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Research

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 (Mądry 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' IMMs. 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.

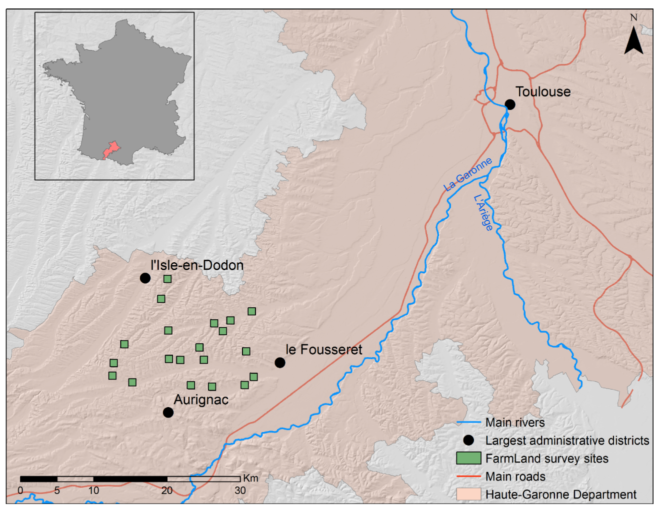
To detect elements in each group map that are most likely to be related to farmers' land management practices type, we propose to consider the consensual part of each group map, i.e., to consider only concepts and links cited frequently (e.g., cited by > 30% of farmers) within a group, following Fairweather (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 km². 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 ± 65 ha (mean ± SE). In beef cattle farms, herd sizes ranged from 40 to 160 livestock units (LU), with a mean of 93 ± 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 IMMs 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 IMMs). 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

