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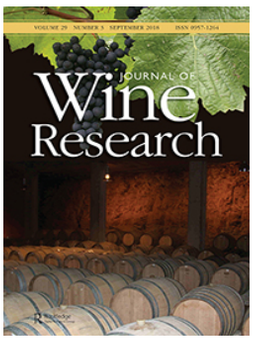

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Typing winegrower profiles to ease agroecological change in viticulture practices in the Loire Valley, France

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ABSTRACT

Viticulture is a perennial agricultural system that is rooted in tradition but must also adapt to change (e.g. climate change, authorized rate of pesticide uses in the European Union). Viticulture includes a variety of practices whose objective is to produce wine grapes. To help viticulture systems adapt to changes, both field viticulture practices and value chain activities within winegrower networks must be considered. Here, we used socioeconomic and technical surveys to investigate these potential influences on winegrowers' decision-making in regard to adapting to changes, so as to develop a typology of winegrowers in the Loire Valley, France. The surveys were conducted in 2010 with 37 winegrowers managing 56 fields. To our knowledge, this study is the first to use this method to quantify viticulture networks. Our results showed that winegrowers within the same networks share similar behavioural patterns, with non-harvest viticulture practices (e.g. vine density planting, number of buds) characterizing winegrower profiles. Further, our typology reveals viable options for changing practices in a manner that aligns with the sociocultural characteristics of each profile. Agricultural extension services can especially make use of this typology as a starting point to help winegrowers adapt to changes in a more personalized and successful way.

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Viticulture; winegrower networks; Loire Valley; agroecological change

Introduction

In response to environmental and/or legislative contextual changes brought about by various inevitable (e.g. climate change) and avoidable (e.g. air pollution) agroecological issues, farmers must decide how to adapt their growing practices accordingly. Many large-scale methods have been developed to manage the objectives and actions required (McFadden et al., 2011). The resilience-experimentalist ('with high emphasis on stakeholder and complex models') and decision-theoretical ('with simpler models') frameworks are often used in adaptive natural resource management (McFadden et al., 2011). At regional and local levels, farm profiling has also been applied (Kostrowicki, 1977;

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Landais, 1998) to assess the current situation and evaluate adaptations and responses to innovations introduced into cropping systems.

Various practices derived from different methods have been used to characterize annual crops. Deffontaines and Landais (1988) defined grain and oilseed crop systems. Perrot (1990) developed definitions for dairy systems. van der Ploeg et al. (2009) analysed and conceptualized farming diversity and demonstrated technical, societal, and multifunctional ties among farms with similar cropping systems. Several authors described cropping system practices that were believed to be logically organized to achieve specific farming goals, such as the impact of the cropping system on production quality and quantity (Debaeke et al., 2009; Loyce et al., 2002).

Such examples of farm profiling are often descriptive and qualitative and seldom include univariate or multivariate statistical analyses of cropping system practices. Moreover, they rarely account for farmers' social networks. However, socially-derived criteria may explain the observed agroecologically motivated changes in cropping practices (e.g. organic certification, grassing between vines to decrease runoff, promoting vineyard biodiversity), such as those seen in Burgundy vineyards to increase system sustainability (Compagnone, 2005). In the present study, we used multivariate data for technical and trade networks to develop tools to assess vineyard management, highlighting variability on the ground in terms of winegrowers' adaptive responses to a variety of agroecological issues.

Analyses of production systems are often used to quantify socioeconomic and environmental performance or output variables such as work satisfaction (Besser & Mann, 2015), profitability (Ash et al., 2015), and climate change (De Salvo et al., 2015). For this reason, product origin labels should be designated as input variables. For many years, much of the wine in France has been produced in delimited geographical areas in accordance with local production rules and methods including (i) those related to a protected designation of origin (PDO) of the product and (ii) distribution, sales, and marketing organizations. The PDO (INAO, 2016) describing France's wine production areas incorporates human factors (e.g. collective knowledge of a village's winegrowers, vine planting, and management practices) that manage economic development and environmental changes. PDO fields may be described using the precise combined knowledge of the winegrower practices and social profiles that are regarded in the present study.

Separate and combined technical analyses of viticulture practices and wines have been used to explain differences in PDOs. Indeed, several techniques are available to assess terroirs, using vineyard characteristics such as experimental plots, winegrower surveys, statistical analyses, and soil assessments in the natural environment (e.g. altitude, slope, aspect, and insolation) (Morlat & Lebon, 1992). Other studies applied more complex analytical methods involving vineyard and wine cellar practices. Morlat and Symoneaux (2008) related organic matter fertilization to field-scale grape and wine quality. Renaud-Gentié et al. (2014) combined several vineyard practices at the field and farm scales to assess their environmental impacts according to the technical management route. And Thiollet-Scholtus et al. (2014) characterized various PDO Loire Valley wines according to viticulture and oenology practices and the sensory attributes of the wines. Moreover, Thelier-Huche and Morlat (2000) characterized differences in product quality among vineyards by combining field-scale technical and social analyses, including quantitative measurements and farmer perception surveys.

