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RESEARCH ARTICLE

Converting to organic viticulture increases cropping system structure and management complexity

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Abstract Organic viticulture is an effective cultivation method that can reduce the environmental impacts of grape growing while maintaining profitability. For some vineyards, simple adjustments can suffice to make the conversion to organic farming; however, for most, major changes in system structure and management must be implemented. Here, we showed for the first time that converting to organic viticulture impacts vineyard complexity. We used six complexity indicators to assess modifications to cropping system structure and management: number of fields, number of difficult-to-manage fields, vineyard area, number of field interventions, number of technical management sequences, and number of management indicators. These six indicators were assessed through interviews carried out with winegrowers from 16 vineyards between 2008 and 2012. Changes in vineyard performances during conversion were also measured. We demonstrate that conversion to organic viticulture increased the complexity of vineyard structure and management for the 16 vineyards surveyed. While this increase allowed agronomic performances in all vineyards to be maintained, it also came with an increase in labor requirements (of up to 56%) compared to conventional agriculture. We conclude that the six indicators are appropriate for assessing changes in vineyard complexity and could be extended to all agricultural systems to better anticipate the implications of organic farming conversion for a farm's biophysical, technical, and decisional subsystems.

Keywords Agroecology · Conversion · Cropping system · Complexity · Farming system · Cropping system management · Number of fields · Organic farming · Technical operations

1 Introduction

To address current climatic, socio-economic, and environmental changes, farmers must modify their cropping systems to reduce environmental impacts while ensuring feasibility and profitability at farm level (Wery and Langeveld 2010). For some farms, simple adjustments, such as modifying pesticide and fertilizer doses, can suffice to cope with the changing context; however, in most cases more significant modifications in farm structure, farmland organization, and crop management may be necessary (Darnhofer et al. 2005). For example, reducing the environmental and health impacts of European agriculture implies considerably limiting synthetic chemicals through an integrated pest management approach that requires more diversified cropping systems (in space and time) and a more complex management of interactions between plants, soils, pests, and diseases (Barzman et al. 2015). Experimental results show that synthetic chemical-based crop protection can be replaced by more environmentally friendly but less effective ingredients (bio-control) and increased prevention of pest recurrence (e.g., in vineyards, Lafond et al. 2013). These measures require more information on the plant and disease status at field level and a deeper understanding of how the various components of the cropping system function to appropriately adjust

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interventions (Léger and Naud 2009; Barzman et al. 2015). In turn, this will likely lead to an increase in complexity of the cropping system.

Complexity refers to a system having many components that are difficult to define and understand (Flood and Carson 1993). A system's complexity increases with the number of components (i.e., structural complexity) and the number of interactions between these components (i.e., functional complexity) (Cadenasso et al. 2006; Lamanda et al. 2012). It can be hypothesized that a key trade-off farmers must manage is balancing the biological advantages of complexity driving the farming system's agroecological efficiency (Duru et al. 2015) and the need to simplify the system's structure (e.g., number of fields and number of plants grown) and management (number of field interventions) to optimize socio-economic factors such as labor and costs. Many studies show that plant diversification with long and diversified rotations are mandatory to reduce pesticide dependency and limit the environmental impacts of agricultural systems (Vereijken 1997; Aouadi 2015). As noted by Altieri (1995), crop rotations, polycultures, agroforestry, cover cropping, and animal integration are necessary to make a sustainable transition to agroecology. These changes lead to an increased number of biophysical components (number of activities, number of crops) and technical components (crop management sequences, technical operations) associated with these activities and crops. Consequently, an agricultural system's complexity is expected to increase during the transitional phase to agroecology.

Organic farming is increasingly viewed by consumers, decision makers, and farmers as a way to promote the adoption of environmentally friendly cropping systems and reduce the environmental impacts of agriculture in Europe (Hansen et al. 2001; Darnhofer et al. 2005). Conversion to organic farming may be a complete break from a farm's operations or a continuous process of adaptation depending on the farm (Lamine and Bellon 2009) and the motivations for conversion (Darnhofer et al. 2005). During conversion, farmers must stop using synthetic chemicals and mineral fertilization to comply with organic farming certification requirements. Substituting inputs allowed in organic farming (e.g., copper instead of systemic fungicides) for synthetics may be considered a minor change but in practice requires significant changes in crop management to avoid declines in yield and/or grape quality (Fermaud et al. 2016). In vineyards, major outbreaks of certain diseases can stem from just one poor application of fungicide and result in a near total yield loss (Caffi et al. 2010). While conversion to organic farming for annual crops often entails more complex rotations, rotation is rarely an option for high-value perennial crops such as grapes. In fact, in addition to complying with organic regulations, farmers must also combine multiple preventive practices to control pests and diseases. As such, conversion to organic farming can be considered a typical example of a system transition that is likely to lead to increased vineyard complexity, especially if the goal is to maintain land or labor productivity and product quality.

