A new approach for comparing and categorizing farmers' systems of practice based on cognitive mapping and graph theory indicators

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Abstract

Farmers' practices are characterized not only by complexity at the farm scale, but also by diversity at the regional scale. In order to assess this diversity, a systemic approach is needed for comparing and classifying systems of practice. We developed a cognitive mapping approach (CMASOP) for comparing and clustering these systems within the social-ecological environment. In this paper, we introduce the two methods we used to implement our approach and report on the results of applying them in a study of grassland management in livestock grazing systems in Belgium. The *comparison* showed that systems of practice categorized according to certain descriptive factors (geographical, technical orientation) had some significant differences. The *clustering* of cognitive maps provided the basis for establishing a typology of the systems of practice. The comparative analysis of clusters revealed very significant differences among factors closer to the studied issue (grass forage management) than was the case with the approaches based on descriptive factors. Our study demonstrated that, in studies of the diversity of systems of practice, using a combination of statistical methods and semi-qualitative modelling can take account of the inherent complexity of these systems.

Highlights

► We sought to assess the diversity of agricultural systems of practice. ► We used an original combination of statistical and semi-qualitative approaches. ► The systems of practice differed significantly among the various types of farmers. ► Using CMASOP and clustering provides a typology of farmers' systems of practice.

Keywords: Fuzzy Cognitive Mapping, Agricultural practices, Systems of practices, Social-ecological Systems, Comparative analysis, Clustering

1. Introduction

Farming practices and farm management are increasingly being recognized as key elements in determining the economic success and sustainability of individual farms (Landais et al., 1988; Mazoyer and Roudart, 2002; Brodt et al., 2006). In their analyses of farm management, agricultural economists have demonstrated the role of individual decision making (Johnson et al., 1961; Gasson, 1973 in. Brodt et al., 2006). The decisions that farmers take reflect a wide range of personal goals and values, accounting for two important characteristics of farming practices: complexity at the farm scale and diversity at the regional scale (Landais et al., 1988).

In order to understand the complexity of social-ecological systems (SES), including farming systems, semi-quantitative approaches for modelling them have been developed, based on local knowledge (Özesmi and Özesmi, 2004). The work of Axelrod et al. (1976) was seminal in this field. Using information from the public, he created directed graphs (i.e., a network of nodes and directed edges) to show causal relationships, calling these representations 'cognitive maps'. Kosko (1986) applied fuzzy causal function (i.e., edges weighted from −1 to 1) to the relationships, creating 'fuzzy cognitive maps' (FCMs). Farm management studies have successfully used FCM approaches to gain insight into how farmers think their production system works (Fairweather, 2010). Drawing on both these approaches, we developed the Cognitive Mapping Approach for analysing Systems Of Practices (CMASOP) in SES (Vanwindekens et al., 2013). We illustrated the relevance of using this cognitive mapping-based approach via a study of forage management in grassland-based livestock farming systems in southern Belgium (Vanwindekens et al., 2013).

Two typological approaches are used in analyses of farming system diversity: structural and functional (Landais et al., 1988; Tittonell et al., 2010). Structural typologies distinguish farms according to descriptive factors (size, technical and eco-

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nomic orientation, wealth and resource endowment indicators), whereas functional typologies take account of regulatory systems (governance) (Lazard et al., 2010) and consider differences in practice as the main indicator of diversity (Cristofini et al., 1978; Landais et al., 1988; Perrot, 1990; Landais, 1998; Mbetid-Bessane et al., 2003). Unlike structural typologies, functional typologies also take into account the dynamics of farming strategies, which should improve farm categorization (Tittonell et al., 2010). The complexity of the social components of farming systems taken into account by functional typologies is usually limited to a few issues, such as farmers' general objectives, strategic choices and farm history (Alary et al., 2002; Gaspar et al., 2008; Tittonell et al., 2010). Given the difficulty of understanding farmers' decision-making process and motivations in an inductive way, however, few studies have sought to categorize farms according to farmers' practices and decision making (Girard, 2006; Thenard et al., 2007; Valbuena et al., 2008).

In studies conducted by anthropologists on farmers' practices, the focus has tended to be on farmers' perceptions and representations of their farming systems in terms of the practices they use, the knowledge they have, etc. (Darré et al., 2004; Lasseur, 2005). From his work in the early 1990s on the heterogeneity of farming practices, (van der Ploeg, 2010) introduced the concept of 'farming styles', which he defined as 'a distinctive and valid way of farming that is shared by a large group of farmers'. He saw it as a dynamic approach that included both material and symbolic dimensions. The concept of 'farming style' has a social dimension and represents communality, which contrasts with our 'systems of practice' concept, where the focus is on the individual (Vanwindekens et al., 2013).

In the social and natural sciences, categorization and classification methods are commonly used to study diversity. Categorization is a supervised learning method that groups objects into pre-established classes. Classification, or clustering, is an unsupervised multidimensional type of analysis in which objects (or descriptors) are grouped into new classes, or clusters, based on certain variables (Legendre and Legendre, 1998, p.305). For the sake of clarity in this paper, we will call the classes of objects 'groups' when derived from categorization based on descriptive factors (geographical and technical factors) and 'clusters' when derived from clustering systems of practice.

In order to study the diversity of farmers' practices, we combined cognitive mapping and statistical methods for comparative and clustering analyses. Little previous work has been done on in this field. Mathevet et al. (2011) compared stakeholder groups involved in water management in the Camargue, France, based on the presence of certain variables in mental models. Özesmi and Özesmi (2003, 2004) proposed clustering stakeholder groups' social cognitive maps according to the variables they included. Ortolani et al. (2010) studied farmers' perceptions of agri-environmental schemes using a method based on the presence of *variables* to compare and cluster farmers' cognitive maps.

