Participatory research in ecology for agroecological transitions: a case study in viticulture

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Abstract

Participatory ecological research in agricultural contexts is on the rise. Developing collaborations between farmers and ecology researchers would both foster the acquisition of fundamental knowledge, and guide farmers towards the adoption of ecological practices. However, the concrete impacts of these participatory approaches on farmers' practices are still poorly characterized. In this paper, we tackle this issue by considering as a case study a participatory research project in viticulture (EcoVitiSol®) conducted in 2022-2023 in the AOC Côtes-de-Provence vineyard (France). EcoVitiSol® (EVS) engages winegrower in a participatory research approach aiming to assess the relationships between agronomic practices and soil microbiological quality. Participant winegrowers enter close collaborations with ecology researchers both to collect data, and to discuss global and individual soil health diagnostics during co-interpretation workshops. We conducted 22 semi-directed interviews with participant winegrowers in order to understand how their engagement in EVS has impacted their practices, knowledge, and professional social networks. We found that EVS impacts on agronomic changes depends primarily on contextual factors: more precisely, winegrowers modified (or plan to modify) their practices according to EVS diagnostics only if their current technical itinerary is not well stabilized, and if they do not face limiting environmental constraints. Besides, we show that winegrowers interpret their individual EVS diagnostic on the basis of what we characterize as their formal, experiential and ethical knowledge. Third, we suggest that out of the scientific results they provide, participatory research projects in ecology are valuable in that they foster peer group discussions. We deduce from these results some recommendations to optimize the impacts for agroecological transitions of ecological participatory research engaging farmers. We finally discuss our results in the light of the abundant literature which tries to elicit the factors influencing farmers' adoption of environmentally sustainable practices.

I-Introduction

Agroecological transitions have emerged since the 1980s as a horizon of public policy action to face the environmental and economic limitations of modern agriculture as it developed after the Second World War (Compagnone et al. 2018; Loconto and Fouilleux 2019). Despite this coexistence of a diversity of models and practices, agroecology (as a set of agricultural practices) is usually opposed to conventional agriculture in its attention to the maintenance of biological regulation and ecological interactions within cultivated areas (Toffolini et al. 2019). It is commonly claimed that this root principle entails a search for local solutions, adapted to each ecosystem and farming context (Prost et al. 2023) – this dynamics being opposed to the top-down linear process where agronomists disseminate generic knowledge to farmers through technical advisors (Duru et al. 2015). This search for locally adapted solutions for agroecological transitions reinforce the role of the farmers as knowledge holders and producers (Šūmane et al. 2018; Salembier et al. 2018). Consequently, much attention and efforts have been devoted to the development of participatory research and innovation practices in agronomy, which involve different forms of collaborations between agronomists and farmers to generate, discuss and disseminate knowledge and innovations (Pagliarino et al. 2020)[1]. As elicited in recent literature reviews (e. g Jackson-Smith and Veisi 2023), most of these participatory research approaches aim to develop new agricultural techniques and assess their impact on food production and the environment. These approaches are growingly studied by human and social sciences to assess notably: the motivation of participants to agronomic participatory research (Thompson et al. 2019), the kind of knowledge which is produced (Toffolini et al. 2020); the impact of participatory research in terms of agricultural innovations (Hellin et al. 2008); the role of agronomists to accompany agroecological transitions (Salembier et al. 2018), or the organization of collective innovation in agriculture (Berthet and Hickley 2018).

However, out of agronomy, the context of agroecological transitions has given momentum to other scientific disciplines as relevant to agricultural innovations, primarily ecological sciences. Indeed, reducing the pressure exerted by agriculture on ecosystems needs to rely on ecological knowledge when designing and assessing agroecosystems (Berthet et al. 2019). Besides, the strengthening of agricultural productivity demands to evaluate ecosystem services on working farms (Bretagnolles et al. 2018). Participatory research in ecology in agricultural contexts is then on the rise (Ryan et al. 2018). It may involve citizens and/or professional farmers in studying pollination and pollinators (Le Féon et al. 2016); evaluating soil invertebrate biodiversity (Billaud et al. 2021); assessing ecosystem services such as the decomposition of dung (Kaartinen et al. 2013). However, the possible impacts of these participatory research approaches in ecology for agroecological transitions are still poorly studied: how collaborations between farmers and ecology researchers might foster individual and collective changes in agronomic practices? What kind of famers' participation in ecological research should be developed in order to define more sustainable