Faced with reduced economic profitability and societal concern driven by pesticide use, many French winegrowers are looking to transition to a more sustainable system and see conversion to organic viticulture as a solution (Lamine and Bellon 2009). The number of vineyards engaged in an organic conversion process has risen sharply in just a few years. From 1995 to 2007, the organic vineyard surface area in France has increased by a factor of 4.6 and now accounts for 9% of the country's vineyard area (Agence Bio 2016). Languedoc-Roussillon has the largest area of organic vineyards in France, with 31% of the national organic vineyard area (Agence Bio 2016).

Nevertheless, not much attention has been given to the conversion phase from conventional to organic farming. A search on CAB Abstract (consultation June 2015) combining the three words "conversion," "organic," and "farming" returned 1593 results for a topic search and only 75 results for a title search. Most of the studies are static comparisons between conventional and organic farming performances, mostly based on yields (De Ponti et al. 2012; Seufert et al. 2012), or are comparisons between organic farms after conversion (Halberg et al. 2006). These studies look mostly at agronomic, economic, or environmental performances at field level that are viewed as the consequences of changes undertaken for conversion. Because they focus on field scale and the biophysical subsystem, these studies offer a limited capacity to analyze the farm conversion pathway. When carried out at farm level, they center on economic performances and drivers and often take a normative approach using linear programming (Acs et al. 2007). There are also a few sociological studies based on comprehensive interviews with farmers that provide qualitative information on the context and the socio-economic drivers of change based on farm life trajectory analyses (Guthman 2000). But these studies do not make it possible to link these drivers to changes in cropping system management and performances during the transition to organic farming. Literature on technical and organizational changes implemented during conversion is therefore scarce and, when it does exist, is mostly at field scale (Polge de Combret-Champart et al. 2013); it may occasionally pertain to farm scale, but never with an integrated approach of both field and farm scales. The majority of these studies deal with arable crops or mixed farming while very few concern vineyards.

In this paper, we analyzed the change in vineyard complexity when converting to organic viticulture as an example of a perennial cropping system in transition. We developed a conceptual model of cropping system complexity to determine the contribution of the biophysical, technical, and decisional subsystems to this complexity.

2 Material and methods

2.1 Framework for the cropping system complexity analysis

2.1.1 Definitions and conceptual framework

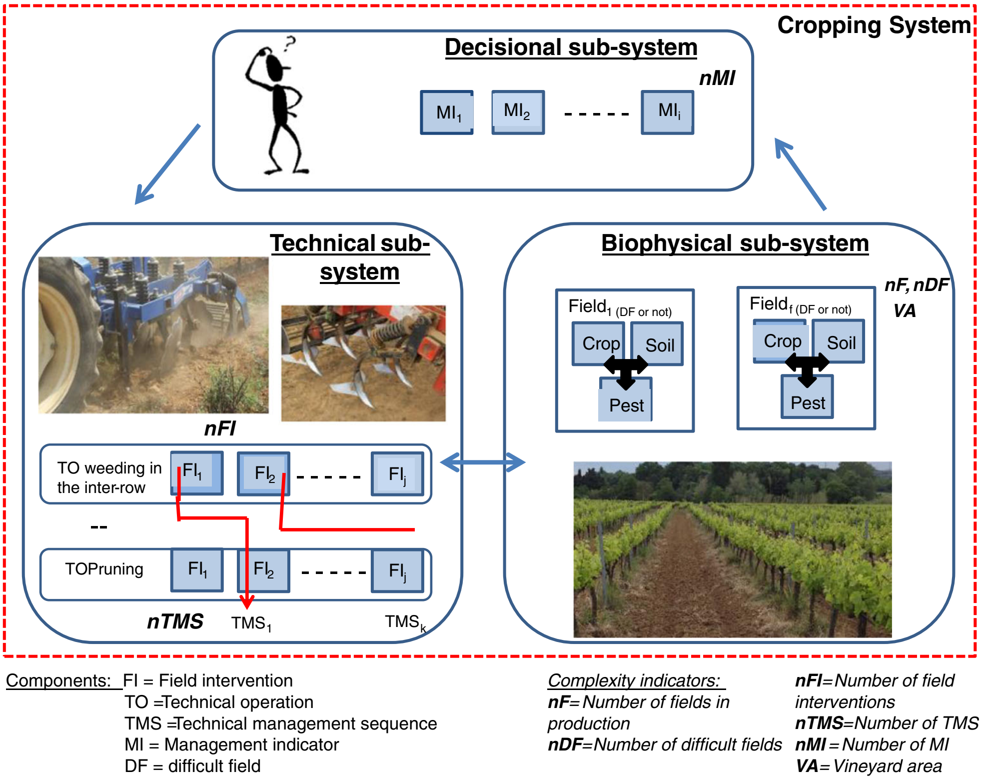
According to Le Gal et al. (2010), cropping system structure and management can be described as the result of a combination of a biophysical subsystem and a technical subsystem interacting under the influence of a decisional subsystem (Fig. 1). The biophysical subsystem is composed of fields. Each field is composed of crop, soil, pest, and disease components, which are likely to vary for each field, all interacting through biological and physical processes (Lamanda et al. 2012). The field attributes driving such diversity and performances are soil characteristics, slope, pest pressure, ecological infrastructures (hedges, trees, etc.), and crop characteristics (genotype, density, age, etc.). The technical subsystem is the whole set of components across time and space called "field interventions," which are the actions performed on a daily basis by farmers in a field or a group of fields and which work together to manage the biophysical subsystem under the constraints of farm resources (e.g., labor). These field interventions are combined by the farmer in space and time in "technical management sequences" with sufficient interactions to be considered a system. Field interventions may also be grouped by theme in "technical operations" when they have the same target, such as pruning (target = plant vigor) or phytosanitary treatments (target = pests and diseases) (Fig. 1). The technical and biophysical subsystems are influenced by the decisional subsystem, which comprises decision rules for crop land allocation, crop combinations (in space and time), and crop management (Le Gal et al. 2010). These decision rules are activated by management indicators (Fermaud et al. 2016).