Work we have conducted previously has shown that farmers tend to see their practices, why they use them and what effects they have in terms of *relationships* (Vanwindekens et al., 2013). In applying CMASOP, the relationships identified in farmers' open-ended interviews form the basis of their cognitive maps (Vanwindekens et al., 2013). In the study reported here, the presence of relationships in farmers' cognitive maps was therefore a criterion in clustering the systems of practice. In this paper, we describe two complementary CMASOP modules: one focusing on a comparative analysis of the systems of practice, the other on clustering these systems of practice. We then apply these modules to a case study of forage management in grassland-based livestock farming systems in two regions of Belgium (Ardenne and Famenne) and compare the systems of practice by: (i) categorizing them according descriptive criteria (agroecological area, technical orientation of farms); (ii) clustering them according to the presence of relationships in the farmers' cognitive maps; and (iii) clustering them according to the presence of variables in these cognitive maps.

2. Material and methods

CMASOP is a cognitive mapping approach used to analyse systems of practice in SES (Vanwindekens et al., 2013). At its core are four steps: 1 - surveying the systems of practice; 2 - coding the transcribed open-ended interviews; 3 - creating individual cognitive maps (ICMs); 4 - creating social cognitive maps (SCMs). We added two steps to this: 3' (between steps 2 and 4) - categorizing or clustering the ICMs; and 5 - conducting a statistical comparison of the SCMs (Figure 1). The 49 ICMs obtained from applying CMASOP to an analysis of forage management in the two Belgian grassland regions (Vanwindekens et al., 2013) were used as inputs in the comparative analysis.

2.1. Step 3': Partitioning the ICMs

2.1.1. Categorization

Partitioning ICMs can be based on geographical (e.g., agroecological area, administrative regions) and technical (e.g., farm size, production type) criteria. In our case study, we created four binary partitions. One was based on a geographical criterion: agroecological region (two levels: Ardenne/Famenne, n=28/21). The other three were based on technical criteria commonly used in the typology of livestock farming systems in southern Belgium (Stilmant et al., 1998; Hennart et al., 2010): presence of dairy cattle (two levels: presence/absence, n=20/29); presence of at least 5% of maize in the forage area (two levels: grass/maize, n=22/27); and stocking rate (threshold 1.7 LU/ha, two levels: low/high, n=13/36).

2.1.2. Clustering

We used the presence of relationships in the ICMs to cluster them. The clustering process was divided in two stages: computing a dissimilarity matrix and then classifying individuals according to this matrix.

We computed the dissimilarity matrix of the systems of practice by using an asymmetrical coefficient for the analysis of binary data in Q-mode (Legendre and Legendre, 1998). The choice of Q-mode was determined by the objective of the clustering (i.e., individual farmers). The choice of an association measure relevant for binary data was determined by the nature of our data (presence/absence of relationships in the ICMs). We chose an asymmetrical coefficient because it was not relevant to view the absence of a relationship in two ICMs (i.e., negative matches) as

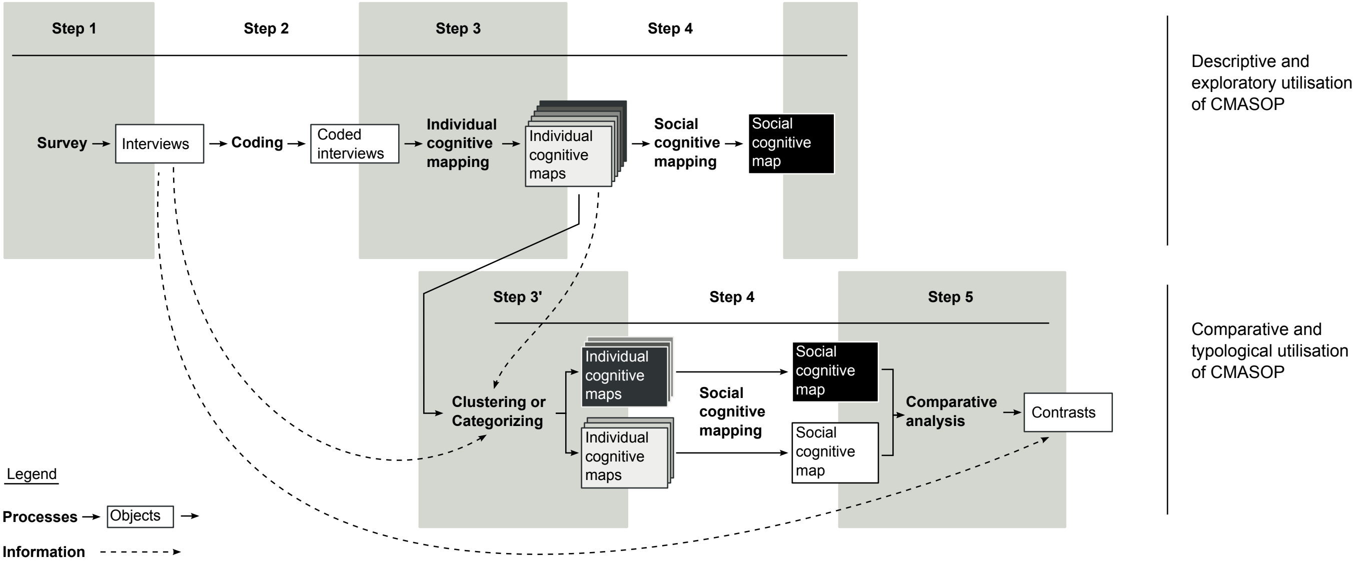


Figure 1: In order to enhance the comparative and typological applications of CMASOP (Vanwindekens et al., 2013), the four-step semi-qualitative approach was supplemented by two steps (step 3', an intermediate step between steps 2 and 4; and step 5). The ICMs were grouped by categorizing (using information from the interviews) or by clustering (using information from the ICMs themselves). SCMs were computed for each group and cluster, and a pairwise comparison was conducted using the comparative analysis module. Significant differences were revealed, and retrieving the relevant interview excerpts linked to these differences improved our understanding of them.

an indication of resemblance. Negative matches were very common in our dataset as most of relationships (n=86) were cited only once: the ICMs contained an average of 11.8 ± 5.0 relationships out of the 166 observed relationships across all the ICMs. Taking into account the three configurations (a: presence-presence combination; b: presence-absence combination; and c: absence-presence combination), the Sorensen coefficient (Gower and Legendre, 1986) was computed by Equation 1 using R (ade4 package Dray and Dufour, 2007).

$$Coeff_{Sorensen} = \frac{2a}{2a + b + c} \quad (1)$$

We used fuzzy c-means clustering (Kaufman and Rousseeuw, 1990; Maechler et al., 2011) to classify the 49 ICMs into two clusters. We chose fuzzy c-means clustering because of (i) the qualitative nature of the information in the ICMs and (ii) the human aspects of the decision-making processes and the practices. We divided the ICMs into only two clusters because of the limited number of ICMs in our study (n=49), and for the sake of clarity in demonstrating their use in the analysis.