1These participatory practice endorse a diversity of labels which reflect the variety of spaces and contexts where they take place, as well as the diversity of forms of famers' involvement into the research and innovation processes: on-farm experimentation (Lacoste et al. 2022), living-labs (Toffolini et al. 2023), open-innovation platform of devices (Berthet et al. 2018), citizen science (Van de Gevel et al. 2020), co-innovation processes in experimental stations (Cardonna et al. 2018) production models, and to encourage famers to adopt them? This contribution tackles these issues by considering as a case study a participatory research project in viticulture (EcoVitiSol®). In a nutshell, EcoVitiSol® engages winegrower of different vineyards territories accross France in a participatory research approach aiming to assess the relationships between agronomic practices and soil microbiological quality. EcoVitiSol® both aims to build fundamental knowledge in ecology, and to initiate individual (at the scale of the farms) and collective (at the scale of the vineyards) changes towards more sustainable practices.

With 20% of the pesticides used for 3 % of the agricultural surface in France, and a strong mechanization, viticulture is indeed widely criticized for its impacts on air, water, and soil pollution (Karimi et al. 2020). Transition towards more sustainable models is then both a challenge and a necessity for this sector, since current practices strongly affects its environmental and economical viability (Costantini et al. 2018). Differents kinds of participatory approaches have been developed to involve winegrowers in the design of such innovative agricultural systems (Renaud-Gentié et al. 2023). Many of them focus on the reduction of pesticides use: it is for instance the case of the DEPHY network in France, which engages winegrower in on-farm experimentations aiming to demonstrate their capacity to reduce their pestide use (Fouillet et al. 2023). Such on-farm experimentations approaches are sometimes combined to co-design and/or co-evaluation workshops in order to encourage the implementation of new pest management strategies (Perez et al. 2023). Serious games were also used to stimulate thinking about innovative pesticide-saving practices (Hossard et al. 2022). Another form of participatory approach is reported by Madouas et al. (2023) who document a participatory action research initiative, engaging both winegrowers, NGOs, elected officials and civil society in the design and implementation of less pesticide-intensive viticultural practices in France, Switzerland and Germany.

Out of this issue of pesticides use, soil management is a central element of agronomic strategies for winegrowers (Renaud-Genié et al. 2023). It is also a key lever for agroecological transitions, since reduction of herbicides may entail an increase of soil tillage to control weeds – historically, tillage was indeed progressively replaced by herbicides during agricultural modernization processes (Fried et al. 2019). Yet, soil management practices have strong impacts on soil ecological quality (Christel et al. 2021). In particular, the microbiological state of the soils (the abundance and diversity of the microbial communities) depends on the modalities of tillage, fertilization, crop protection and crop rotation (Lemanceau et al. 2015). At a more global scale, understanding the impacts of the different farming system as a whole (e.g. conventional, organic, biodynamic farming) on soil ecological quality is then crucial for agroecological transition in viticulture. It implies to take into account the diversity of technical itineraries (or pathways of technical operations, Sebillote 1974) which characterize the different systems of production. To do so, the implication of winegrowers into this research process may be usefull, in order to identify relevant variables impacting soil ecological quality, and to interpret the quantified diagnostics.

In this context, EcoVitiSol® is the first large-scale study aiming to evaluate physical, chemical and microbiological quality of vineyard soils, for three different farming system (conventional, organic, biodynamic). This 5 years-old program, led by INRAE researchers from the *UMR Agroecologie* lab in Dijon (Burgundy), is co-funded by INRAE and the professional organizations (e.g syndicate) representing winegrowers from the vine growing region under study. As described later, conventional, organic and biodynamic winegrowers are directly involved during the different steps of the process, from data collection to results analysis during co-interpretation workshops. After a previous campaign in the Burgundy and Alsace vineyards (2019-2020), the EcoVitiSol® method was applied in 2022-2023 to the *AOC Côtes-de-Provence* vineyard, in South-Eastern France (hereafter, CDP), in collaboration with the local winegrowers' professional organization (*syndicat des vins de Côtes-de-Provence*). The study presented in this paper aims to empirically assess the impacts of CDP winegrowers' engagement into the program, in terms of winegrowers' practices, knowledge, and exchanges among their professional networks. It sheds light on the way co-produced ecological scientific knowledge interacts with existing states of practices, knowledge and networks of actors to impulse agronomic changes. We begin this paper by presenting EcoVitiSol® into more details, as well as our resarch questions and methods (section 2). We then expose our results by investigating sequentially three dimensions of EcoVitiSol® impacts — practice, knowledge and professional networks (section 3). We deduce a global scheme of how EcoVitiSol® may influence angroecological transition at the individual and territorial scales, and we finally discuss our results in the light of the literature which has studied, over the last decades, the factors that influence farmers' adoption of environmentally sustainable practices (section 4). The ambition of this last section is also to propose some ways for improving the integration of participatory research approaches such as EcoVitiSol® into territorial transition trajectories.