The framework described in Fig. 1 allows for an integrated analysis (i.e., multiple scales and multiple subsystems) of cropping system complexity to take into account the number of components and their interactions across a farming system's three subsystems (biophysical, technical, and decisional).

2.1.2 Indicators to analyze cropping system complexity

Using information that can be gleaned from interviews with farmers, we defined six complexity indicators (Fig. 1). In the biophysical subsystem, the *vineyard area* in production and the *number of fields* in production were analyzed at vineyard scale. We also identified the dynamics of *fields pulled out* of production (i.e., grapevines removed), especially if the farmer considered the fields difficult to manage. Winegrowers have three land use possibilities after removing grapevines: replant young grapevines for decades-long production, grow a different type of crop, or leave the land fallow. The complexity indicators in the technical subsystem were the *number of*

Fig. 1 Conceptual representation of the cropping system. The cropping system is composed of a biophysical and a technical subsystem in interaction under the influence of a decisional subsystem. The biophysical system is composed of fields each corresponding to a crop-pest-soil system. The technical system is a set of technical management sequences divided into technical operations, and the decision system is a set of management indicators used for decision-making. The complexification is analyzed throughout six complexity indicators (number of fields in production, number of difficult fields, number of field interventions, number of technical management sequence TMS, number of management indicators, and vineyard area) related to the different components of these three subsystems of the cropping system



technical management sequences, calculated at vineyard scale (e.g., all of a vineyard's fields) and the *number of field interventions*. Two *technical management sequences* were considered to be distinct if they differed on at least one technical operation with possible impact on field performance. In practice, these differences resulted in varying rates of input use (e.g., labor) or the use of different equipment, knowledge used to manage inputs or groups of fields to which inputs are applied. The number of field interventions was assessed for each vineyard's most complex and simplest technical management sequence, i.e., the technical management sequence with the highest and lowest number of field interventions, respectively. This indicator was assessed for all field interventions together, then for phytosanitary and soil management interventions only. In the decision subsystem, we considered the management indicators used by the winegrower to act on one component of the biophysical subsystem such as soil (e.g., soil behavior when drying) or a disease (e.g., plant vigor affecting sensitivity to powdery mildew). The *number of management indicators* was analyzed at vineyard scale. These six indicators were selected for their quantitative aspect and calculated by taking into account the information available through interviews with winegrowers. The framework defined in Fig. 1 uses these six indicators across the three subsystems to analyze the structural complexity of the cropping systems (i.e., the number of components in each subsystem). It does not, however, aim to analyze the interactions among subsystem components required to be able to analyze functional complexity. Nevertheless, we assume that as the number of components increases, the number of interactions among them is likely to increase as well, thereby linking structural and functional complexity.

2.2 Framework application to the analysis of vineyard conversion to organic viticulture

Our research was carried out in the Languedoc region in southern France, which has a Mediterranean climate. We focused on vineyards that had converted to organic farming in 2008 or 2009 and for which winegrowing was the main activity.