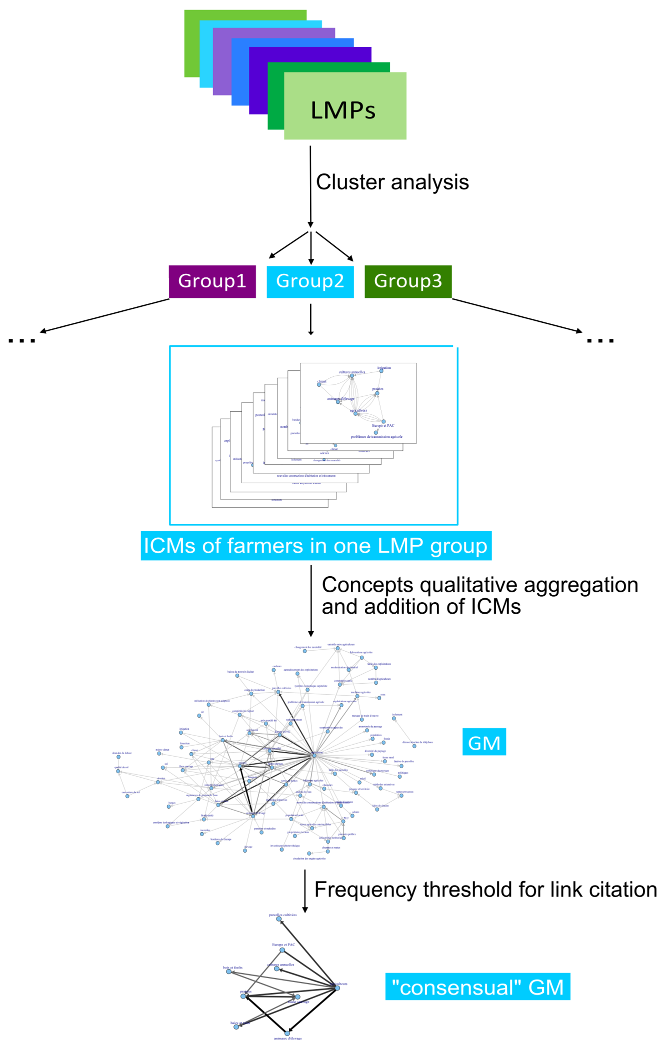
Land management practices groups

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 α = 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	Systematic and preventive
		INTEG	Integrated treatments or crop monitored to adjust treatments
		NO P	No pesticides
	Type of tillage	DEEP	Deep tillage
		SHALL	Shallow tillage
		NO T	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	Removed within the past 5 years
		OLD_R	removed before the past 5 yr
		PLANT	Planting and no removal
	Type of grass strips management	UNDIF	Undifferentiated management from the neighboring crop
		EXTENS	Extensive uptake distinct from the neighboring crop
		NO GS	No grass strips
	Frequency of hedges upkeep	FREQ	Frequent
		RARE	Rare
	Type of hedges upkeep practices	CHEMI	Chemical upkeep
		MECHA	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 ± 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 ± 3.3	6.1 ± 1.9	87 ± 15	1.8 ± 0.6	2.4 ± 1.7	4.4 ± 1.7	18 ± 22	144 ± 56	3.8 ± 0.7
CROP 2	8	3.7 ± 2.0	6.7 ± 1.5	55 ± 20	2.6 ± 0.9	2.0 ± 0.5	8.1 ± 1.4	72 ± 30	147 ± 28	2.5 ± 1.3
CROP 3	9	3.9 ± 1.5	5.2 ± 2.1	47 ± 33	1.5 ± 0.4	1.6 ± 0.5	5.8 ± 2.3	63 ± 33	74 ± 52	1.1 ± 1.0

Table 3. Descriptive statistics for the three types of semi-natural areas management practices identified for typology 2 (mean ± 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 ± 9	79 ± 20	70	0	50	60	20
SN 2	10	38 ± 26	68 ± 21	30	0	0	100	70
SN 3	6	14 ± 11	94 ± 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 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).

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	*P* (Fisher's exact test)	Adjusted *P*
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

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

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						
From	To	CROP1	CROP2	CROP3	*P* (Fisher's exact test)	Adjusted *P*
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

$^{**}P < 0.01$, $^{*}P < 0.05$, $^{\dagger}P < 0.10$.

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,

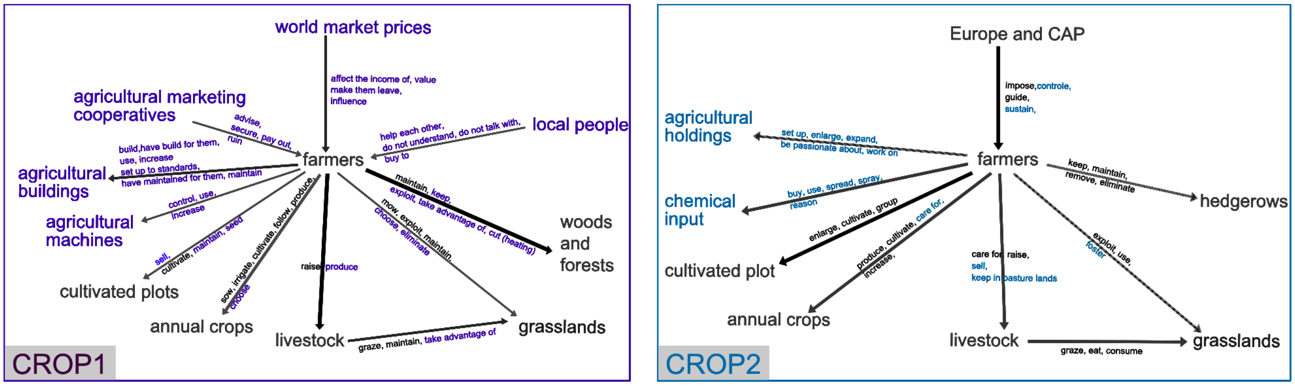
Table 6. Concepts tested during the comparative analysis of farmer groups based on types of semi-natural areas management practices (typology 2).

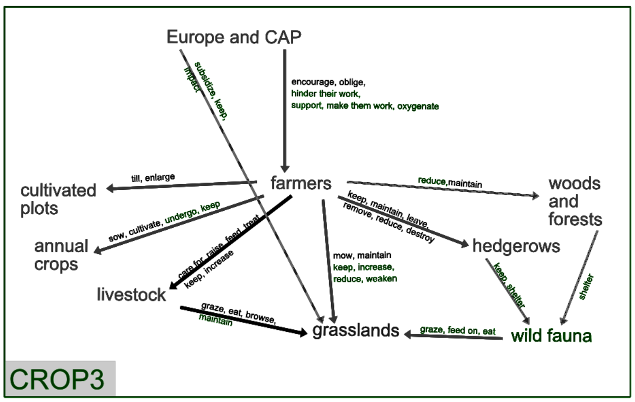
Concept category	SN1	SN2	SN3	*P* (Fisher's exact test)	Adjusted *P*
Agricultural machines	0.70	0	0.17	0.002**	0.060†
Soil quality	0	0	0.50	0.008**	0.110
Woods and forests	0.50	0.80	0	0.011*	0.110
Slopes	0.10	0.70	0.33	0.023*	0.168
Erosion	0.10	0	0.50	0.028*	0.168
Biodiversity	0	0	0.33	0.046*	0.168
Water 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

$^{**}P < 0.01$, $^{*}P < 0.05$, $^{\dagger}P < 0.10$.