With the above in mind, understanding the diversity and practical characteristics of farm profiles helps farmers adapt their practices to agroecological and climate change. The aim of the present study was to type or define such profiles for winegrowers, identifying practices that are crucial to winegrowers' decision-making in response to challenges posed by unpredictable events. We characterized these profiles according to both viticulture practices and social networks and sought to present all possible combinations thereof, inclusive of winegrowers' memberships in technical and trade networks and product marketing strategies. To these ends, the assessment tools we developed identify levers and obstacles facing winegrowers confronted with various forms of change, specifically that of climate change (Battaglini et al., 2009; Neethling et al., 2016). The present study may be the first to consider the often-overlooked association between viticulture practices in vineyard systems and winegrower social networks and their influences on the decisions winegrowers must take to respond and adapt to inevitable changes in their local settings. We therefore anticipate that this will be of help to winegrowers, as they seek appropriate sources of advice and guidance to adapt most effectively in their local contexts.

Materials and methods

Loire Valley vineyards as a case study

The Loire Valley encompasses four geographical areas that cover 70,000 hectares (ha) and produce four million hectolitres (hL) of wine annually. Muscadet, Sancerre, and Touraine contain 69 of the 85 Protected Designations of Origin (PDO) that yield regular- to high-quality still white wines (Figure 1). Anjou was not included in the present study as it produces mainly red wines.

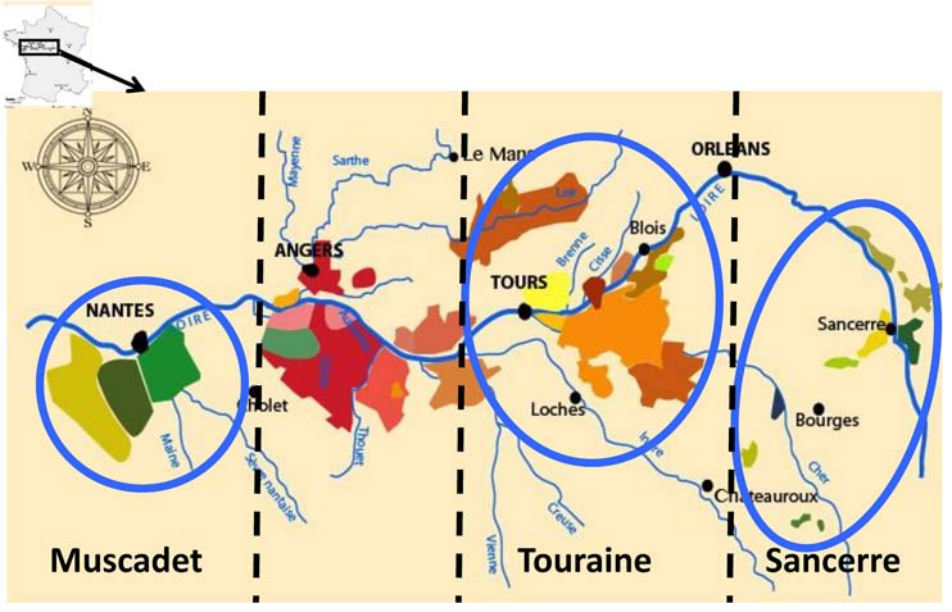

Figure 1. Locations (circled) of the vineyards studied in the Loire Valley, France.

These geographical areas have the following characteristics:

- Temperature and precipitation gradients: (i) strong oceanic influence in Muscadet, (ii) moderate oceanic influence in Touraine, and (iii) weak oceanic influence in Sancerre (Quénol et al., 2014).
- Wine prices in the Loire Valley vary by quality and area. Sancerre produces 'high-quality' wines on 2,900 ha of vineyards. Touraine and Muscadet produce 'regular-quality' wines on 12,600 and 10,300 ha, respectively (InterLoire, 2019).

With the assistance of agricultural extension services in Muscadet, Sancerre, and Touraine, winegrowers and fields were selected at random to ensure heterogeneity of the regional climate and wine prices. The focus was on winegrowers who had a mean vineyard area of $\leq$10 ha. Initially, the winegrowers who were contacted belonged to various networks including public and private winegrower advisors, winegrower contractors, producer associations, and other winegrowers. Thereafter, snowball sampling was implemented, in which the winegrowers surveyed were asked to identify others who's technical and trade networks differed from their own. The ultimate goal was to compile a representative series of winegrowers. As snowball sampling depends on voluntary responses, however, it does not ensure full representation. The final sample of 37 winegrowers amply represented the overall area of the Loire Valley. However, results similar to those obtained here were reported by studies that assessed relatively fewer sites, such as the 22 surveyed in the Argentinean Pampa by Salembier et al. (2016).

Within each vineyard, representative fields were selected according to the dominant white grape variety characteristic of that area: (i) Sauvignon Blanc in Sancerre and Touraine and (ii) Melon de Bourgogne in Muscadet. This sampling approach ensured that grape variety did not contribute to any of the diversity observed in farm profiles and practices. The winegrowers selected their field samples according to the following criteria: (i) each field represented a dominant viticulture system and (ii) no more than three fields were chosen per vineyard to represent the diversity in field quality (low-, medium-, and high-price). Of the 37 winegrowing sites, 56 individual field plots were selected that encompassed the diversity of wine-selling strategies and viticulture practices of the vineyards in each area. We defined 'wine selling strategies' as how winegrowers chose to sell their wines (e.g. 100% to a co-operative, merchants, or restaurants; 100% in direct sales from their own cellars; a mixture of 30% to restaurants, 30% to merchants, and 40% in direct sales).

Data collection

A graduate student conducted two different surveys on two separate site visits to each vineyard. The first survey was completed in April 2010. It contained open-ended questions intended to define fixed winegrower typologies (Supplementary Material 1). It also contained 95 closed questions addressing the major characteristics of the farm, sales, marketing, workers, viticulture, oenology, information, communication, public relations, and winegrower concerns. Wine production topics included geographical, historical, and human factors. There were no questions about modification of practices or the winegrower's ability or willingness to change practices (Supplementary Material 1). The

initial survey collected essential information about the decision-making process that winegrowers use for viticulture practices (Kostrowicki, 1977).