2.2. Step 4: Generating SCMs

For each group and cluster, the ICMs were aggregated into one (SCM), as described by Vanwindekens et al. (2013). Two SCMs were then generated for each partition.

2.3. Step 5: Comparative analysis

A comparative analysis of the SCMs was conducted in order to identify similarities and differences in the systems of practice in the groups and clusters. The two SCMs generated for each partition underwent an automated pairwise comparison based on statistical tests of graph theory indicators: relationship weight and variables' indegree, outdegree and centrality.

2.3.1. Relationship weight

For each ICM, the relationship weight was 1 (one) if the relationship had been cited at least once and 0 (zero) if it had not been cited. For each SCM, the relationship weight was the sum of the weights of this relationship in the ICMs that made up that SCM (i.e., the number of interviewed farmers who cited this relationship at least once). Differences in relationship weights among the groups were determined using the Fisher Exact Test. The input for this test was a two-by-two contingency table with two modalities (relationship either present or absent) and two populations (two groups of farmers).

2.3.2. Variables' indegree, outdegree and centrality

The centrality of a variable is the cumulative weight of relationships entering and leaving this variable. The weight can be divided into indegree and outdegree, the former referring to the cumulative weight of relationships entering the variable, the latter to the cumulative weight of those leaving it (Özesmi and Özesmi, 2004). In ICMs, the indicators of a particular variable are ordinal. The distribution of these indicators was compared between two groups of ICMs using the Mann-Whitney Test. The input for this tests was the distribution of indicators of ICMs by group. The output was a p-value that showed if there were statistical differences between the compared groups in the indegree, outdegree or centrality of a variable.

2.3.3. Outputs of the comparative analysis and retrieval of citations

The output of Step 5 was a list of relationships and variables whose indicators demonstrated significant differences among the clusters. The semi-automated process built into our method allowed easy retrieval of citations linked to the identified differences. This tool was useful for interpreting the results and explaining differences in the relationships and variables among the clusters.

2.4. Comparison with another FCM clustering method

We compared our clustering method with the one developed by Özesmi and Özesmi (2003) and based on the presence or absence of variables in ICMs. This involved clustering the 49 ICMs according to the presence/absence of variables. To ensure consistency in our methodological choices, we used the Sorensen coefficient to compute the dissimilarity matrix and the fuzzy c-means clustering technique, as before.

3. Results

3.1. Comparison of systems of practice categorized according to descriptive factors

The 49 CMs were partitioned according to four descriptive factors: one geographical criterion (agroecological area) and three technical criteria (maize coverage, stocking rate and dairy herd presence/absence).

3.1.1. Categorization based on agroecological area

The partition based on agroecological area (Ardenne and Famenne) revealed significant differences for (i) two relationships and (ii) seven variables (Table 1 and Figures 2). That is, the weights of two relationships and the values of the indicators of seven variables differed significantly between the two areas. The total weight of the two relationships was 20, which was 3.4% of the total weight (580) of all the relationships in the study. The total centrality of the seven variables was 271, which was 23.4% of the total centrality ($580 \times 2 = 1,160$) of all the variables in the study. Significant differences in the relationships linking the 'weather', 'second cut' and 'soil type' variables are described here.

The relationship linking 'weather' to 'second cut' had significantly different weights in the two regions (Ardenne 2, Famenne 14, $p < 0.001$). Some graph indicators linked to these two variables also showed significant differences between the agroecological areas: outdegree and centrality of 'weather' (both $p < 0.05$) and indegree of 'second cut' ($p < 0.05$). Qualitative analysis of the citations from the Famenne farmers' interviews indicated that in their area the second cut was highly dependent on climatic conditions, especially on rain occurring in early summer (July). The risk of drought typical of Famenne does not occur in the Ardenne highlands, which have a wetter climate.

The outdegree and centrality of the 'soil type' variable was significantly higher for farmers in Famenne than those in Ardenne. Analysis of a detailed graphical display of the SCM showed that 'soil type' was linked to other variables ('hay', 'plot utilization', 'third cut' and 'stocking rate') by relationships with a weight of 1 (i.e., cited by only one farmer). Citations linked to these relationships revealed the heterogeneity of soils in Famenne and showed that, in most of the cases, these soils are superficial and are characterized by weak water reserves, which increases the climatic risk of forage production in this area.

3.1.2. Categorization based on technical factors

In the categorization of systems of practice based on the three technical criteria, we again compared differences in relationship weights (Table 2 and Figure 3) and in the values of indicators of variables (Table 3 and Figure 3). The partition based on 'maize coverage' revealed seven relationships with a total weight of 111 (Σw=111; i.e., 19.1% of the total weight of all the relationships) and three variables whose total centrality was 148 (Σc=148; i.e., 12.8% of the total centrality of all the variables). The partition based on 'stocking rate' revealed three relationships (Σw=42, 7.2%) and five variables (Σc=235, 20.3%). And the partition based on 'dairy herd presence/absence' revealed five relationships (Σw=69, 11.9%) and five variables (Σc=13, 11.5%). An exhaustive presentation of the results of the comparison is beyond the scope of this paper, but we can highlight some results (Tables 2 and 3):

1. The centrality of the 'third cut' variable and the weight of the relationship linking 'weather' to 'third cut' were higher in maize farmers' ICMs because growing maize and harvesting a third grass cut are more suited to milder climatic conditions (Famenne).
2. The weight of the relationship linking 'first cut' to 'hay' was higher for forage producers, who tend to make hay from the harvest of the first grass cut. The weight of the relationship linking 'first cut' to 'silo' and 'second cut' to 'hay' was higher for maize farmers, who usually ensile the first cut and make hay from the second one.
3. The weight of the relationship linking 'second cut' to 'silo' was higher for farmers with high stocking rates, reflecting their tendency to ensile their second cut.
4. The centrality of the 'growth stage of grass' and 'cutting date' variables and the weights of relationships linking 'weather' to 'cutting date' and 'hay' were higher for farmers with low stocking rates, illustrating the importance of producing hay in the more extensive livestock farming systems.