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

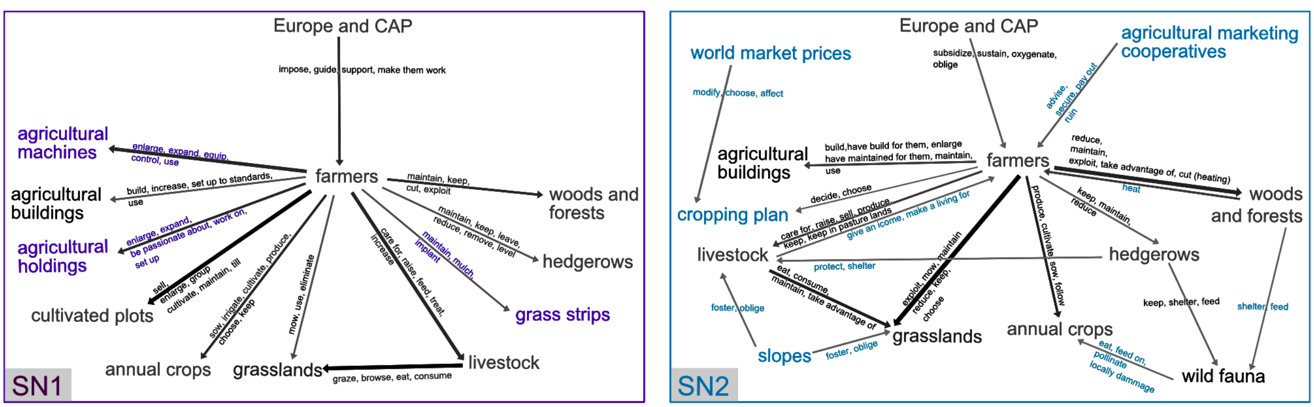
Fig. 3. Group maps for farmers with distinct cropland management (frequency threshold for links = 0.3). Concepts and links that were frequently cited in only one of the three groups appear in color code for that group (i.e., CROP1, 2, or 3).

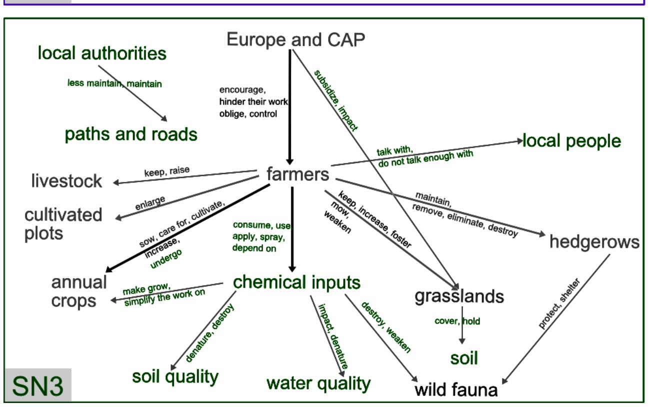




	Description	Sample size (N)	frequency threshold for cited links (k)
CROP1	large and specialized intensive crop farms	9	2.7
CROP2	large and diversified mixed crop-cattle farms using integrated crop management	8	2.4
CROP3	medium and small farms with low crop diversity and extensive crop management	9	2.7

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).





	Description	Sample size (N)	frequency threshold for cited links (k)
SN1	farmland mosaic dominated by crops and low upkeep of hedges	10	3
SN2	farmland mosaic dominated by grasslands, with medium upkeep of very few hedges	10	3
SN3	diversified farmland mosaic with regular extensive upkeep of many hedges	6	1.8

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

Link direction						
From	To	SN1	SN2	SN3	*P* (Fisher's exact test)	Adjusted *P*
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

$^{**}P < 0.01$, $^{*}P < 0.05$, $^{\dagger}P < 0.10$.

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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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.