The second survey contained 19 closed questions addressing the cropping system practices involved in grape production, including vineyard training, annual viticulture, and harvest (Supplementary Material 1). The surveys were completed by May 2010. They characterized viticulture and production practices in each field. Questions were related only to the general management practices associated with producing PDO white wines in each of the three geographical areas of this study. The surveys did not attempt to account for the complexities and interrelationships of cropping systems. These have since been addressed in an earlier study (Renaud-Gentié et al., 2014). The conclusions of the trade (winegrower) and technical (viticulture practice) surveys were used to propose the opportunities or restrictions to change in viticulture during ecological transitions.

We would like to acknowledge here that, though no further data collection has taken place since the completion of the study in 2010, others have begun to assess winegrowers' perceptions of their ability to adapt to agroecological and climatic changes. This includes Neethling et al.'s (2016) interviews with winegrowers in 2012 and 2013 in Anjou-Saumur, who tended to be reactive to agroecological changes. And Teil's (2020) interviews conducted between 2012 and 2015 in Anjou and Alsace with winegrowers who not only adapt regularly to weather variations but also concentrate efforts on helping the vines to adapt to perceived change. Both studies were part of the larger 2012–2016 Long-term Adaptation to Climate Change in Viticulture and Enology (LACCAVE) project organized by what is now known as the INRAE (Ollat et al., 2018), which has in part investigated future adaptation scenarios among vine-to-wine participants. In addition, Iliff's (2020) exploratory research of interviews among winegrowers in the Pays Nantais, which were published throughout the last decade, highlights tensions between climate change and legislative/marketing restrictions. Combined with these previous efforts, we anticipate the application of our typology to ongoing and future studies will be of benefit as researchers refine or develop their own assessment tools and as winegrowers decide whether and how to implement potential adaptations (van Leeuwen et al., 2018), many of which we discuss here.

Method of profiling winegrowers

Previous studies devised innovative methods to describe farm diversity (Doorman, 1990). Our approach was to establish winegrower profiles based on the study of Kostrowicki (1977) and on additional parameters related to social aspects of the farming system. The survey framework and winegrower classification system were inspired by descriptions of farm style diversity of van der Ploeg et al. (2009). We assumed that winegrowers could be categorized according to an established typology by identifying the extent to which technical and trade networks supported changes in viticulture practices.

To develop a fixed typology based on winegrower networks, the first survey was textually analysed, based on the pioneering strategic analyses of Crozier and Friedberg (1977) and Martin (2012). The objective was to understand the patterns that might emerge when winegrower networks present opportunities for organized, strategic interactions that could enable winegrowers to respond to issues or changes arising in the field

(Olaya & Ruess, 2004). We followed an agricultural constructivist approach (Landais, 1998). The assumptions made for our typology were derived from analysis of our first survey and our expert opinion (F.S., an authority on Loire Valley cropping systems; Sarrazin [2006]; Sarrazin and Lemercier [2002]). We established winegrower profiles based on criteria related to technical and trade networks (Table 1).

The initial typology allowed us to identify the logic behind the adaptive behaviour and decision-making processes of winegrowers. It also identified the organizing forces and local sociotechnical functions of winegrowers and other players. In this way, factors responsible for the cohesion and divergence observed among winegrowers could be identified, including factors that represented opportunities or obstacles to change in viticulture practices.

Statistical characterization of viticulture practices

To identify relationships between viticulture practices and winegrower profiles, discriminant factorial analysis (DFA) was performed on eight quantitative variables to identify which of these were able to discriminate among the winegrower profiles, while a factor analysis of correspondences (FAC) was performed on 11 qualitative variables (Table 2, survey answers #6 and #9). DFAs identify variables best able to discriminate between *existing* groups pre-determined from social profiles, i.e. the analysis does not offer any statistical verification/test of the pre-defined groups. Using DFA and FAC methods together makes it possible to take into account all the practices of the winegrowers when constructing the typology. This makes it possible not to restrict oneself to a few quantitative variables. The technical variables, from the follow-up survey, were selected according to (i) annual viticulture and vineyard training system practices, and (ii) practices that were independent of each other. The 'annual viticulture' practices were considered potential short-term levers for agroecological change, whereas the 'vineyard training system' practices were considered potential medium- to long-term levers for agroecological change.

For DFA and FAC, we assessed winegrower (each of which is a point whose coordinates are calculated from the weighted coordinates of all weighted points in a set). In each set of winegrower fields, each field had the same weight, and the profile barycentre coincided with the centroid. Then, 'Winegrower barycentres' to refer to individual grower centres and 'Profile barycentres' to refer to the 4 group centres. DFA predicted the home cluster for new data that were spatially separated in each analysis. These statistical analyses were performed in XLStat-Pro v. 2009 (Addinsoft, Paris, France). The resulting analysis suggested specific viticulture practices that helped explain winegrower membership in the various technical and trade networks (Supplementary Material 1).

Results and discussion

In this section, we characterize winegrowers according to their social profiles (Tables 1 and 3) and viticulture practices (Figures 2 and 3). We then discuss the extent to which winegrower networks may present levers or obstacles to adaptive options in any context of agroecological change. For DFA and FAC, the coordinates of the variables, profile barycentres, and individual fields of the principal components are listed in Supplementary Material 2.