The farm sampling grid was defined so as to cover a large range of vineyard situations and constraints with regard to vineyard cropping system management and performance. The sample of interviewed vineyards was based on a three-factor classification of the vineyards in the study area:

I. Vineyard area: Our hypothesis was that a farm's vineyard area has an impact on labor constraints and its capacity to adapt to organic viticulture. We considered four types, which were determined using the thresholds of 5, 10, 20, and 35 ha. We choose to exclude small vineyards (<5 ha) as they would not be considered economically viable in the Languedoc region.
II. Winemaking criteria: A distinction was made between winegrowers associated with a cooperative or having their own wineries. Our hypothesis was that winegrowers with their own wineries have greater room to maneuver with regard to technical and economic aspects than winegrowers associated with a cooperative (excluding labor).
III. Soil and landscape zone: Pedoclimatic constraints were characterized by three soil and landscape zones. Our hypothesis was that disease risk and soil operation constraints varied by type of soil and local climate. We focused on three typical soil and landscape zones for the region (A—Faugères, B—Montagnac, C—Vergèze, and coastal) as described by Coll (2011) and which represent a diverse range of water deficit and pest pressure.

We choose to interview one vineyard per cell from the sampling grid due to the time required for the interviews. The vineyards were identified using Agence BIO's directory (http://annuaire.agencebio.org/), which lists vineyards from the first year of conversion. Considering that certain criteria combinations do not exist in reality (e.g., >40 ha × winemaking = no; >40 ha × zones A/C × winemaking = yes; 5–10 ha × zone C × winemaking = yes; 5–10 ha × zone A/C × winemaking = no), 16 vineyards were surveyed between 2008 and 2012. Vineyard areas varied from 5 to 36 ha and the number of fields varied from 9 to 34 fields.

A detailed survey of the three subsystems described in Fig. 1 was conducted on the 16 vineyards, with the number of variables to collect for each vineyard field on a farm being a limiting factor both for researchers and winegrowers. We focused on the European organic label (European Council Regulation EC No. 834/2007) and the official 3-year conversion period to analyze changes in each vineyard. The survey was separated into two phases: an interview at the beginning of the conversion phase (year n-3, 2008, or 2009 for most vineyards) and a second interview the first year the vineyard was certified in organic viticulture (year n). Each of these interviews (two interviews per vineyard) lasted between 2 and 3 h.

The first interview of the survey collected general information on the vineyard and production factors before conversion, field description, and elements to differentiate the various fields taken into account by the winegrower in conventional viticulture, the various technical management sequences before conversion, and the indicators of decision-making associated with these technical management sequences. The second interview collected the various technical management sequences after conversion, the management indicators of decision-making associated with the various technical management sequences, field description and elements to differentiate the various fields taken into account, and the production factors used (vineyard area, equipment, etc.) by the winegrower when the vineyard was fully converted to organic viticulture. Qualitative information on performances (yields, weed control, pest and disease control, quality) were also collected, as well as quantitative information related to labor changes. Yield and grape quality are two especially difficult indicators to assess in vineyard systems. The main reasons for this are that winegrowers use different units to express yields (hl ha^{-1} or T ha^{-1}), plant density in the field may change from year to year (meaning that yield dynamics at the field or plant scale can differ), and yield objectives may vary considerably from one vineyard to another, making it impossible to easily compare two vineyards. We therefore chose to ask winegrowers to provide their personal assessment on yield dynamics instead of quantitative data. With regard to labor, we identified the number of workers per hectare before and after conversion. The number of workers per hectare is calculated using both the permanent and temporary workers and the vineyard area. We calculated the percentage of labor changes between organic viticulture and conventional for the 16 vineyards surveyed. When other cropping systems were present on the farm (e.g., cereals), they were not analyzed as they represented a minor share of the area. Winemaking and commercialization were only considered as contextual elements of the system at farm level but were not analyzed as biophysical or technical systems.

We summarized useful information to analyze the interviews. First, the whole group of fields was represented on a paper and the various characteristics of these fields were indicated on the figure. This figure enabled us to analyze the field and vineyard area dynamics. This was also a good way to discuss the changes in the technical subsystem. We then identified the most frequent technical management sequence for the vineyard and the adaptations for each field (along with the corresponding management indicators). The second step was to analyze the changes in the technical and decisional subsystems. Finally, we created a table summarizing all the general information on the vineyards, the values of the six indicators before and after conversion, and the qualitative data on performances (pedoclimatic zone, winery, vineyard area before/after conversion, number of fields, etc.). This database was used for final analysis and the figures presented in this article. Statistical analyses were performed with R statistical software (R Core Team 2015). Differences between data before and after conversion were tested using paired *t* tests (Logan 2010). Differences between pedoclimatic zones, winemaking, or area classifications were tested using Kruskal-Wallis tests and hierarchical clustering. Hierarchical cluster analysis was used to determine the typology of vineyards in conversion.