TYPOLOGY 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

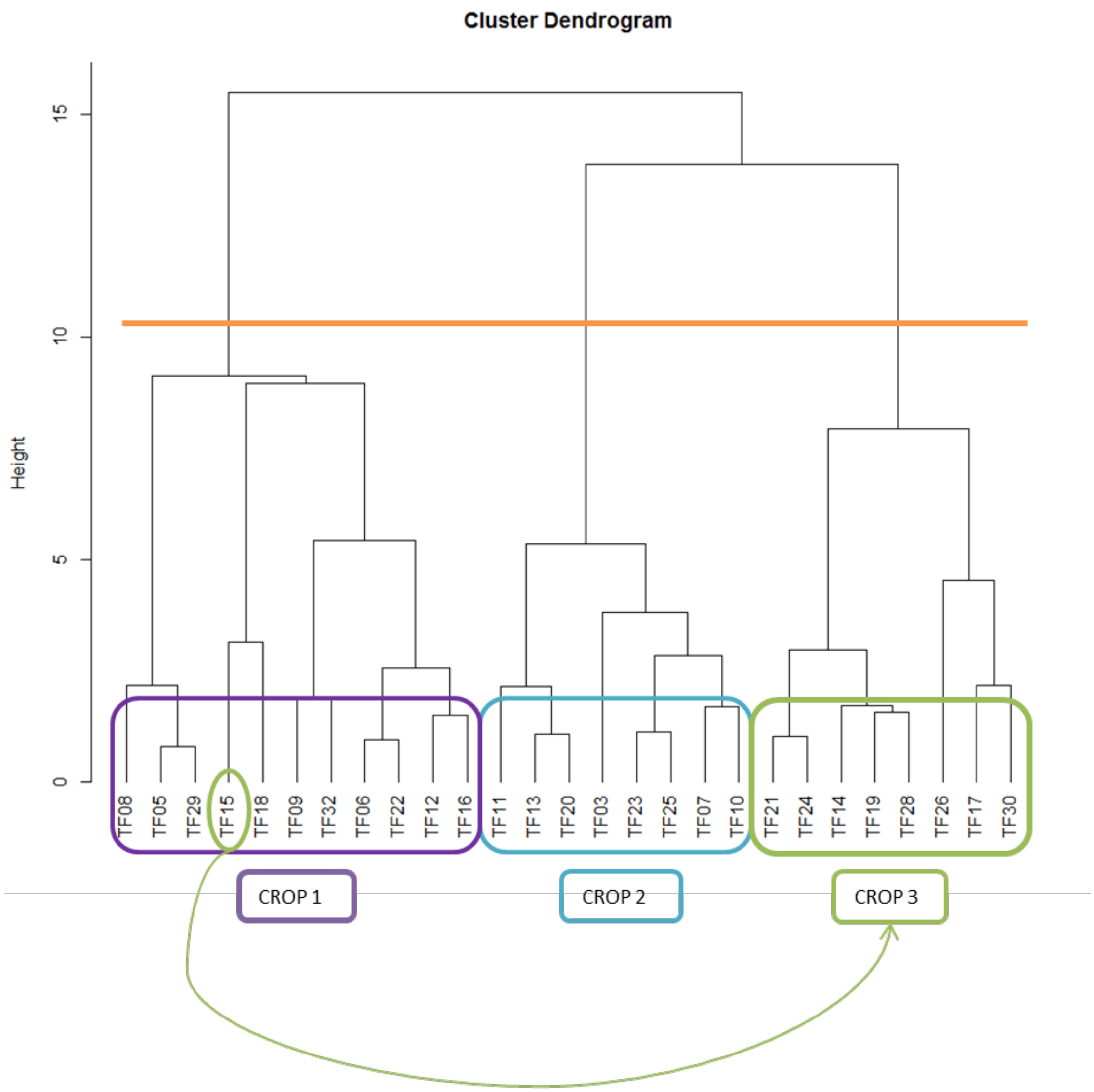

Figure A1.1 Cluster Dendrogram obtained from the AHC on the scores of famers on the axes of the multivariate analysis on cropland management practices