Table 1. Selected practices used to perform textual network analysis by a social expert (trade network information in green and technical network information in blue).

Structural elements	Distinguishing variables	COP	DIN	NEG	VAL
Farm	Farm size (ha)	6.5 ha small in SAN; 18 ha = middle in TOU	45 ha = large in MU; 16.5 ha = small in TOU	30.6 ha = middle in MU; 16.5 ha = small in TOU	34.5 ha middle in MU; 13.1 ha middle in SAN; 26 ha = large in TOU
	Cropping system	Mixed	Vineyard only	Mixed	Mixed
Selling & marketing	Member of a co-operative network	Yes	No	No	No
	Selling network	100% co-operative in Touraine	Merchants (80%) & direct sales	Merchants (80%) & direct sales	Direct sales, exportation, merchants
	Marketing network	Co-operative grouped	Individual	Individual	Individual
Workers	Workers in the farm	The winegrower and his family	Employees	The winegrower	The winegrower and his family
	Money invested in labour	Low	High	Low	High
	Farmer's age (mean)	55	46	50	44
	Education level	High, medium, or low	Medium	Low	High or low
Viticulture & enology	Money invested in processes	No	Yes	No	Yes
	Subscription to technical journals and networks	Yes	Yes	No	Yes
	Using extension services network	No	No	No	Yes
	Connected to advisors network	Co-operative technician	No one	Trader	Yes
Information/ communication	Affiliation with business network	50% yes	Yes	No	Yes
Public relations	Affiliation with private network (e.g. football, school)	No	No	No	50% yes
Owner concerned (open answer)		Environmental legislation Soil erosion			
			Selling price		Selling price
				Children inheriting	Children inheriting

Table 2. Selected practices used to perform DFA or FAC of the 59 fields studied in 2010 in Loire Valley (France).

Statistical use	TMR position	Name of the practices	Description of practices
DFA (quantitative practices)	Vineyard training system	YEAR	Year of planting of the vineyard
		TRELLIS	Number of wires (1, 2 or 3) in the trellis system used to support the arched vine shoots
		DENS	Planting density of the vineyard (plant/ha)
	Annual viticulture practices	W_PRUN_time	Winter pruning time between October and March
		BUD_nb	Number of buds left after winter pruning
		TOPPING	Height of pruning/topping at the top of the vine (m)
		TOPPING_nb	Number of prunings/toppings at the top of the vine
		HARVEST	Number of days between the harvest date of the plot and the harvest date of the other white wine plots harvested on the farm (days)
FAC (qualitative practices)	Vineyard training system	Variety	Variety of grape planted in the field. MU: Melon de Bourgogne. Sancerre and Touraine: Sauvignon blanc.
	Annual viticulture practices	W_PRUN_TK	Winter pruning technique (one cane Single Guyot; two canes Double Guyot)
		interROW	Cover crop of the soil between vine rows (Fgrass: full-row grass cover, Hgrass: half-row grass cover, CHEM: chemical weeding, TILL: soil tillage)
		underROW	Cover crop of the soil under the vine row (CHEM: chemical weeding, TILL: soil tillage)
		CUTBUD	Cutting buds at the bottom of the vine (yes/no)
		DISBUD	Disbudding (yes/no)
		THIN_clust	Leaf thinning (yes/no)
		THIN_LEAF	Cutting some grapes to control yield (yes/no)
		THIN_LEAFt	Vine physiological period of leaf thinning (no/cluster_closed/harvest)
		CRUSH	Crushing vine shoots after winter pruning to return organic matter to the soil (yes/no)
		BLEND	Blending grapes from the fields just after harvest and before fermentation

Winegrower technical and trade networks correspond to four different profiles regardless of geographical area

In the three geographical areas of our case study (Muscadet, Touraine, and Sancerre), we identified four distinct winegrower profiles (COP, DIN, NEG, and VAL) (Table 3). However, they were not bound to any single area in the Loire Valley. Profile memberships could also overlap.

(1) COP winegrower profiles were found in the Touraine and Sancerre vineyards. COP winegrowers do not invest in additional labour as they either do the work themselves or rely on the assistance of family members throughout the year. The only technical network to which they belong is one that shares equipment with other winegrowers. This practice reduces the burden upon any individual winegrower of incurring the costs for large or specialized processing machinery. COP winegrowers do not consult with any agricultural extension services to make their management decisions. They prefer to read technical literature to educate themselves in viticulture practices. COP winegrowers are affiliated only with co-operative selling networks. Membership in a co-operative network entails (i) signing a closed contract with certain viticulture practices and only a few winegrowers, and (ii) being elected to the co-operative management board and participating in strategic decision-making for the co-operative.