3.1.3. Comparison of the results from the partitions based on descriptive factors

From the four partitions based on descriptive factors (Figure 3), the 'maize coverage' partition produced the highest number of relationships with significantly different weights between the groups (n=7). The total weight of the revealed relationships (Σc=111, 19.1%) was far higher than that in the three other partitions based on descriptive factors. These results indicate that, among the four factors tested, the 'maize coverage' factor had the greatest impact on grass forage management systems of practice. The second most important factor in grass forage management was 'dairy herd presence/absence' (n=5, Σc=69, 11.9%) and the third was 'stocking rate' (n=3, Σc=42, 7.2%). The comparison of farmers according to agroecological area revealed the lowest number of relationships (n=2, Σc=20, 3.4%), but the most significant differences.

The clustering methods applied to systems of practice revealed new partitions. The comparative analysis module was used to characterize the clusters.

Table 1: Relationships and variables revealed by the comparative analysis based on agroecological area (Ar Ardenne, Fa Famenne ; *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$)

	Ardenne n = 28	Famenne n = 21	p-value	signif
Weight of Relationships				
Weather⟶Second cut	2	14	$2.3e-05$	Fa >Ar ***
Suckling herd⟶Cutting date	0	4	$2.8e-02$	Fa >Ar *
Outdegree of Variables				
Weather	31	42	$2.4e-02$	Fa >Ar *
Suckling herd	0	5	$1.8e-02$	Fa >Ar *
Soil type	3	11	$2.3e-02$	Fa >Ar *
Indegree of Variables				
Second cut	2	18	$3.7e-06$	Fa >Ar ***
Forage and Feed purchase	6	0	$4.5e-02$	Ar >Fa *
Third cut	2	8	$2.0e-02$	Fa >Ar *
Centrality of Variables				
Weather	31	42	$2.4e-02$	Fa >Ar *
Forage quantity	14	16	$3.6e-02$	Fa >Ar *
Soil type	3	11	$2.3e-02$	Fa >Ar *

3.2. Comparison of systems of practice clustered according to ICM content

Each clustering exercise partitioned the ICMs into two clusters. The two clusters based on relationships revealed by the ICMs were labelled A1 (n=24) and A2 (n=25). The two clusters based on variables revealed by the ICMs were labelled B1 (n=21) and B2 (n=28).

3.2.1. Comparison of systems of practice clustered according to relationships

A comparison of the results from (i) the comparative analyses applied to the categorization method (descriptive factors) and (ii) the comparative analyses applied to the clustering method showed that the clusters based on farmers' ICMs did not match the geographical or technical factors. Most of the factors (agroecological area, forage management and stocking rate) were not significantly different between the clusters. Only with the 'dairy herd presence/absence' factor were there significant differences between clusters (*p-value* < 0.05): farmers with dairy cattle were significantly more present in cluster A1 (n=14) than in cluster A2 (n=6).

We compared the SCMs of clusters A1 and A2 using the comparative analysis module (Tables 2, 4 and Figure 3). Eight relationships and six variables were significantly influenced by the systems of practice clusters. The total weight of the eight revealed relationships was 132 (22.8% of the total weight of all the relationships) and the total centrality of the six revealed variables was 322 (27.8% of the total centrality of all the variables).

The revealed relationships and variables in the SCMs (Figures 4(a) and 4(b)) showed that five of the relationships were directly linked to harvesting and grass conservation modes, thus linking cutting operations (first, second or third cuts) to conservation modes (silo, hay, bale wrap). The weights of the relationships linking the three cutting operations to silo were all significantly higher in the SCM of cluster A1 ($p < 0.001$, $p < 0.001$ and $p < 0.05$ for the 'first cut', 'second cut' and 'third cut', respectively). The centrality of the 'silo' variable for farmers in this cluster ($p < 0.001$) was also significantly higher. In contrast, the weights of the relationships linking 'first cut' to 'hay' ($p < 0.05$) and linking 'second cut' to 'bale wrap' ($p < 0.01$) were significantly higher in the SCM of cluster A2. There was also significantly higher centrality of the 'bale wrap' and 'hay' variables for farmers in cluster A2 ($p < 0.05$).

Two of the relationships concerned motivations behind technical choice. The first one, linking 'supplementation' to 'bale wrap', was significantly higher for cluster A1 ($p < 0.05$). The centrality of the 'supplementation' variable was also higher for cluster A1 ($p < 0.05$). The need for forage supplementation was an important reason for conserving forage in bale wraps for farmers in cluster A1. The second relationship, linking 'weather' to' cutting date', was also significantly higher in the SCM of cluster A1 ($p < 0.05$).

The relationship linking 'topography' to 'plot utilization' under grazing or cutting schemes reflected ecological constraints (i.e., steeply sloping lands). This ecological constraint was cited more often by farmers in cluster A2 ($p < 0.05$) than those in A1.

In summary, the systems of practice used by farmers in cluster A1 were based on silaging their grass, whereas bale wrapping and hay production were the preferred conservation modes for farmers in cluster A2. There were differences in the ecological and technical constraints (topography, weather, supplementation and suckling herd) cited by farmers in these clusters that explained their choices (cutting date, plot utilization and conservation mode).

3.2.2. Comparison of systems of practice clustered according to variables

In this section we outline the results of clusters comparison based on the presence of variables in ICMs, as proposed by Özesmi and Özesmi (2003). The comparative analysis showed that:

- the weights of six relationships were significantly different in clusters B1 and B2; these relationships had a total weight of 77 (13.3%) (Table 2 and Figure 3).

Table 2: Relationships revealed by the comparative analysis. Numbers in brackets refer to explanations in the text.