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

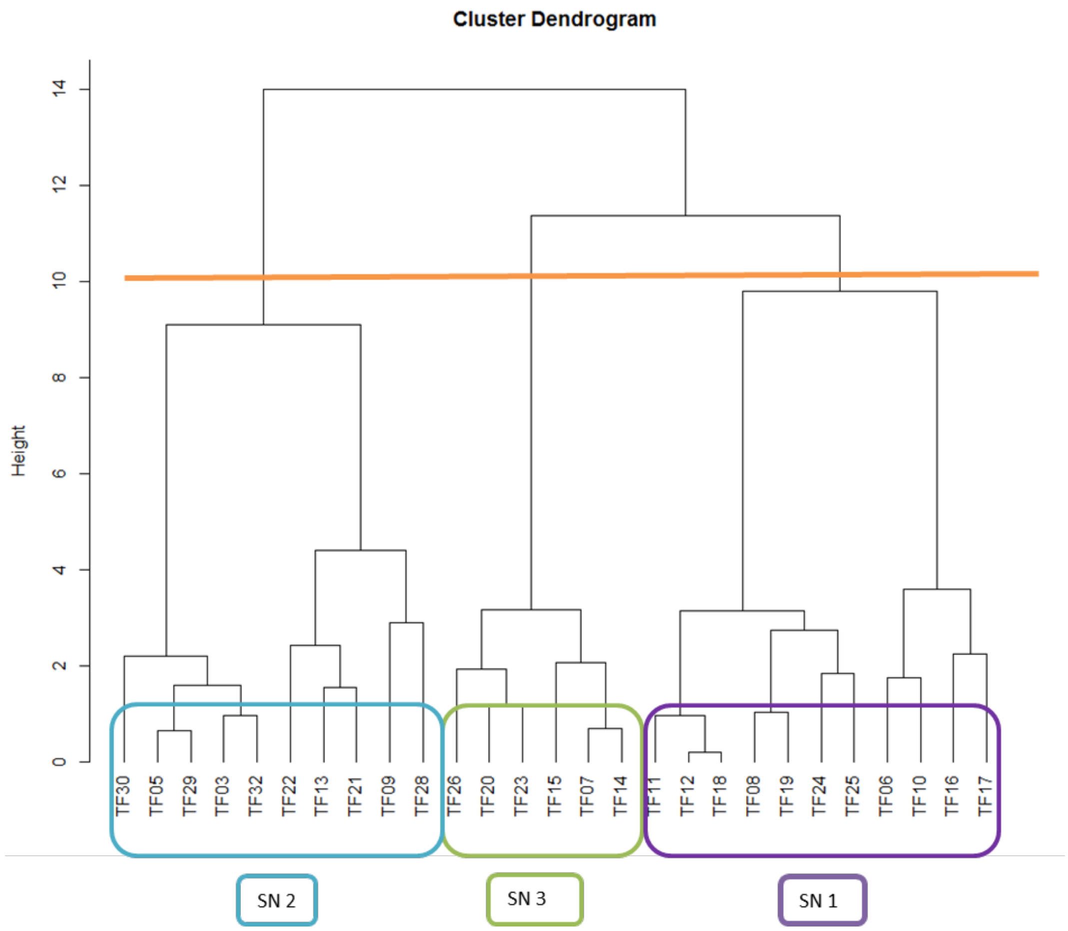

Figure A1.2 Cluster Dendrogram obtained from the AHC on the scores of famers on the axes of the multivariate analysis on semi-natural areas management practices.

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).

