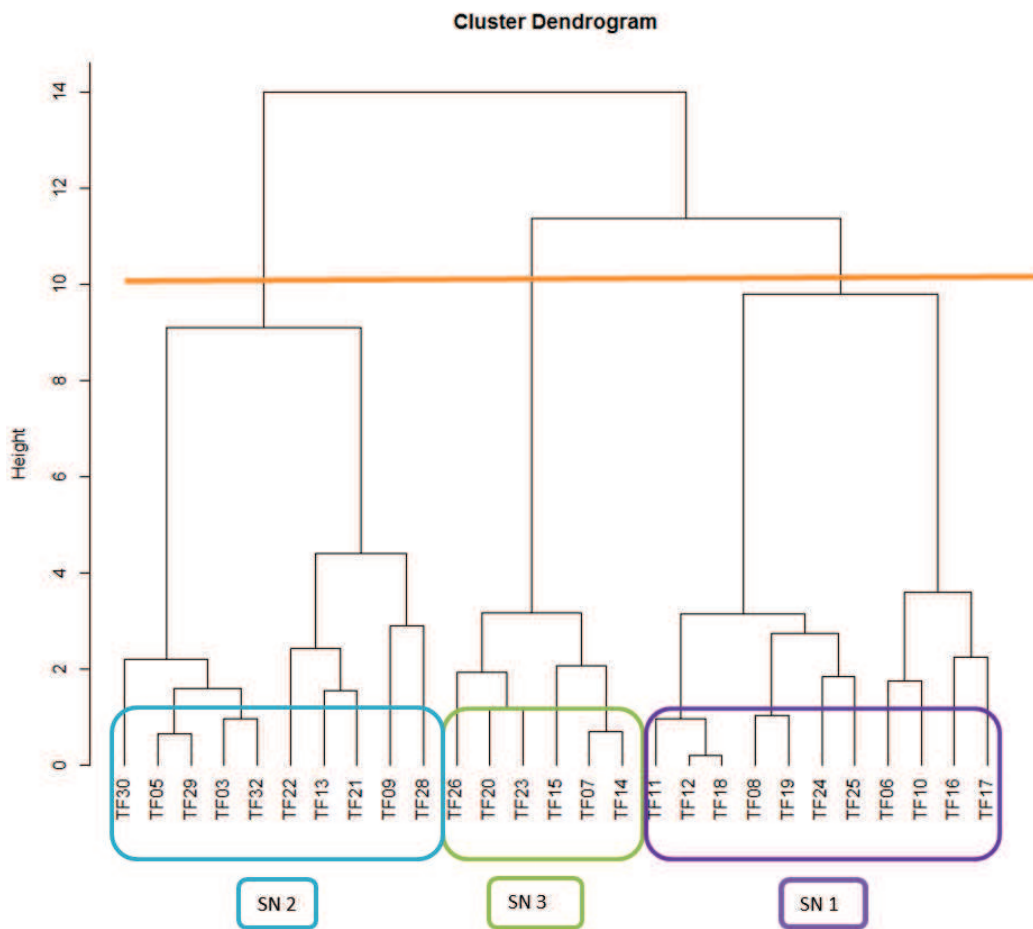
TF15 (Farmer number 15) was clustered in the CROP1 group mainly because of his high share of annual crops in his cropping plan. However, this farmer has a very extensive farming system with no use of pesticide, no fertilization of temporary grasslands and no tillage, which makes his crop management closer to farmers in CROP3. We thus included TF15 in CROP3 management practices instead of CROP1.

## Typology 2: semi-natural areas management practices

We selected 4 axes that represented 68% of the total inertia.