2-Context and methods

a- EcoVitiSol® in Côtes-de-Provence

The *AOC* (controlled denomination of origin) *Côtes-de-Provence* vineyard is the first rosé wine-producing region in France, with a total surface of 20332he and a production of 978000 hectolitres/years. It comprises 35 000 producers, with 372 private cellars and 38 wine cooperatives. This large geographic area includes a diversity of soils, with a dominance of sandyloam and sandyclay textures. It is characterized by a Mediterranean climate, with relatively low rainfall, which makes water management an important issue for this vine growing region. The AOC is managed by a professional union (*syndicat des vins de Côtes-de-Provence)* which defines product specifications and control winegrowers compliance, and impulse reflections for agronomic changes at the regional scale. This organization was directly involved in the different stages of the EcoVitiSol® (hereafter, EVS) approach, together with the EVS consortium. This EVS consortium was composed by 4 researchers from INRAE (UMR Agroécologie, Dijon); 2 researchers from the ENS Paris (Laboratoire de géologie); the association *Soin de la Terre* which advises winegrowers about biodynamic farming; and one enterprise providing numeric tools for geographic data management (Agaric-IG).

From April to June 2022, participant winegrowers were recruited by the *syndicat* through information meetings and personnal contacts. Depending on the wine estate they come from, these participants might be the heads of the farms or the crop managers. 63 plots belonging to 52 wineries were selected (23 plots in conventional farming, 22 in organic faming, 18 in biodynamic faming, see Figure 1). In november 2022, soils were sampled by members of the EVS consortium which circulated among the wineries during one week. The sampled plots were selected by the winegrowers, on the basis of a set of general criteria defined by the researchers (mainly, the age of the vines and the seniority of the mode of production). The sampling zones were then defined with the winegrowers during the field campaign, with considerations of homogeneity and representativity of the plots. During the sampling processes, a 20 to 30-minutes discussion with every winegrowers allowed to co-construct a fine description of their technical itineraries: tillage practices, type of cover crops, use of vine protection products (pesticides and coper), type of mineral and/or organic fertilization, managements of vine shoots, use of irrigation. During this discussion, researchers also explained the objectives and the protocole of the study, and gave some insights about soils microbiology. They also exchanged with winegrowers about the possible effects of their practices on soil ecological quality.

After this field campaign, soil samples were sent to the different research laboratories from the EVS consortium and analyzed along three dimensions. First, classical physico-chemical variables were characterized (pH, texture, organic carbon, nitrogen, coper). Second, a part of the samples were analyzed through thermical analysis (Rock-Eval® method) in order to quantify the stable and active forms of soils' carbone (Kanari et al. 2022). Finally, soil's DNA was extracted from a third part of the samples in order to conduct microbioloical analysis (see Christel et al. 2023 for a detailed description of the protocol). In a nutshell, the extracted DNA was quantified to measure molecular microbial biomass. Then, DNA was purified and taxonomic microbial genes were quantified through qPCR in order to estimate the fungi/bacteria ratio. A part of this DNA was finally sequenced in order to evaluate bacterial and fungal biodiversity. All these indicators were compared to the RMQS national referential for soils microbiological quality (Dequiedt et al. 2020). The RMQS provides theoretical values for microbiological indicators depending on soils parameters and geographical positions. These theoretical values were compared to measured ones, and soil indicators are then converted into distinct diagnostics of soil state: organic carbon, fungi/bacteria ratio, fungal and bacterial biodiversity, and a global evaluation which indicated if agronomic practices improve or affect soils' microbiological quality.

The third step of the EVS protocol has consisted of two co-interpretation workshops which were organized on the 5th and 6th of December 2023 in two different places of the AOC Côtes-de-Provence. Each of them has gathered members of the EVS consortium, representants of the *syndicat* and half of the winegrowers. The workshops, which lasted for about 3 hours, were organized into two phases. First, members of the EVS consortium presented a general state of the art about agriculture and soils' microbiological quality. They then presented the results obtained in vineyards sampled in 2019 (Burgundy and Alsace), and the aggregate results obtained in Côtes-de-Provence, depending on production mode (conventional, organic and biodynamic) and agronomic practice (tillage and cover crop management). Roughly, these results show a positive impact of cover crop on microbiological quality, and a negative impact of tillage.