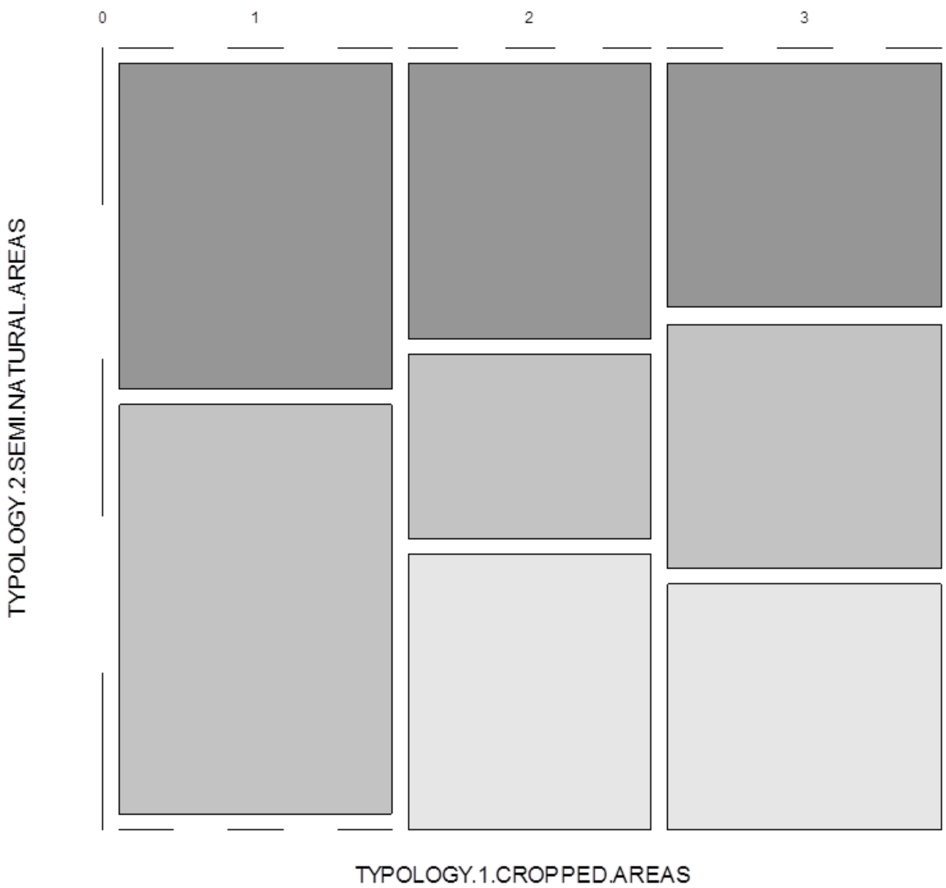

Figure A1.3 Comparison of the distributions of farmers between groups based on cropped land management practices similarities and groups based on semi-natural area management practices similarities. Fisher Exact Test for Count Data p-value = 0.114.

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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)

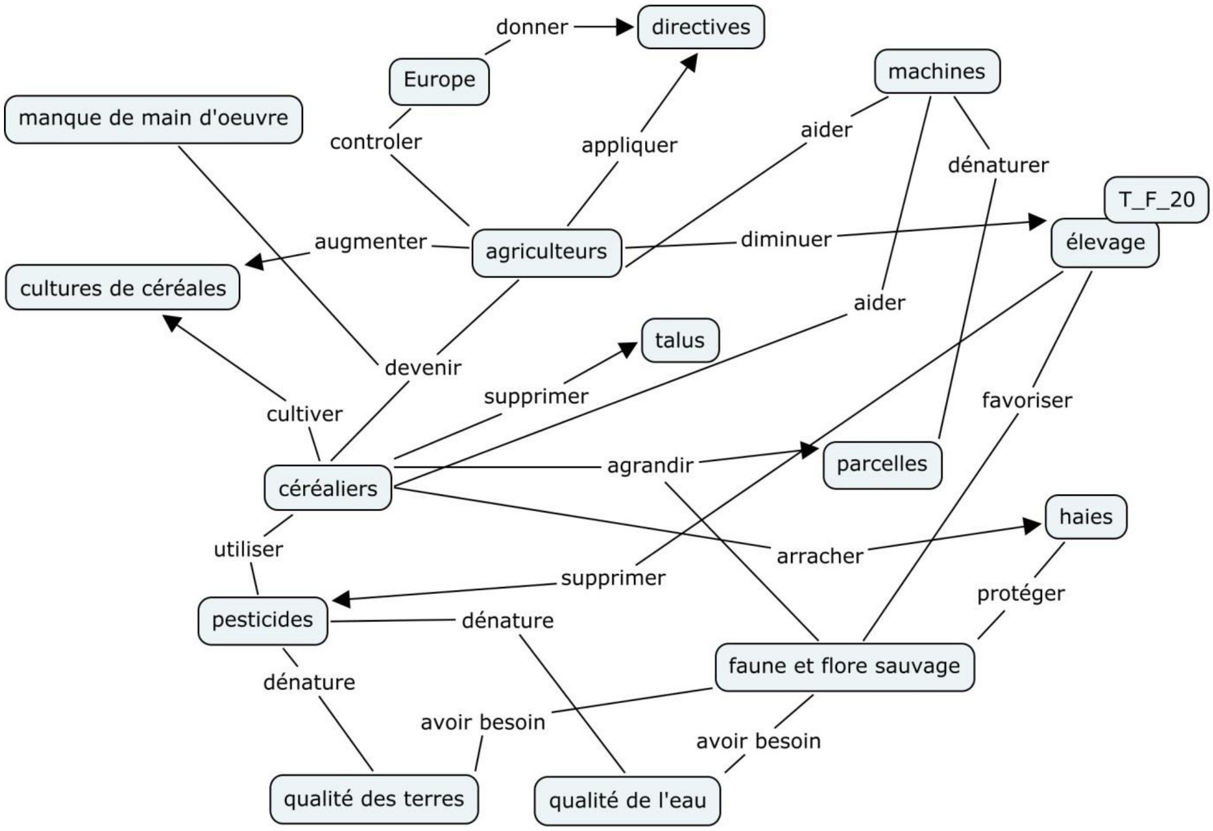

Figure A2.1 Example of an original ICM

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)

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

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