**Table A1.2 Contribution of the indicators used for Typology 2 on the 4 axes (see Table 1 in the main text for the meaning of indicators' codes**

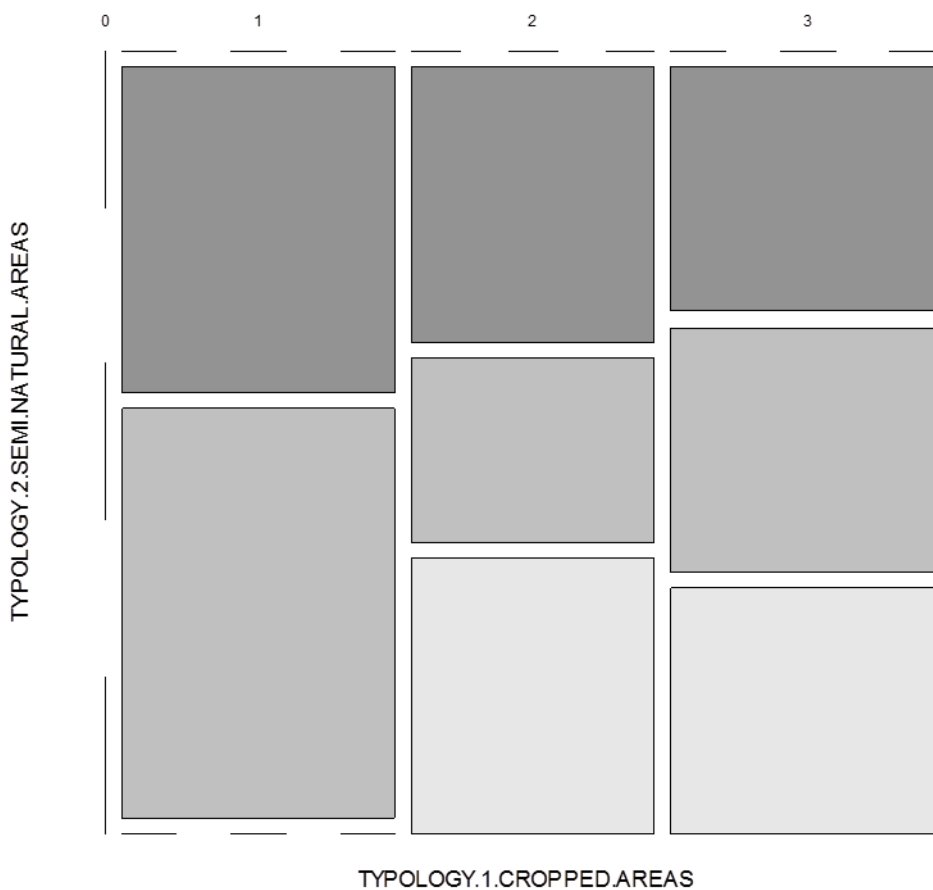
| INDICATORS | AXE 1 | AXE 2 | AXE 3 | AXE 4 |
|------------|-------|-------|-------|-------|
| RECENT_R   | 1     | 27    | 444   | 3730  |
| OLD_R      | 318   | 60    | 260   | 3056  |
| PLANT      | 621   | 371   | 3041  | 74    |
| FREQ       | 97    | 499   | 163   | 52    |
| RARE       | 426   | 2196  | 719   | 227   |
| CHEMI      | 919   | 117   | 373   | 702   |
| MECHA      | 736   | 93    | 299   | 562   |
| PROPPP     | 2976  | 170   | 218   | 735   |
| UNDIF      | 614   | 727   | 758   | 17    |
| EXTENS     | 1404  | 136   | 732   | 199   |
| NO_GS      | 213   | 3393  | 19    | 184   |
| AES        | 568   | 745   | 1857  | 159   |
| NO_AES     | 199   | 261   | 650   | 56    |
| HEDGE_D    | 908   | 1204  | 468   | 248   |



**Figure A1.2 Cluster Dendrogram obtained from the AHC on the scores of famers on the axes of the multivariate analysis on semi-natural areas management practices.**

## COMPLEMENTARY RESULTS

We investigated the correlation between Typology 1 and Typology 2 to assess whether farmers' crop area management are related to their semi-natural area management. We found that semi-natural areas management practices types were not significantly different between cropland management practices types (two-sided Fisher Exact test p value =0.114). This result suggests that semi-natural area management and cropland management are two relatively independent sub-systems that need to be analyzed separately. However, none of the farmers with most intensive cropland management practices (CROP1) belonged to the group of farmers with extensive semi-natural area management practices (SN3).