3 Results and discussion

3.1 Change in the degree of complexity of the biophysical subsystem

The "number of fields" and "vineyard area" complexity indicators show that the biophysical subsystem did not evolve in the same way for all vineyards during conversion (Fig. 2a). The vineyard area remained unchanged in 6 of the 16 vineyards, increased in 6 vineyards, and decreased in 4 vineyards. Only two vineyards showed an increase in both vineyard area and the number of fields (Fig. 2a). The variability of the number of fields per vineyard in our sample was high (5 to 34 after conversion). This range is not specific to organic

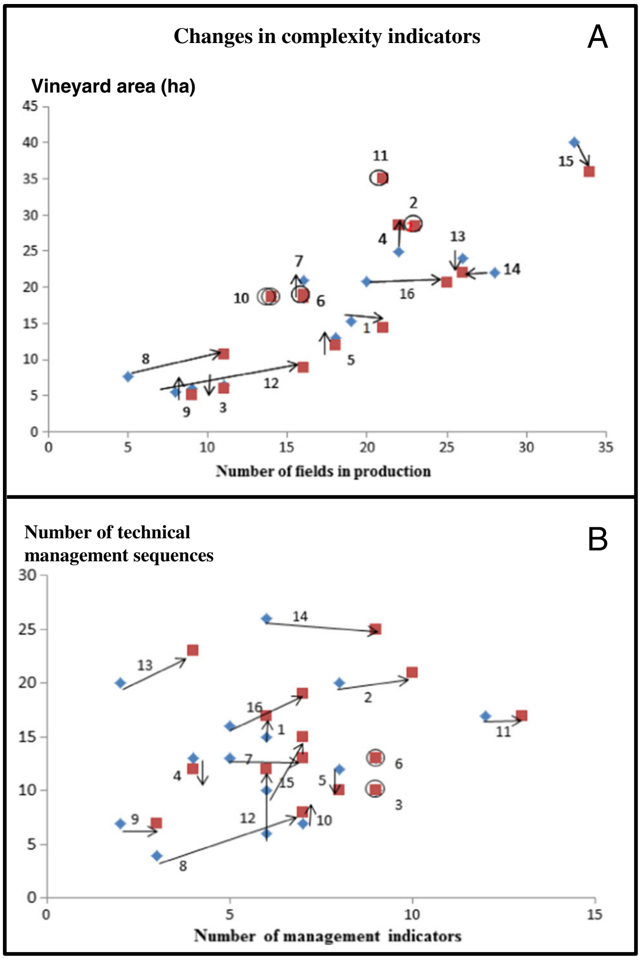


Fig. 2 For the 16 farms interviewed, **a** represents the dynamics in the vineyard area related to the number of fields in production. **b** The dynamic of the number of technical management sequences and the number of management indicators. Conventional farming is represented by *diamonds* and organic viticulture by *squares*. The *arrows* show the dynamic from conventional to organic viticulture for the various farms

viticulture and can be observed in conventional vineyards in the region as well. Field size was relatively small (0.25 to 2 ha maximum per field), which is typical of the region's vineyards.

For most of the vineyards (10 of 16), the number of fields remained unchanged during the conversion to organic viticulture. However in vineyards 4, 5, 7, and 9, vineyard area was higher after conversion, indicating field turnover and rearrangement. The number of fields increased for one third of the vineyards and decreased for only one vineyard.

The dynamics of the group of fields during conversion was given particular attention, with both the number of fields and young vineyards not yet contributing to grape production being taken into account. Results show that 12 of the 16 farms pulled out fields whereas only 7 planted or purchased fields. For the majority of vineyards, fields were pulled out before conversion (6 of 16) or at the start of conversion (5 of 16), while 6 of the 16 vineyards planted new fields during the conversion. An accelerated turnover of fields with the conversion to organic viticulture can also be noted in 12 of the 16 vineyards: (i) in most of the vineyards, more fields were pulled out than planted, and (ii) 8 of 16 winegrowers considered the fields for which vines were pulled out before conversion too difficult to manage for organic viticulture. These management problems with regard to organic viticulture rules were related to (i) waterlogging or stones in soil that limit soil tillage, which is nearly unavoidable in organic viticulture for herbicide-free weed control, (ii) high pest and disease pressure or varieties that are highly sensitive to pests and diseases that raised the risks of yield and grape quality losses, (iii) varieties with a high potential for vegetative growth that require more work to control plant vigor (thinning, bud pruning, winter pruning), which is necessary to reduce pest and disease pressure, and (iv) low inter-row width limiting mechanized operations on soil and plants when used to replace pesticides (e.g., soil tillage instead of herbicide). As a result, in vineyards 2, 4, 5, 7, and 9, the number of fields remained stable during conversion; although they showed no apparent changes, the number of difficult-to-manage fields actually decreased. These fields were removed from the system in favor of vineyard fields designed specifically for organic farming by using varieties that are less susceptible to disease, adjusting plant density, and adapting inter-row width to equipment. Other cases of pulling out fields were not linked specifically to conversion but were part of field dynamic patterns linked to decreasing yields in old fields.