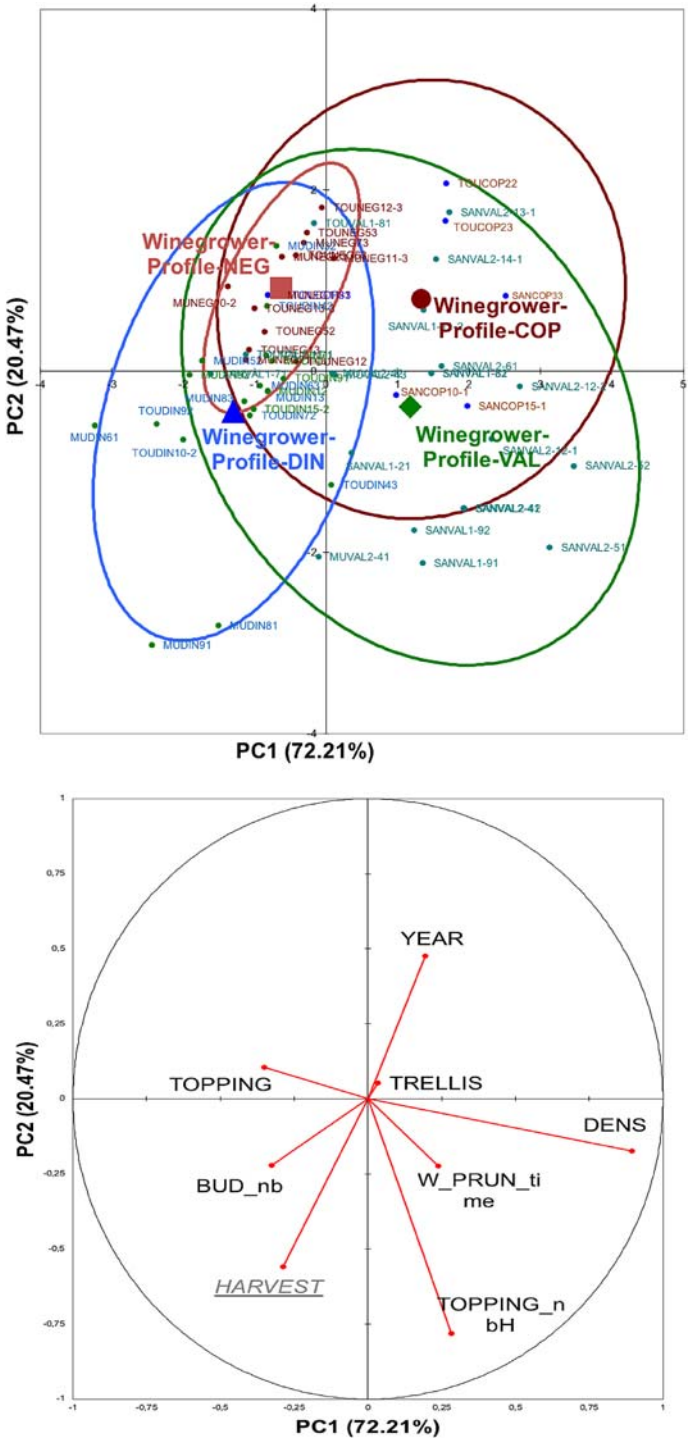

Figure 2. Discriminant Factorial Analysis of the quantitative practices of the cropping system. Winegrower barycenters were projected as illustrative quantitative variables (COP in circles; DIN in triangles; NEG in squares; and VAL in diamonds) on the top. Practices of cropping systems are shown with their banner name in black (e.g. topping) on the bottom. Harvest practice is in grey, underlined and italic.

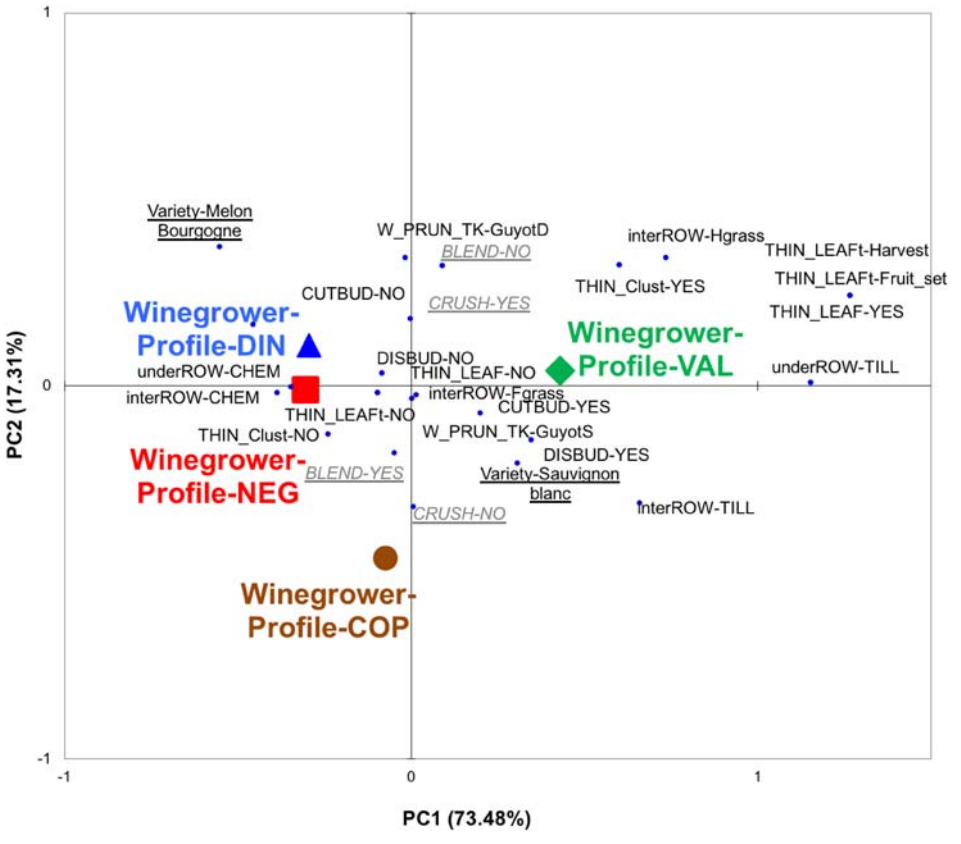

Figure 3. Factor Analysis of Correspondences of qualitative practices of the cropping system. The latter are shown with their names in black (e.g. blending of grapes, tilling of the soil cover crop under the vine row). Winegrower barycenters were projected as illustrative quantitative variables (COP in circles; DIN in triangles; NEG in squares; and VAL in diamonds). Harvest practices are in grey, underlined and italic.