**Figure A1.3 Comparison of the distributions of farmers between groups based on cropped land management practices similarities and groups based on semi-natural area management practices similarities. Fisher Exact Test for Count Data p-value = 0.114.**

## LITERATURE CITED

- Köbrich, C., T. Rehman, and M. Khan. 2003. Typification of farming systems for constructing representative farm models: two illustrations of the application of multivariate analyses in Chile and Pakistan. *Agricultural Systems* 76(1):141–157.

## Appendix 2. Individual and group mental models methods and results

### MENTAL MODELS ELICITATION INTERVIEWS

Interviews took place at farmers' house. They lasted on average 1 hour and a half (+/- 38 min). Before starting, the area of study was presented on a map with only rivers and main cities and the methodology was explained with an example. The overarching question was: "how would you describe the functioning of the local agricultural landscape?" It was then split into three specific sub-questions to help the respondents formalize the representation of their individual mental models: (1) who are the main stakeholders that have an impact on the local agricultural landscape? (2) What are the main biophysical components of the local agricultural landscape? (3) What are the main processes and drivers of change that changed or that you foresee are likely to change the local agricultural landscape within a decade timeframe? Each of these questions led the respondent to create three lists of items that were written as they cited them. Farmers were free to cite any concepts they liked within the frame described above, no predefined categories or examples related to the subject of the interview were given. However, in order for them to familiarize with the elicitation method a simple model representing the interviewer's mental model of the "interview system" was showed and explained beforehand. The next step consisted in iteratively drawing a network by linking the previously cited item. The instructions for this drawing step were: describe how do these concepts interacts for you. How do stakeholders interact with each other and with the landscape components, how are components interrelated and how do they impact stakeholders, how do drivers of change influence the system?

The respondents gave instructions to the interviewer on how to link the concepts by indicating concepts to be linked, link direction) and named the links through an action verb. This fourth step was completed using a laptop and the Cmap Tool software (Florida Institute for Human and Machine Cognition (IHMC) <http://cmap.ihmc.us/>). It allowed building and amending the concept map in front of the interviewee who was able to control directly that his words were correctly understood. Respondents could select concepts from the list they had established beforehand with no obligation of selecting all of the items and they were allowed to add some if they felt it necessary.

Below is an example of results from an interview (in French):

- (1) Who are the main stakeholders that have an impact on the local agricultural landscape?
  - Agriculteurs
  - Europe
- (2) What are the main biophysical components of the local agricultural landscape?
  - Forêt
  - Forme des terrains (relief)
  - Rivières
  - Talus
  - Champs
  - Faune et flore sauvage
- (3) What are the main processes and drivers of change that changed or that you foresee are likely to change the local agricultural landscape within a decade timeframe?
  - Manque de main d'œuvre agricole
  - Plus de céréales
  - Moins d'élevage

- Plus de pollution (produits chimiques)