After a session of general discussion, individual results are distributed to winegrowers, under the form of four-pages diagnostic files presenting indicators for carbon, microbial biomass and biodiversity, as well a global indicator of soil quality. These indicators are placed into red to green scales: the red (resp. the green) color indicates that the sample is under (resp. over) the reference level. Consequently, a ‘‘red’’ diagnostic means that the corresponding soil is in a ‘‘bad global microbiological state’’ ; an ‘‘orange’’ diagnostic means that the soil is in a ‘‘non-critical global microbiological state, but to be monitored’’ ; a ‘‘green’’ one means that the soil is in ‘‘a good global microbiological state’’. A free discussion session then allows scientists and winegrowers to freely exchange in small groups in order to co-interpret individual results in the light of plots' characteristics and technical itineraries. The whole process can be considered without ambiguity as a form of participatory research, since it proposes a strength collaboration between researchers and winegrowers both in data collection, and in results interpretation. As confirmed in our data from semi-directed interviews (see section 3), participants themselves clearly contrast this approach with more usual forms of collaborations with experts (public or private agronomy advisors, analytical laboratories).

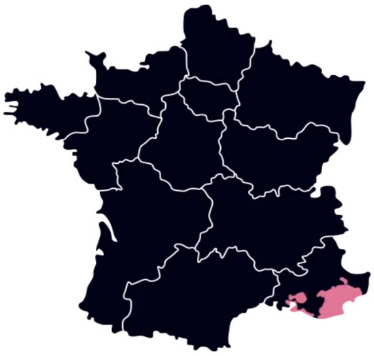 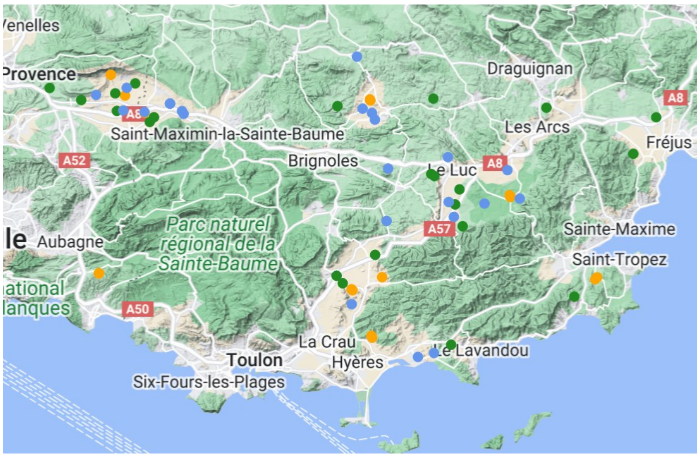

Figure 1. On the left: location of the AOC Côtes-de-Provence vineyard (France). On the right: spatial distribution of the sampled plots. The colors of the spots indicates the mode of production: green=organic (22 samples), blue=conventional (23 samples), orange=biodynamic (18 samples).

b-Research questions

As exposed in the Introduction section, participatory research approaches in ecology engaging farmers are on the rise. In addition to their value for scientific knowledge production, these approaches are often described as a potential way to improve farmers' awareness of biodiversity and environmental issues, and to foster agroecological transitions (Billaud et al. 2021). However, it is still largely unknown how these forms of collaborations between public researchers and professional (farmers, advisors, producers' professional groups) may concretely impact agronomic practices, at short and long terms. When tackling this issue, one should take in consideration the diversity of individual situations faced by farmers, and specifically by winegrowers. Each of them is inserted in specific professional networks (Thiollet-Scholtus et al. 2020), faces specific (or local) environmental and economic situations (Merot et al. 2019), develops and applies local or fundamental knowledge (Šūmane et al. 2018, Toffolini et al. 2017), and may be active in innovation networks (Berthet and Hickey, 2018, Richardson et al. 2022). These aspects of individual situations may mediate in a complex way the impacts of winegrowers' engagement into participatory research programs in ecology. This study then proposes to explore the way participatory research interacts with winegrowers' practice, knowledge and professional networks, by taking the application of EcoVitiSol® in Côte-de-Provence as a case study. Two remarks deserve to be done at this stage.