	Agroecological area	Maize in the forage area	Stocking rate	Presence of dairy cattle	Clustering based on relationships	Clustering based on variables
	Ar Ardenne Fa Famenne	Gr <5% Ma >5%	Lo <1.7 LU/ha Hi >1.7 LU/ha	Pr Presence Ab Absence	A1 cluster A2 cluster	B1 cluster B2 cluster
First cut⟶Silo	-	Ma >Gr * (2)	-	-	A1 >A2 ***	B1 >B2 *
First cut⟶Hay	-	Gr >Ma * (2)	-	-	A2 >A1 *	-
Second cut⟶Silo	-	-	Hi >Lo * (3)	Pr >Ab *	A1 >A2 ***	-
Second cut⟶Bale wrap	-	-	-	Ab >Pr *	A2 >A1 **	-
Second cut⟶Hay	-	Ma >Gr * (2)	-	-	-	-
Supplementation⟶Bale wrap	-	-	-	-	A1 >A2 *	-
Inputs price⟶Forage and Feed purchase	-	Gr >Ma *	-	-	-	-
Weather⟶Second cut	Fa >Ar ***	Ma >Gr *	-	-	-	-
Weather⟶Hay	-	-	Lo >Hi * (4)	-	-	-
Weather⟶Cutting date	-	-	Lo >Hi * (4)	-	A1 >A2 **	-
Weather⟶Third cut	-	Ma >Gr * (1)	-	-	-	-
Weather⟶Grazed area reduction	-	-	-	-	-	B2 >B1 *
Plot-farm distance⟶Plot utilization	-	-	-	-	-	B2 >B1 *
Plot-farm distance⟶Dairy cows	-	-	-	Pr >Ab *	-	-
Plot-farm distance⟶Meat cows	-	Gr >Ma *	-	Ab >Pr **	-	B2 >B1 *
Plot-farm distance⟶Yearlings	-	-	-	Ab >Pr **	-	B2 >B1 *
Suckling herd⟶Cutting date	Fa >Ar *	-	-	-	-	-
Third cut⟶Silo	-	-	-	-	A1 >A2 *	B1 >B2 **
Forage quantity⟶Cutting date	-	-	-	-	-	-
Forage quality⟶Cutting date	-	-	-	-	-	-
Topography⟶Plot utilization	-	-	-	-	A2 >A1 *	-

Table 3: Variables revealed by the comparative analysis (geographical and technical groups). Numbers in brackets refer to explanations in the text.

	Agroecological area Ar Ardenne Fa Famenne			Maize in the forage area Gr <5% Ma >5%			Stocking rate Lo <1.7 LU/ha Hi >1.7 LU/ha			Presence of dairy cattle Pr Presence Ab Absence		
	Indegree	Outdegree	Centrality	Indegree	Outdegree	Centrality	Indegree	Outdegree	Centrality	Indegree	Outdegree	Centrality
First cut	-	-	-	-	-	-	-	-	-	-	-	-
Second cut	-	Fa>Ar ***	-	-	Ma>Gr *	-	-	-	-	-	-	-
Third cut	-	Fa>Ar *	-	Ma>Gr **(1)	Ma>Gr *(1)	Ma>Gr **(1)	-	-	-	-	-	-
Supplementation	-	-	-	-	-	-	-	-	-	-	-	-
Forage and Feed purchase	-	Ar>Fa *	-	-	Gr>Ma *	Gr>Ma *	-	-	-	-	-	-
Bale wrap	-	-	-	-	-	-	-	-	-	-	-	-
Forage maize	-	-	-	-	-	-	-	-	-	-	-	-
Hay	-	-	-	-	-	-	-	Lo>Hi *	-	-	-	-
Silo	-	-	-	-	-	-	-	Lo>Hi *	Lo>Hi *	-	Pr>Ab *	-
Plot utilization	-	-	-	-	-	-	-	-	-	-	-	-
Permanent grassland	-	-	-	-	-	-	-	-	-	-	-	-
Alfalfa	-	-	-	-	-	-	-	Lo>Hi *	-	-	-	-
Dairy cows	-	-	-	-	-	-	-	-	-	Pr>Ab *	Pr>Ab *	Pr>Ab **
Meat cows	-	-	-	-	-	-	-	-	-	-	Ab>Pr ***	Ab>Pr ***
Pregnant cows	-	-	-	-	-	-	-	-	-	-	-	-
Suckling herd	Fa>Ar *	-	-	-	-	-	-	-	-	-	-	-
Yearlings	-	-	-	-	-	-	-	-	-	-	Ab>Pr **	Ab>Pr **
Soil type	Fa>Ar *	-	Fa>Ar *	-	-	-	-	-	-	-	-	-
Plot-farm distance	-	-	-	-	-	-	-	-	-	-	-	-
Forage quality	-	-	-	-	-	-	-	-	-	-	-	-
Forage quantity	-	-	Fa>Ar *	-	-	-	-	-	-	-	-	-
Animal health	-	-	-	-	-	-	-	-	-	-	-	-
Growth stage of grass	-	-	-	-	-	-	Lo>Hi *(4)	-	Lo>Hi *(4)	-	-	-
Cutting date	-	-	-	-	-	-	-	Lo>Hi *(4)	Lo>Hi *(4)	-	-	-
Topography	-	-	-	-	-	-	-	-	-	-	-	-
Weather	Fa>Ar *	-	Fa>Ar *	-	-	-	-	-	-	-	-	-
Autonomy	-	-	-	-	-	-	-	-	-	-	-	Ab>Pr *