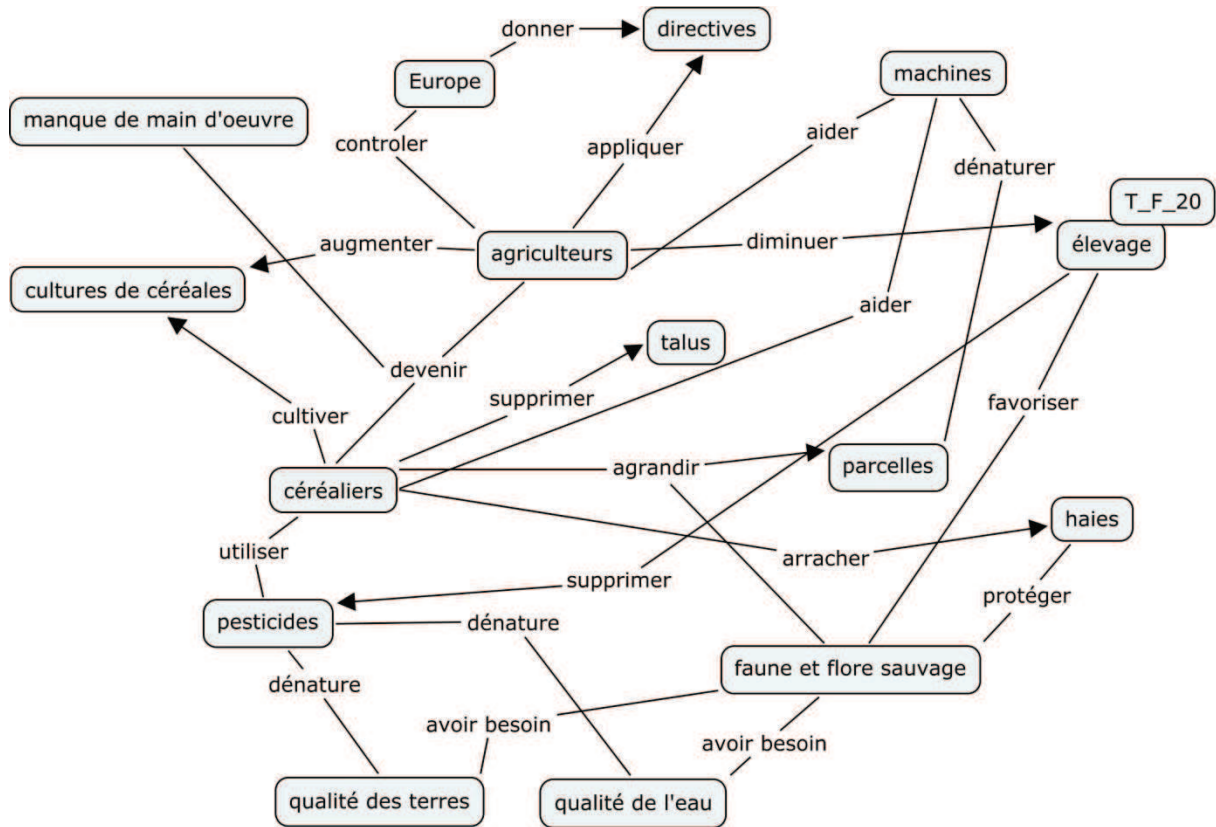


Figure A2.1 Example of an original ICM

### CONCEPTS CATEGORIZATION

During the IMMS elicitation interviews, farmers were free to cite, select and add any concept they liked to their conceptual map and link them in their own way. This led to a great variety of concepts and links included in the ICMs. As we were interested in similarities between ICMs, we condensed concepts that had a close meaning into a broader combined category using qualitative aggregation (Özesmi and Özesmi 2003). Following Carley's and Palmquist's (1992) idea that, within an IMM, the meaning of a concept is embedded in its links to other concepts, we ensured the reliability of the categorization process by systematically referring to ICMs to check whether the meaning of the category was consistent with the links flowing through the concepts. We then consolidated the categories by cross checking them with three different researchers (CV, AG, RM) until an agreement was reached. Below are some examples of aggregated categories (Table A2.1).

**Table A2.1. Examples of the qualitative aggregation process: for each broader category, the original words uttered by farmers we included in this broader category are indicated (in French)**