First, the data we mobilize in this study has been collected right after the end of the project (January-May 2024, see next section). Our research was then designed to capture mainly short-term impacts. It is worth noting that this schedule (with the interviews done right after the end of the project) was also chosen in order to access more accurate and detailed feedbacks on the EVS methodology from the participants. Second, as EVS was applied in 2018-2019 in two other regions (Burgundy and Alsace), it would have been possible to conduct a similar study in these vineyards to get a more exhaustive view of EVS's impact. However, as previously highlighted, we make the assumption that this impact strongly depends on territorial and individual situations; we then made the choice to focus on one specific EVS campaign in order to avoid biais or complexity due to the diversity of local contexts.

c-Methods

Out of the observations conducted during the two workshops (5th and 6th of December, 2023), we led a series of interviews with winegrowers. Following the two workshops, emails were sent to participant for semi-directed interviews. Based on the answers we got, we were able to conduct 22 semi-directed interviews (30 min to 1h) from March to May 2024. This tight schedule was constrained by the limited availability of winegrowers after the winter period. The interview grid focused on 6 points:

-General characteristics of the wine estate and professional trajectory of the interviewee

-Agronomic trajectory of the wine estate: evolutions of the technical itinerary, potential agronomic problems or environmental constraints faced by the winegrower

-Professional socialization of the interviewee: participation in professional organizations, number and types of technical advisors, interactions with other winegrowers

-Internal R&D agenda: physical, chemical and biological analysis, on-field experimentations, works led in collaborations with public researchers in agronomy or ecology, and with private compagnies

-Opinion on EVS: perception and evaluation of the program in general, and winegrower's interpretation of his/her individual diagnostic

-Modifications of practices following EVS, as concretly realized or envisioned.

The interviews were transcribed and qualitatively assessed by classifying relevant information for each of the 22 cases, following distinct dimensions (physical and economical characteristics of the wine estates, frequency of soils quantitative analysis, types of knowledge expressed by winegrowers, environmental constraints or agronomical problems, exchanges during the EVS workshops, etc.). This first analysis of collected data allowed to reconstruct, for each case, a description of the winegrowers' and wine estates characteristics, agronomic trajectories, as well as EVS' integration with winegrowers' practices, knowledge, and professional networks. We present in box 1 to 3 some examples of these detailed descriptions obtained from interviews' analysis. Finally, these individual results were confronted and discussed in order to elucidate general pathways of impacts for EVS. It is worth noting that this phase of interpretation was conducted in close collaboration with members of the *syndicat*. We also conducted one interview with the director of the *syndicat*. Its aim was to better grasp the current issues faced by the Côtes-de-Provence vineyards, as well as the objectives and expectations of this professional organization when engaging in EVS.

3-Results

Among the 22 interviewees (5 women and 17 men), 10 winegrowers practice conventional farming, 8 organic farming, and 4 biodynamic farming. 3 of them belong to wine cooperatives, and 19 have private cellars. Global EVS results were distributed as follows: 5 plots have a ‘‘red'' global diagnostic regarding soil microbiological quality, 12 have a ‘‘green'' one, and 5 an ‘‘orange'' one. In our sample, there is no significant correlation between the color of the diagnostics, the modes of production, and the size of the wine estate.

a-Typology of agronomic situations

The qualitative analysis of the interviews reveals three groups of winegrowers, characterized by specific agronomic situations. We show (section 3-b) that these agronomic situations are good predictors of the impacts of EVS on agronomic practices. This three-dimensions typology is based on two variables: (i) the stability of the technical itinerary (is the winegrower in a phase of search for modifications of his/her agronomic practices?) ; (ii) the presence of strong environemental constraints. As explained bellow, we consider as environmental constraints some physical, biological or climatic conditions that concretly and effectively (that is, in a way that is precisely described by the winegrowers) challenge the winegrowers in their search for a satsifaying technical itineray. It is worth noting that we did not find any correlation between this typology, wine estate characteristics (mode of production, size of the farm) and socio-demographic factors such as age, gender, or education of the crop manager.

Group A (9 winegrowers)

Group A includes winegrowers who are satisfied with their technical itinerary, which is well stabilzed. In this group, 6 winegrowers have a ‘‘green’’ global diagnostic, and 3 of them a ‘‘orange’’ one.

Group B (8 winegrowers)

Winegrowers from this group are unsatisfied with their current technical itinerary, since they have identified an agronomic problem they would like to solve. The identified problems or issues are diverse: lack of organic matter (2 winegrowers); lack of vigor for some vines (1); bad structure of the soil (3); willing to redice tillage (1). Contrary to Group C, this search is not challenged by strong environmental constraints. In this group, 6 winegrowers have a ‘‘green’’ global diagnostic, 1 has a ‘‘orange’’ one, and 1 has a ‘‘red’’ one.