The three indicators of biophysical complexity of the cropping system at farm level (number of fields, number of difficult fields, and vineyard area) were sensitive to the conversion to organic viticulture and provide complementary information for each vineyard. The vineyard area associated with the number of fields (Fig. 2a) showed a change in pulled-out fields that could be masked with the analysis of the number of fields alone. Some of these fields were pulled out and replanted with easy-to-grow varieties in organic viticulture or with the same characteristics (density, architecture, and varieties) as other fields. Thus, the increase in biophysical subsystem complexity characterized by an increase in both the number of fields and the vineyard area was limited to two farms (8 and 12). Conversion to organic viticulture in those cases was linked to the extension of the vineyard area.

3.2 Change in the degree of complexity of the technical subsystem

3.2.1 Number of field interventions

Conversion to organic viticulture increased the number of field interventions by 15% on average (Table 1), although they varied widely between vineyards (0 to 57%). Three vineyards (3, 6, and 12) showed no changes in the number of field interventions during conversion, while five showed considerable changes for this indicator. Conversion to organic viticulture resulted in an average increase of 25% in soil interventions and 14% in phytosanitary interventions, with significant differences between vineyards. This can be explained by the fact that certain vineyards were already more closely aligned with organic viticulture standards before their official conversion, especially with regard to herbicide-free weed control.

3.2.2 Technical management sequences

At vineyard scale, the number of technical management sequences was assessed before and after conversion (Fig. 2b). Considerable differences exist between vineyards. In all, 69% of the vineyards underwent changes during conversion: the number of technical management sequences increased in vineyards 1, 2, 8, 10, 12, 13, 15, and 16 and decreased in vineyards 4, 5, and 14. There was no change for vineyards 3, 6, 7, 9, or 11. For all vineyards, the number of technical management sequences was lower than the number of fields (Fig. 2b). This means that for all vineyards, winegrowers considered some fields similar in term of management despite certain biophysical entities (soil, variety, density, etc.). They therefore simplified the natural biophysical diversity to ease the technical management of the farmland. The change in the number of technical management sequences during conversion to organic viticulture was significantly influenced by the pedoclimatic zone (Kruskal-Wallis P value = 0.0108). In zone A, the number of technical management sequences increased whereas it decreased in zones B and C. This is due to soil heterogeneity in zone A, which combines stony soils in hilly areas and deeper soils in plains.

Table 1 Changes in the number of field interventions (FI) during the conversion in the set of vineyards for the simplest technical management sequence (TMS) and for the more complex TMS

	Before conversion			After conversion			Evolution after-before		
	All Fl	Soil Fl	Pests and diseases Fl	All Fl	Soil Fl	Pests and diseases Fl	All Fl	Soil Fl	Pest and disease Fl
Simplest TMS[a]	19.5	3.7	6.9	23.2	5.8	8.6	21%*	73.%*	28%*
More complex TMS[a]	22.3	4.4	7.5	27.2	6.7	9.9	23%*	70%*	37%*

In this study, we distinguished the soil interventions and the pest and disease treatments

*Significant *t* test ($P = 0.05$)

[a] In terms of nFl and nTMS

3.2.3 Change in the technical subsystem complexity

While the biophysical subsystem complexity increased in some vineyards only, the complexity of the technical subsystem increased in all vineyards during the conversion to organic viticulture. The number of technical management sequences and the number of field interventions were significantly higher after conversion than before, especially with regard to soil interventions and pest and disease control. This increased structural complexity of the technical system made the vineyard more complex for the winegrower to manage. The increase in the number of technical management sequences (for the same number of fields) showed that the conversion to organic viticulture required improved adjustment of the technical interventions to the biophysical diversity of the fields, thereby increasing the number of links between the technical and the biophysical subsystems. This type of management approaches precision agriculture and necessitates more knowledge of the system and its processes and therefore more information (Morgan and Murdoch 2000) when the objective is to maintain a high level of performance for the whole system.