(2) DIN winegrower profiles occurred in the Muscadet and Touraine vineyards. The profiles of the DIN winegrowers lie between those of NEG and VAL. As a rule, they belong only to the equipment-sharing network in the Touraine region, sharing larger equipment so that individual winegrowers need not invest in their own tools. However, DIN winegrowers do not necessarily share the same viticulture practices. For example, one winegrower may prune buds at the bottom of the vine, whereas another winegrower may prefer not to do so. Most winegrowers in the Touraine and Muscadet vineyards do not consult with any agricultural extension services

Table 3. Summary of winegrower profiles according to technical and trade networks.

	NEG	COP	DIN	VAL
Technical network	One	One	One	Several
Trade/selling network	One	One	Several	Several
Technical and trade network interconnections	The same	Different	Different	Different
Likelihood of changing practices	+	++	+++	++++

and thus do not rely upon them for decision-making guidance. Most of the DIN winegrowers are simultaneously engaged in several other technical and social networks, such as viticulture syndicates, city policymaking committees, or sports and school associations. DIN winegrowers are not associated with any particular selling network. They sell up to 80% of their wine to merchants and then sell the rest directly. Most DIN winegrowers expressed the desire to improve their wine selling methods.

(3) NEG winegrower profiles are located in the Muscadet and Touraine vineyards. NEG winegrowers do not share viticulture practices. Moreover, Touraine-NEG winegrowers do not invest in labour and do not consult with any agricultural extension services. They are, however, associated with wine merchants. Touraine-NEG winegrowers depend entirely upon technical and sales contracts with wine merchants and sell them >80% of their product. NEG winegrowers are not affiliated with any other technical networks. They abide by the terms of signed contracts with wine merchants rather than those of PDO-Touraine practices. They do not intend to change their viticulture practices, wine quality, or wine prices, as these parameters are not included in their wine merchant contracts. The wine merchant network encompasses both the technical and trade networks of NEG winegrowers.

(4) VAL winegrower profiles apply to those whose product is highly valued. They occur in Muscadet, Touraine, and Sancerre. Labour investment is high for both the Touraine-VAL and Muscadet-VAL winegrowers. All VAL winegrowers except those in Touraine have strong technical networks based on close ties with agricultural extension services that assist with viticulture practices. Unlike the Touraine-VAL winegrowers, those in Sancerre-VAL and Muscadet-VAL have invested large amounts of time and money in oenological practices and processes to advance their business. VAL winegrowers have extensive trade networks that include direct sales, exportation, and merchants. Many VAL winegrowers have established these multiple points of contact as they believe that selling wine is becoming increasingly difficult. Most of the VAL winegrowers concurrently engage in other technical and social networks, such as viticulture syndicates, city policymaking committees, and sports and school associations. Few Touraine-VAL winegrowers are not associated with these groups.

Winegrower membership in various networks should be considered in the attempt to identify potential obstacles to adaptation to agroecological change resulting from alterations in the environment, climate, law, or culture (Table 3). Battaglini et al. (2009) demonstrated that many winegrowers recognize their need for climate change information to help them plan modifications to their viticulture practices. Technical and trade networks may be used to transmit such information. The DIN and VAL winegrowers in our study had numerous and diverse networks (Table 3). Thus, they may be better equipped to adapt their viticulture practices than the COP and NEG winegrowers. The latter belong to few or even no networks. As they are not part of any formal network, the COP, DIN, and NEG winegrowers may continue to rely on word-of-mouth or the opinions of close friends and family to change their management practices (Table 1). In contrast, VAL winegrowers associate closely with agricultural extension services and may benefit from professional expertise. Nevertheless, they may also be subjected to pressure from their peers to modify their practices accordingly. We found that VAL winegrowers such as those in Burgundy already relied upon agricultural extension services networks to help them

implement more ecologically friendly viticulture practices (Compagnone, 2005, 2014). Moreover, winegrower profiles (Table 3) indicated that technical and commercial networks and their interconnections may favour changes in viticulture practices that increase its sustainability (Chiffoleau & Touzard, 2014).

Winegrowers share the same universal harvest practices but have different viticulture practices

To define our winegrower typology, we considered various vine-to-wine factors. Our analyses revealed a relatively wide range of viticulture practices among winegrowers. As such, winegrower profiles could be characterized based on trade and technical networks, as well as non-harvest viticulture practices.