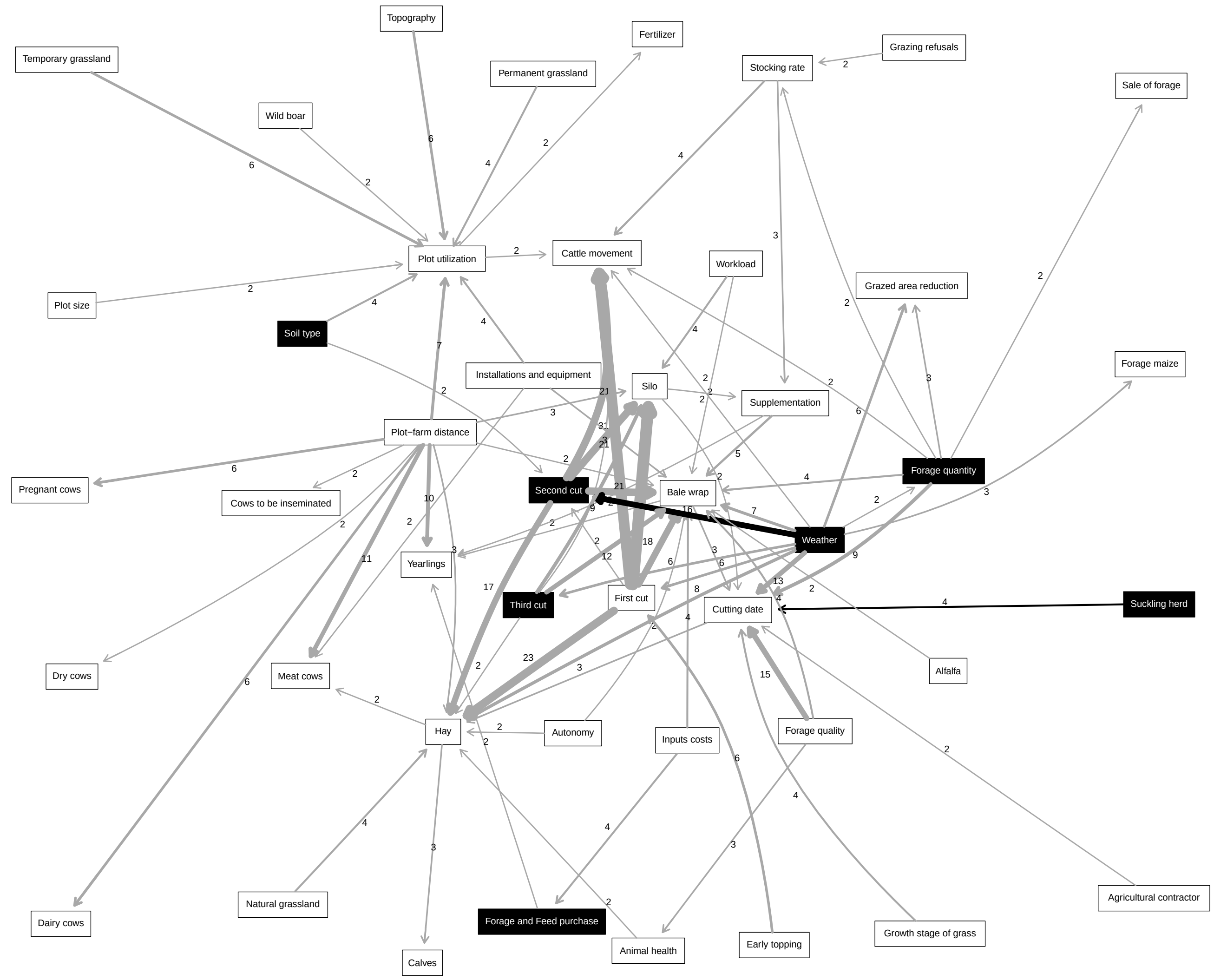


Figure 2: Relationships and variables revealed by the comparative analysis of groups based on agroecological area. This analysis showed significant differences in terms of relationship weights and values of the indicators (indegree, outdegree, centrality) of variables. The cognitive map is the simplified SCM of the 49 ICMs (Vanwindekens et al., 2013), where only those relationships with a weight of 2 or more are shown).

- the values of the indicators of eight variables were significantly different in clusters B1 and B2; these variables had a total centrality of 384 (33.1%) (Table 4 and Figure 3).

The highest values of significantly different indicators were found mainly in one cluster: 14 in B2, but only 5 in B1.

4. Discussion

In this section we discuss the main features, strengths and limitations of the comparative and typological applications of CMASOP. We also look at further developments of this approach.

The CMASOP comparative analysis module was successfully used to reveal differences in farmers' systems of practice. The relationships and variables shown to be significantly different among groups of farmers were specific to each tested partition of the set of ICMs. For each comparison, the combination of qualitative and semi-quantitative tools provided by CMASOP (Vanwindekens et al., 2013) was helpful in understanding, describing and characterizing the systems of practice used by each group/cluster of farmers.

The clustering approach classified farmers according to their systems of practice as revealed by the ICMs. The comparative analysis applied to the clustering results provided a complete characterization of the systems of practice in the two clusters and an understanding of what set them apart. In applying these approaches in our case study, we noticed that the clusters did not match any of the partitions based on the four descriptive factors. The clusters tended to distinguish themselves in terms of the method chosen to conserve harvested grass, which was central to the studied issue (grass forage management). This key parameter has not been used before in typologies of livestock farming

Table 4: Variables revealed by the comparative analysis (Clusters)

	Clustering based on relationships			Clustering based on variables		
	Indegree	Outdegree	Centrality	Indegree	Outdegree	Centrality
First cut	-	-	-	-	B2 >B1 *	-
Second cut	-	-	-	-	-	-
Third cut	-	-	-	B1 >B2 **	-	B1 >B2 *
Supplementation	A1 >A2 *	-	A1 >A2 *	-	-	-
Forage and Feed purchase	-	-	-	-	-	B2 >B1 *
Bale wrap	-	A2 >A1 *	A2 >A1 *	-	-	-
Forage maize	-	-	-	-	-	-
Hay	-	-	A2 >A1 *	-	-	-
Silo	-	A1 >A2 ***	A1 >A2 ***	-	B1 >B2 *	-
Plot utilization	-	A2 >A1 *	-	-	B2 >B1 ***	B2 >B1 ***
Permanent grassland	-	-	-	-	-	-
Alfalfa	-	-	-	-	-	-
Dairy cows	-	-	-	-	-	-
Meat cows	-	-	-	-	-	-
Pregnant cows	-	-	-	-	-	-
Suckling herd	A2 >A1 *	-	A2 >A1 *	-	-	-
Yearlings	-	-	-	-	B2 >B1 **	B2 >B1 **
Soil type	-	-	-	B2 >B1 **	-	B2 >B1 **
Plot-farm distance	-	-	-	B2 >B1 **	-	B2 >B1 **
Forage quality	-	-	-	-	-	-
Forage quantity	-	-	-	-	-	-
Animal health	-	-	-	-	-	-
Growth stage of grass	-	-	-	-	-	-
Cutting date	-	-	-	-	-	-
Topography	-	-	-	-	-	-
Weather	-	-	-	-	-	-
Autonomy	-	-	-	-	-	-

systems in Belgium (Stilmant et al., 1998; Hennart et al., 2010) or abroad (Maseda et al., 2004).