| <b>BROADER CATEGORY</b>                | <b>ORIGINAL CONCEPTS (in French)</b>  |
|--|---|
| farmers                                | agriculteurs; agriculteurs et éleveurs ; anciens agriculteurs ;<br>céréaliers ; éleveurs ; jeunes agriculteurs ; paysans ; polyculture<br>élevage   |
| local authorities                      | CG ; collectivités ; communautés de communes ; communes ;<br>conseil général ; conseil municipal ; employés de la voirie ; maire ;<br>mairies ; politiques  |
| agricultural marketing<br>cooperatives | techniciens coop ; coopératives   |
| Europe and CAP                         | Bruxelles ; Europe ; PAC  |
| local population                       | citadins ; citoyens ; habitants ; habitants locaux ; néoruraux ;<br>nouveaux arrivants ; promeneurs ; retraités ; familles des villages ;<br>gens de l'extérieur ; villages   |
| livestock                              | animaux ; animaux d'élevage ; bovins lait ; bovins viande ; élevage<br>; moutons ; troupeaux ; vaches ; animaux domestiques ; bovins ;<br>vaches à lait ; vaches à viande ; vaches et moutons   |
| grass strips                           | bandes enherbées  |
| agricultural buildings                 | bâtiments agricoles ; bâtiments d'élevage ; construction neuves ;<br>constructions agricoles ; constructions agricoles photovoltaïques ;<br>hangar photovoltaïque ; stabulation   |
| woods and forests                      | bois ; forêts   |
| paths and roads                        | chemins communaux ; routes ; routes et abords des routes ; voirie   |
| annual crops                           | blé ; céréales ; céréales d'hiver ; colza ; cultures ; cultures de<br>céréales ; cultures sèches ; maïs ; céréales à paille ; céréales de<br>printemps ; maïs tournesol ; récoltes de printemps (maïs, soja) ;<br>soja ; surfaces en cultures ; tournesol |
| agricultural holdings                  | exploitations agricoles ; petites exploitations   |
| wild fauna                             | abeilles ; abeilles (petite noire) ; chevreuil et lièvre ; faune sauvage<br>; gibier ; insectes ; lapins ; lièvres ; blaireaux ; chevreuil ; limaces ;<br>palombes ; perdreaux ; poissons ; ragondins ; sangliers   |
| hedgerows                              | arbres ; haies ; haies pérennes ; talus   |
| chemical inputs                        | chimie ; désherbants ; engrais ; engrais minéraux ; pesticides ;<br>phyto ; produits ; produits phyto   |
| agricultural machines                  | engins agricoles ; machines agricoles ; matériel agricole ; tracteurs   |
| cultivated plots                       | champs ; grandes parcelles bien parallèles ; parcelles ; terre<br>cultivées ; terres agricoles  |
| grasslands                             | cultures en herbe ; enherbement ; herbe ; prairies ; prairies<br>artificielles ; prairies naturelles ; prairies temporaires ; prairies<br>permanentes ; prés verts  |
| slopes                                 | coteaux ; fortes pentes ; parcelles difficiles d'accès ; pentes ; relief ;<br>terre accidentées ; terre difficiles à travailler ; terres en coteaux plus<br>de 20% ; topographie ; vallons très pentus  |



|                                |  |
|--------------------------------|--|
| world market prices            | adaptation aux marchés ; augmentation du prix des céréales ; cours du marché de la viande ; cours du marché des céréales ; marchés ; prix ; prix de vente ; prix des céréales ; baisse des prix de vente ; contexte financier ; prix du marché   |
| water quality                  | qualité de l'eau   |
| soil quality                   | bonne terre ; couleur du sol ; qualité des terres ; matière organique ; vie du sol   |
| production costs               | augmentation du prix du pétrole ; couts de production ; couts de revient ; couts de transport ; prix du gazole   |
| problems in farms transmission | départs à la retraite ; départs à la retraite sans successeur ; diminution du nombre d'exploitations ; installations ; reprise par les petits ; transmission des exploitations ; vieillissement des agriculteurs ; départs des agriculteurs ; difficulté à s'installer pour les jeunes |
| upgrading of farm equipment    | grossissement du matériel ; mécanisation ; modernisation du matériel   |

## COMPARISON OF ICM STRUCTURES

For each typology, we looked at differences between groups in terms of ICM structure, using graph theory indicators (Vanwindekens et al. 2014). We used indicators such as concept centrality (total number of links going from or going to a concept), indegree (total number of links going to a concept) and outdegree (total number of links going from a concept) and compared the distribution of these indicators between groups using a Kruskal-Wallis rank sum test. We found no statistically significant differences in terms of concept centrality, indegree and outdegree after controlling for false positive and false negative detection rates using Benjamini-Hochberg p-value adjustment technique.

## LITERATURE CITED

- Özesmi, U., and S. Özesmi. 2003. A participatory approach to ecosystem conservation: fuzzy cognitive maps and stakeholder group analysis in Uluabat Lake, Turkey. *Environmental management* 31(4):518–531.
- Vanwindekens, F. M., P. V. Baret, and D. Stilmant. 2014. A new approach for comparing and categorizing farmers' systems of practice based on cognitive mapping and graph theory indicators. *Ecological Modelling* 274:1–11.