First, we analyse the percentage of variation between barycentres explained by each axis. According to the DFA, 72% of the profile barycentres of the DIN, NEG, COP, and VAL profiles are explained on PC1. Moreover, the COP and VAL profile barycentres contrasted those of DIN and NEG on this axis. The most important variables correlated with DFA-PC1 are (i) vineyard planting density, (ii) vine top pruning height, and (iii) number of buds remaining after winter pruning. Their correlations with DFA-PC1 were 0.894, −0.352, and −0.527, respectively. According to the DFA, 20% of the individual profile barycentres of the DIN, NEG, COP, and VAL profiles were explained on PC2. The COP and NEG profile barycentres contrasted those of DIN and VAL on this axis. The most important variables correlated with DFA-PC2 were (i) the number of times the vine top was pruned, (ii) number of days between the harvest date of the study plot and those of the other white wine plots on the same farm, and (iii) vine age. Their correlations with DFA-PC2 were −0.780, −0.558, and 0.476, respectively. Our qualitative data revealed other differences among the four profiles. According to the FAC, the DIN, NEG, and VAL profile barycentres were distinguished mainly by PC1 and viticulture practices (Figure 3). In contrast, the COP profile barycentre was characterized by viticulture practices and vineyard training systems. The total inertia of the PC1 and PC2 axes of the FAC was 91% (74% and 17%, respectively). PC1 was characterized primarily by soil tillage management (24% contribution) under the vine row, grape cutting to control yield (9%), leaf thinning to increase sun exposure (9%), and the Melon de Bourgogne variety (8.5%). In contrast, only the COP profile barycentre was found on the PC2 axis, which was characterized primarily by the Melon de Bourgogne variety (16.5% contribution), no vine shoot crushing after winter pruning (12.5%), no harvested grape blending before fermentation (12.4%), and leaf thinning to increase sun exposure (10.0%).

Secondly, we analyse the percentage of each axes explained by different viticulture practices. Taken together, each profile's barycentre appeared to correlate with different viticulture practices, thus providing more evidence for typological distinctions. The COP profile barycentre was correlated mainly with vine age. The VAL profile barycentre was correlated mainly with planting density, selected winter pruning date, and the number of times the vine top was pruned. The DIN profile barycentre was correlated mainly with the number of days between the harvest date of the test plot and those of the other white wine plots on the same farm, and the number of buds remaining after winter pruning. The NEG profile barycentre was correlated mainly with vine top pruning height (Figure 2; Supplementary Material 2). Notably, these patterns differ

markedly from those for the harvest variables, whose practices are similar among all winegrower networks.

Finally, we identify the 3 harvest practices that are the same among the four profiles. Three harvest practices (i.e. CRUSH, BLEND, and HARVEST) were the same among the four profiles. The HARVEST variable follows mainly the PC2 axis of the DFA, which represents only 20% of the total explanation of the axes. The BLEND variable is found on the PC2 axis of the FAC, which represents only 17% of the total explanation of the axes (Figures 2 and 3; Supplementary Material 2). Our data suggest that the three harvest practices are universal levers for managing viticulture change and do not necessarily aid in typing winegrower profiles. Harvest recommendations must be applicable to all winegrower profiles (Figure 2).

Certain details of the distribution of harvest data must be emphasized to explain the similarity in harvest date but not in grape blending. Twenty-eight of the 56 fields (50%) were harvested on the same date on the same farm, yielding a value of zero for HARVEST. Of the remaining fields, 15 and 13 were harvested 2–4 d and ≥5 d, respectively, after the others on the same farm. There was a 1.2-d difference in mean harvest time between VAL fields and COP and NEG fields. There was a 2.8-d difference in mean harvest time between VAL and DIN fields. The lack of grape blending after harvest and before fermentation accounted for PC2 of the FAC and represented 0.02% of the global FAC contribution (Figure 3).

The levers and obstacles to changing viticulture practices differ among winegrower profiles

HARVEST and BLEND are annual viticulture practices that seem easy to change at first glance. However, changing them would require assuming – incorrectly – that all winegrowers experience the same levers and obstacles. For their part, technical networks allow information about trends in changes in harvesting practices to flow to other winegrowing farms, for example. Of course, winegrowers will not change their harvest dates with each new trend, but because of the flow of information in the network, they become aware and can then decide whether to change. Information is one of the decision-making elements of winegrowers. In comparison, sales networks allow, in particular, information flows about changes in consumer preferences. They could influence practices for choosing the harvest date and blending practices in the cellar for the acid-sugar balance of future wine. In terms of climate change, all winegrowers may have to adapt to changes in harvest date. One potential obstacle to changing the traditional harvest date would be logistical concerns, such as the availability of human labour during an 'off' harvest season. Neethling et al. (2016) described this practice as the adjustment of 'harvest windows'. Nevertheless, the feasibility of this practice according to individual winegrower characteristics has not been investigated. The workforces for COP and VAL winegrowers are essentially family-based and thus more flexible and less costly than the salaried workforces of the DIN winegrowers (Table 1). NEG winegrowers may be the least able to change, as they often have only one harvest and little financial investment in labour (Table 2). In terms of blending fields for winemaking, winegrowers' ability to adapt to change will depend mainly on their investment in processes such as changing the collection vats used during harvest. Financial investment is

less of an obstacle for DIN and VAL winegrowers than it is for COP and NEG winegrowers (Table 2).

Vineyard training practices such as planting density, vine age, and variety are important long-term levers of change, but they are not the same for all winegrower profiles. Individual VAL winegrowers may be best equipped to change their training systems as they have multiple technical networks and information sources. Battaglini et al. (2009) suggested that VAL winegrowers might also be in a favoured position to change varieties. In contrast, as COP winegrowers belong to one network each, they may be able to change viticulture practices only if other members of their co-operative make similar changes.