The results from the comparative analyses and the clustering demonstrated the diversity of the systems of practice. Previous studies of this diversity had been based on the concept of farming style (van der Ploeg, 1994; Vanclay et al., 2006). Most studies on diversity in farming systems have relied on classification based on expert knowledge (Perrot, 1990; Landais, 1998; Schmitzberger et al., 2005). One limitation of these studies was that they threw little light on why farmers chose to implement the practices they did (Girard, 2006). The reasons underlying farmer practices have been studied, however, by agro-sociologists and rural anthropologists (Darré et al., 2004; Lasseur, 2005; Farmar-Bowers and Lane, 2009). These social science studies have produced interesting and complete monographs that show a deep and holistic understanding of farming systems of practice, but they are time-consuming and require great skill, which restricts the number of farmers they can survey.

An original aspect of CMASOP is that it uses a semi-automated method to define systems of practice based on farmers' own perceptions as voiced during qualitative open-ended interviews. The method allows data to be collected from a sample broad enough to establish a typology, while retaining the inductive character of anthropological studies. It is based on farmer knowledge and caters for the complexity of their systems of practice.

The CMASOP clustering module is based on a distance measure depending on the presence/absence of relationships. In comparison with the clustering of cognitive maps based on the presence/absence of variables (Özesmi and Özesmi, 2003, 2004; Ortolani et al., 2010), our results showed that, overall, the weights of revealed relationships were higher in relationship-based clustering ($n=8$, $\Sigma w=132$) than in variable-based clustering ($n=6$, $\Sigma w=77$), whereas the centrality of revealed variables was slightly lower in relationship-based clustering ($n=6$, $\Sigma c=322$) than in variable-based clustering ($n=8$, $\Sigma c=384$). The relationship-based clustering of farmers therefore seems more suited to creating a typology of systems of practice linked to the studied issue.

Two arguments support our approach. The first is that modelling systems of practice is based on a systems approach. In this approach, relationships between elements are fundamental. As defined by von Bertalanffy (1968), a system is a set of elements that are interrelated among themselves and with their environment. The second argument is that relationships are the basic elements of a cognitive map, with each relationship incorporating the information of the two variables it links: source and sink variables.

A drawback of using relationships for comparing systems of practice is that the number of instances of an absence of relationships is high. This issue is related to the double-zero problem (negative matches) for computing association measures (Borcard et al., 2011, pp 32–33). With our method, if a farmer did not cite a relationship when talking about his farming system, this did not imply that this relationship did not exist in his system. In comparing systems of practice, therefore, the absence of a relationship in two ICMs cannot be seen as an indication of similarity between them. This is why we used an asymmetrical coefficient for computing dissimilarities in the relationship-based clustering of systems of practice.

For our study we used an elementary system of practice (forage management in grassland-based livestock farming systems) to illustrate our approach. This system focuses mainly on the technical operations of cutting, conserving and preparing grass forage. We recognize that, in this example, the farmers' percep-