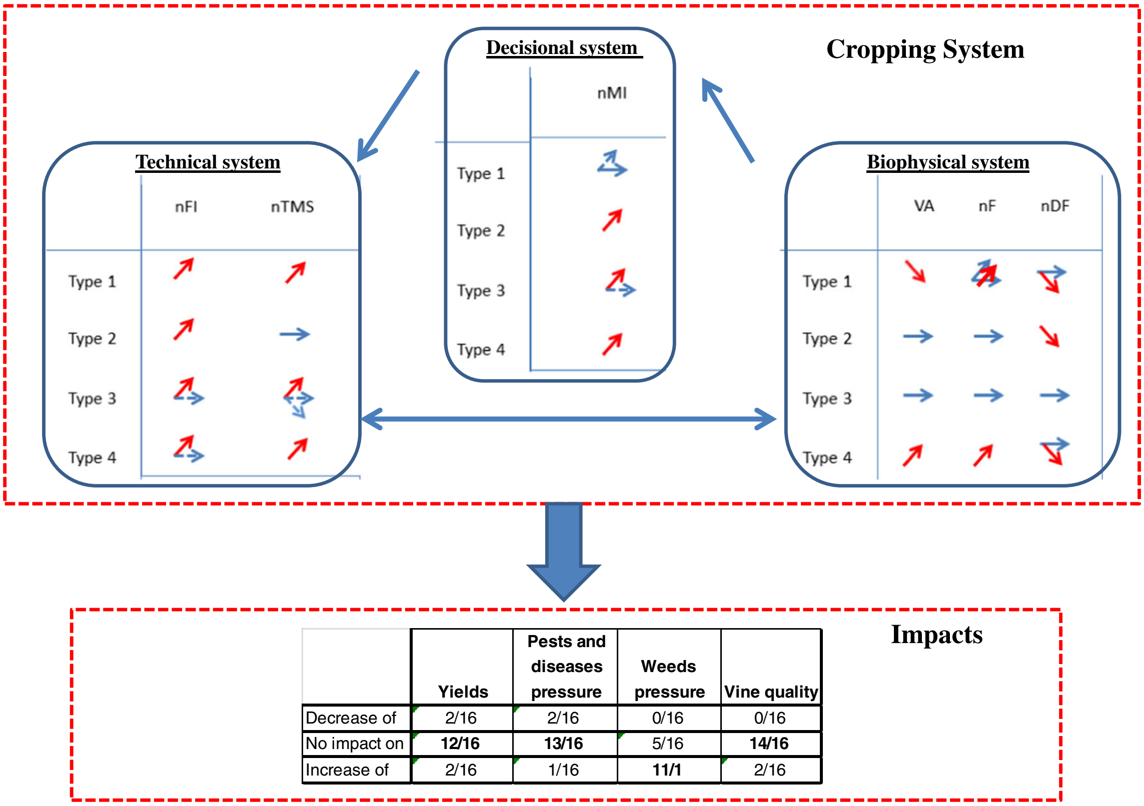
3.3 Change in the degree of complexity of the decisional subsystem

The number of management indicators after conversion varied from 2 to 13 between vineyards (Fig. 2b). The number of management indicators increased with the number of fields (Fig. 2a), most likely because the biophysical diversity that has to be managed rises with the number of fields up to a certain threshold (here, around 22 ha), where labor limitations impose choices between the number of management indicators used and the number of fields on which they are observed. The number of management indicators increased during conversion to organic viticulture in 9 of the 16 vineyards (Fig. 2b), while remaining steady for six of them (1, 3, 4, 5, 6, and 10) and decreasing for only one of them (12). This suggests that organic viticulture requires more knowledge and real-time information on the status and variability of each field's biophysical entities (soil, crop, pests, and diseases) and on the field environment (micro-climate, effect of hedges, etc.). The change in the number of management indicators during conversion was significantly influenced by each vineyard's winemaking objectives (Kruskal-Wallis P value = 0.00171). In fact, for winegrowers associated with a cooperative, the number of management indicators increased strongly (5.9 in conventional and 7.9 in organic viticulture) whereas it increased only slightly (6.4 in conventional and 6.6 in organic viticulture) for winegrowers with their own wineries. This can be explained by the fact that winegrowers with their own wineries were more closely aligned with organic viticulture standards before conversion.

The decisional subsystem became more complex with the conversion to organic viticulture (i.e., the number of management indicators increased) compared to the technical subsystem. This is typical of a cropping system diversification process requiring intensive skills, knowledge, and information (Morgan and Murdoch 2000). Organic viticulture likely requires better real-time characterization and understanding of the biophysical subsystem behavior and dynamics. When converting to organic farming, winegrowers took greater care of field diversity to better adjust field interventions through the date of intervention, pesticide and fertilizer doses, and the choice of fields. This is a direct consequence of the lower efficiency of organic techniques with regard to labor efficiency and grape production (e.g., mechanical weeding, less effective fungicides, etc.) while production objectives (yield and quality) are maintained at the same pre-conversion levels.

3.4 Change in the degree of complexity of the whole cropping system

The six indicators show that converting vineyard systems to organic viticulture leads to an increase in complexity (Fig. 3) of the three cropping system subsystems. This set of indicators made it possible to break down this complexity within the three subsystems (Fig. 1), each characterized by one or two



	Yields	Pests and diseases pressure	Weeds pressure	Vine quality
Decrease of	2/16	2/16	0/16	0/16
No impact on	**12/16**	**13/16**	5/16	**14/16**
Increase of	2/16	1/16	**11/1**	2/16

Fig. 3 The changes in complexity for the four vineyard types established on the pattern of changes during conversion to organic viticulture of the six complexity indicators (*red arrows* for changes in complexity and *blue arrows* no change). Consequences on the agronomic performances are also presented in the performance box

indicators. These indicators have been selected to be easy to understand, not redundant (Herrick 2000), and easy to calculate from information collected during farmer interviews.