A winegrower typology that considers trade networks may identify opportunities and obstacles to changing viticulture practices. The results of our DFA and FAC analyses identified viticulture practices and winegrower networks that differentiate vineyards in the Loire Valley and were used to generate a typology. Mesiti and Vanclay (2006) reported 14 grape grower styles based on winegrower interviews in Australia. They drew upon technical and sales networks to describe a 'professional scientific manager' profile and upon sales and marketing networks to describe 'experienced manager,' 'low-input grower,' and 'traditional grower' profiles. Viticulture practices were profile indicators for only seven of the 14 profiles, but they were not described in detail. In future research, we intend to list practices and network types that must be considered before proposing more context-specific recommendations for sustainable viticulture practices.

Previous studies considered either only a few different practices (Morlat & Symoneaux, 2008; Renaud-Gentié et al., 2014) or a combination of viticulture, winemaking, and ageing practices (Thiollet-Scholtus et al., 2014) in their grape quality and environmental assessments. They did not mention relationships between these practices and winegrower networks. Our results (Table 3) indicate that VAL winegrowers rely upon several information sources, such as technical journals and networks, agricultural extension services networks, and advisor networks. These sources expose VAL winegrowers to many sustainable practices, making it easier for them to adapt to agroecological change than for COP or NEG winegrowers. NEG winegrowers, for example, are connected only to their trade networks; changing practices could be relatively difficult and/or gradual due to contractual obligations. Furthermore, our results indicate that DIN winegrowers are also relatively better equipped than COP or NEG winegrowers to adapt to agroecological change, given their multiple networks. Ideas can be exchanged when equipment is shared with other winegrowers (e.g. regular face-to-face contact), and innovations in viticulture practices are available in the technical journals they read. Chiffoleau (2005) demonstrated the relationship between membership in winegrowers' professional networks and the development of more sustainable viticulture. Chiffoleau (2005) used Daré's definition of the professional dialogue network as being composed of daily or regular technical discussions, equipment exchanges, and joint work. From a sociological viewpoint, Chiffoleau (2005) described the types of winegrower networks that make it possible to change winegrowing practices. We thus follow her approach by demonstrating that there is an agronomic connection between networks and winegrowers' practices.

Trade networks may impede or even prevent changes in practices of COP winegrowers. They cannot modify their practices at the field scale as they have signed contracts with their co-operatives. COP winegrower practices must be adapted in and through the co-operative structure itself. Changes in viticulture practices of COP winegrowers depend

on connections between the winegrowers and the upper management of their co-operatives. Further investigation into the decision-makers involved in the technical and trade networks of the co-operatives may identify levers that could effectively change COP winegrower practices. This research may also clarify how viticulture practices can be made more sustainable and climate-friendly. Such steps have already been taken for local agri-food systems (Chiffoleau & Touzard, 2014).

Conclusion

In the present study, we (i) described profiles of four types of winegrower in the Loire Valley, (ii) used simple survey methods to develop these profiles based on viticulture practices and technical and trade networks, and (iii) identified relationships between harvest- and non-harvest viticulture practices of the winegrowers. Despite our data now being ten years old, we have not noticed in our previous or ongoing work indications of changes in viticulture practices or winegrower networks that veer from the typology presented here. Though, there certainly may be additional variables to now consider amidst ongoing agroecological or climatic change (e.g. pesticide usage, organic/biodynamic practices, etc.). What is of importance is our ability to have developed winegrower profiles for a wide viticulture region through our inclusion of agronomic and sociological variables, which allows for additional inputs to be considered. Our interdisciplinary approach connected technical sciences (viticulture) to social sciences (trade and technical networks) and developed a more holistic, theoretical, and data-driven perspective that enables researchers to better understand the opportunities and obstacles winegrowers encounter when they must modify their viticulture practices in response to agroecological change. The harvest and viticulture variables we used in our study to profile Loire Valley winegrowers align with those of previous studies (Chiffoleau, 2005; Lamine, 2011) and may be applicable in other contexts of the changes required in viticulture practice. The initial parameters to consider in a viticulture system such as vine age, varieties, and trellising systems are crucial for constructing profiles for winegrowers who belong to technical and/or trade networks.

It was essential to recognize the diversity of winegrowers in the Loire Valley to define typologies for them. Mesiti and Vanclay (2006) reported that it is helpful to identify specific winegrower farming styles so that the modes of communication between them and agricultural extension services can be adapted accordingly. Borne out by our survey data, we were able to characterize four distinct winegrower profiles. NEG winegrowers must produce wines in agreement with their wine merchants, while COP winegrowers are constrained by their associations with other members of the co-operative to which they belong. DIN winegrowers are the most autonomous decision-makers, while VAL winegrowers' focus on wines that have high economic and sociocultural value and form flexible, well-connected networks. The present study not only identified winegrower networks and modes of communication but showed that technical and trade networks are levers and/or obstacles to change in viticulture systems in response to agroecological issues.

In addition to the constraints imposed by technical and trade networks, it is also necessary to examine factors such as the winegrowers' willingness and perceived ability to change their practices. These criteria were omitted from this study. Nevertheless,

we acknowledge that there is no single universal recommendation for adaptive change to accommodate individual winegrowers or their profiles. Analysis of the winegrower profiles was only the first step in establishing the effectiveness of the recommendations for adaptive changes in harvest time, grape blending, variety, equipment, and trellising system. All of these parameters must be customized and optimized to increase the sustainability of viticulture systems and enable them to adapt to agroecological change. The winegrower profiles formulated here may help policymakers develop and implement strategies adapted to the geographical areas, practices, and networks of each winegrower. The large differences among the winegrower profiles make it difficult to promote recommended generic adaptations in viticulture practices in response to agroecological change. Nevertheless, the present study indicated that structures are in place to guide the adaptive sociocultural changes that winegrowers must make.

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