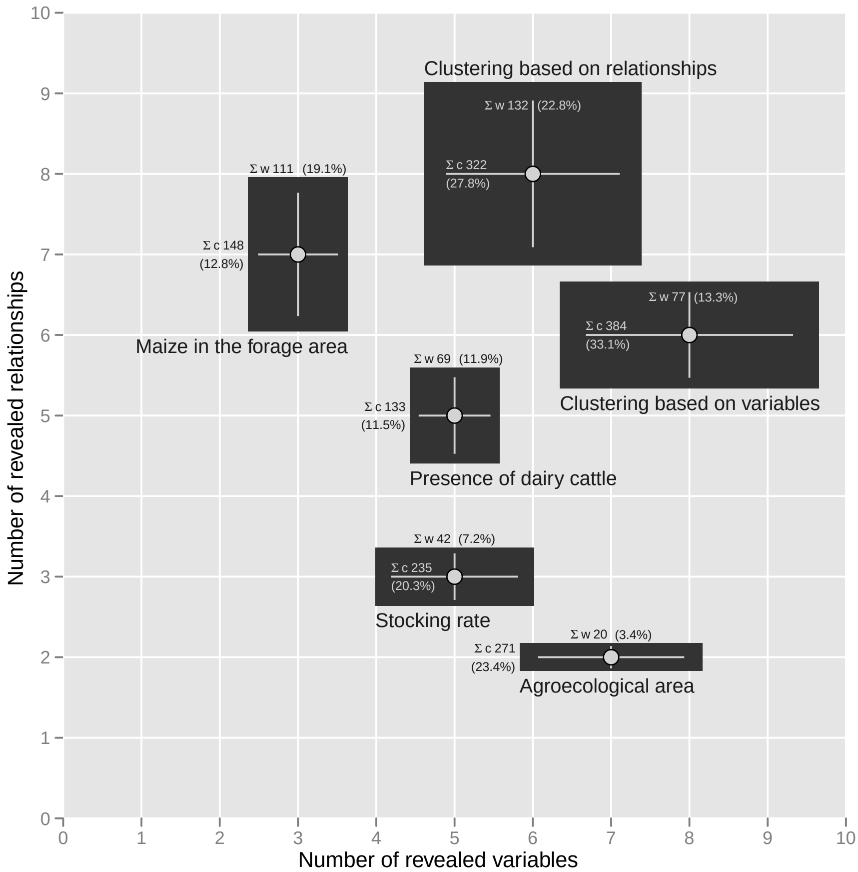


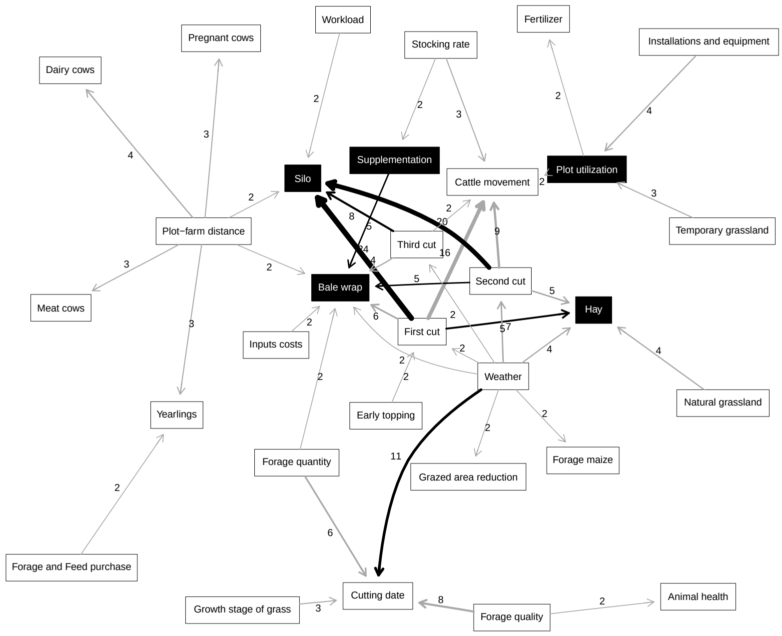
Figure 3: General characteristics of relationships and variables revealed by the comparative analysis are symbolised by boxes. The centre of each box shows the number of revealed relationships (on the y axis) and variables (on the x axis). The dimensions of each box show the total weight of revealed relationships (Σw, on the y axis) and the total centrality of revealed variables (Σc, on the x axis). One unit of coordinates corresponds to 10 % of the total weight of all the relationships (i.e., 580) and to 10% of the total centrality of all the variables (i.e., 1, 160). Within the 100 grey units of the plotting area (100%), the area of each box is exactly proportional to the revealed relationships and variables in terms of weight and centrality, respectively. We provide some quantitative information near the box dimensions.

tions of their own practices and the diversity of factors influencing these practices (e.g., technical, social, economic) were quite simple (Vanwindekens et al., 2013).

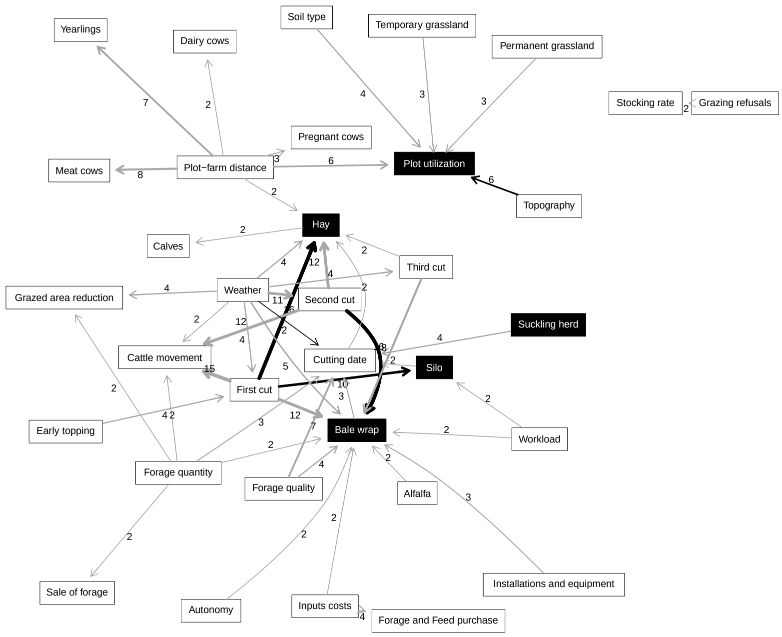
Most practices in farming systems are greatly influenced by social and economic factors and shaped by farmers' perceptions and preferences. The integration of these factors into a study of systems of practice increases the level of complexity. With CMASOP, more complexity leads to more concepts and more relationships between the concepts. One way to address this is to aggregate detailed concepts (during the coding process or after the initial analysis) into one more general concept, in order to limit their number. Using fewer concepts potentially increases a researcher's influence on the interpretation of farmer interviews. It will also affect the nature of relationships because a single relationship embodies a diversity of meanings in a single descriptor. However, because of its automated nature and ease of implementation, the potential of the proposed method lies in its flexibility as to what to explore and how to do it. For example, the relevance of methodological choices, such as aggregating concepts, can be explored *a posteriori* using the method's citation-retrieving module.

The method is designed to be just as efficient in identifying groups in very homogeneous systems as it is in identifying key differences. It is a highly sensitive method, but this sensitivity can be modified by simplifying the coding process or focusing on a subset of concepts. In our case study, the ability to find a relevant and original typology with a simple descriptor such as forage management was a promising indication of the conceptual strength of the method.

From a methodological perspective, the limited size of our sample (n=49) led us to cluster our 'population' into two groups. In extensive surveys of farmers' systems of practice, the sample could just as easily be partitioned into three or more clusters. Further methodological developments could include an automated determination of the number of clusters, and using clustering methods to detect 'outliers' (i.e., farmers with original systems of practice that are of interest in the search for innovative systems) (Geels and Schot, 2007).



(a) Simplified SCM of the cluster A1



(b) Simplified SCM of the cluster A2

Figure 4: Relationships and variables revealed in the SCMs of clusters based on relationships (A1 and A2).

5. Conclusion

Our study on the diversity of systems of practice used by farmers was based on information that those farmers provided in interviews. We developed two complementary applications of our cognitive mapping-based approach known as CMASOP: a comparative analysis module and a clustering module. The results showed that our method was suitable for revealing significant differences between systems of practice used by farmers categorized according to various descriptive factors. The partitioning of farmers depending on their systems of practice differed from the partitioning based on these factors. When applied to clusters, the comparative analysis module revealed significant differences in practices (grass conservation mode, grass forage preparation) more closely related to the studied issue (in this study, grass forage management) than was the case when it was applied to groups categorized by descriptive factors. Future work is needed to assess the relevance of using the semi-automated clustering method for identifying and describing farming styles within a farming community.

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