When combined in statistical analysis, these indicators enable us to categorize the vineyards into four types in terms of increased complexity during organic viticulture conversion (Fig. 3): type 1 (vineyards 1, 4, 11, 15), type 2 (2, 7, 9, 14), type 3 (3, 5 6, 10), and type 4 (8, 12). It is interesting to note that while all vineyard types experienced an increase in complexity, only type 4 saw an increase across all three subsystems at once. For types 2 and 3, we observed no increase in biophysical subsystem complexity, whereas there was an increase in complexity for type 4. For type 1, vineyard area decreased and the number of fields increased or remained stable. The technical subsystem was more complex after conversion for types 1, 3, and 4. The number of technical management sequences did not change for type 2. In the decisional subsystem, the number of management indicators was higher after conversion for types 2, 3, and 4, leading to greater complexity. Finally, complexity rose significantly for type 4 because it involved all three subsystems. For type 2, there was merely a slight increase in complexity that concerned only two indicators. For types 1 and 3, three indicators showed an increase in complexity after conversion to organic viticulture.

Pedoclimatic zone was the criterion which most strongly influenced the increase in complexity during conversion to organic viticulture. This is most likely because it influences weed growth, pest and disease pressure, field accessibility (e.g., for treatment after rain), and soil workability for mechanical weeding (Mueller et al. 2011).

3.5 Changes in cropping system performances during the conversion to organic farming

The analysis of cropping system performances, as declared by winegrowers, showed that yields did not decline during the conversion to organic viticulture in 14 of the 16 farms (Fig. 3). The two other farms are characterized by a decrease in yields and a major increase in technical system complexity (type 1). Grape quality remained stable for 14 of the 16 vineyards. According to the winegrowers, pest and disease pressure was also unchanged during conversion for 13 of the 16 vineyards. However, weed pressure rose sharply in 11 of the 16 vineyards (Fig. 3). For 11 of the 16 vineyards, labor requirements (permanent and temporary) increased with the conversion to organic viticulture (Fig. 4—vertical axis). The extent of this increase—a median of 13.3% and a maximum of 44.4%—was significant given how high labor costs are for

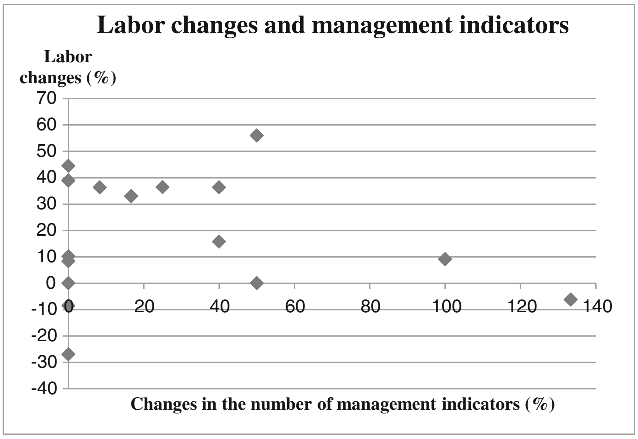


Fig. 4 Labor changes related to the changes in the number of management indicators between organic conventional viticulture

French winegrowers. This larger workload is mainly related to the increase in cropping system complexity (Fig. 4); for example, an increase in the number of management indicators (meaning increased complexity of the decision subsystem) results in greater labor requirements. This is explained by higher weed pressure and mechanical and manual weed control. For 2 of the 16 vineyards (6 and 14), the number of workers per hectare was unchanged. The shift to organic farming therefore led to a more complex cropping system with fewer chemical inputs but more labor. For vineyards 8 and 12, the number of workers per hectare dropped during conversion, which is consistent with the increase in vineyard area related to the plans for growth and the beginning of grapevine cropping activities.

4 Conclusion

Our study shows that the changes in vineyard cropping system complexity during the conversion to low-chemical input (e.g., for organic viticulture) can be analyzed using a set of six indicators across three subsystems. Our framework is likely to be useful for a wide range of cropping systems that may be simpler than vineyards (e.g., based on arable crop rotations) or more complex, such as in mixed farming or agroforestry, or for the study of other types of farm transitions (e.g., to conservation agriculture). Conversion to organic viticulture increased the complexity of the three cropping system subsystems (Fig. 1): biophysical, technical, and decisional. Different types of farm dynamics were observed depending on the subsystems impacted by the increase in complexity. This increased complexity was not associated with yield losses or reduced quality, but in most cases was associated with a significant increase in labor requirements. Our data do not allow for an analysis of how this would impact farm profits, but it is likely that any impacts will depend on the balance between the price premium on organic wine and the cost of labor. Defining and managing this increase in complexity for every farm type is likely to be essential for ensuring sustainable farm transitions. Our framework could be used in a pre-conversion diagnosis of a system’s complexity and the expected impact of organic farming.

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