Group C (5 winegrowers)

Group C is characterized by the presence of strong environmental constrainsts which challenge winegrowers in their search for a satisfaying technical itinerary. For 3 winegrowers, the constraints are linked to the physical characteristics of their sandy soils, which make the sowing of cover crops difficult. Another winegrower reports a strong limitation in the development of cover crop due to water stress. A last one describes the difficulties he faces to adapt cover crops to his clay soils (which is hydromorphic in winter and presents dessication cracks in summer). Winegrowers from this group are all engaged since many years in an intensive search for solutions to adapt their technical itinerary to the environmental constraints they face (e.g, by searching for an equilibrium between the development of cover crops and water stress).

b-Impacts of EVS on agronomic practices

Our analysis indicates that EVS may have clear short-term effects (and possibly long-term effects) on agronomic practices, and that these effects depends primarily on the winegrowers’ agronomic situation. Interestingly, the diagnostic itself is not, in our sample, a determinant of EVS impacts. More precisely:

-In **Group A**, EVS does not have any impact on agronomic practices, whether be real or envisioned, even when the diagnostic is not ‘‘green’’. For winegrowers with a ‘‘green’’ diagnostic, EVS seems to confort technical itinerary and/or long-term agronomic trajectories. For instance, one of them declared that the EVS program reinforced his long-term plan to extend sowing at the edge of the plots.

-In **Group B**, EVS has a clear short-term impact on agronomic practices. 6 winegrowers over the 8 we classified in Group B have immediately implemented (or have clearly planned for the next Fall/Winter season) new practices right after EVS' sampling and/or workshops. These changes are implemented explicitly in order to solve these agronomic problems already identified by the winegrowers. One could make the assumption that (at least in some cases) EVS has accelerated or triggered changes that were already planned. Table 1 presents the changes that were implemented by these 6 winegrowers. Interestingly, this impact of EVS on technical itinerary seems to be independent from the diagnostic itself – that is, changes were implemented in case of ''red'' as well as ''green'' diagnostics. It is worth noting that the changes reported by the interviewees were implemented at different moment depending on the case: after the EVS sampling period (November 2022); between the workshops (December 2023) and the interview (March-May 2024); or for some of them, they are planned for Fall 2024. In Table 1, we indicate if the changes were concretely implemented (and when) or planned for the next months.

-In **Group C,** EVS does not have any impact on agronomic practices. Winegrowers from this group all have ''red'' or ''orange'' diagnostics. They all have been engaged for many years in (unfruitful) tests and experimentations in order to adapt their technical itinerary to strong environmental constraints: consequently, EVS results are not surprising to them, but the program does not offer them the concrete solutions they are looking for.

Winegrower	*EVS global diagnostic*	*Alredy identified agronomic issue*	*EVS-induced changes*
1	Orange	Deficit of organic matter	Augmentation of organic amendment (W)
2	Green	Lack of vigor for some vines	Systematization of horse manure amendment and extension of the cover crops period (W)
3	Green	Soil compaction	Limitation of the use of tractor by stopping tillage under the vines (P)
4	Green	Lack of organic matter	Sowing in all inter-rows (in some test plots) (S)
5	Green	Attempts to diminish tillage	No-tillage in 2 test plots (W)
6	Red	Attempts to diminish tillage	No-tillage during winter (W)

Table 1-Changes implemented by winegrowers from Group B after participation in EVS sampling

and workshops. In the next colomn, S=changes implemented after the EVS sampling period (November 2022) and before the workshops (December 2023) ; W=changes implemented right after the workshops ; P=changes planned for the next (2024) Fall or Winter season.

c-Impacts on winemakers' knowledge

Litterature on agroecological transitions has highlighted for a long time the role of farmers' knowledge (as opposed to knowledge built and diffused by professional scientists) on the development of innovations (Ingram 2014). Various (couple of) concepts have been used to describe the types of knowledge developed or mobilised within farming practice: formal *vs.* informal (Šūmane et al. 2018); fundamental *vs*. applied (Toffolini et al. 2017); local *vs*. generic (Syahrun et al. 2023) etc. In a more systematic approach, Gorman (2002) proposes a taxonomy of knowledge which distinguishes between four types: information (knowing what), skills (knowing how), judgement (knowing when) and wisdom (knowing why). We argue that this last typology, once adapted to our case and slightly modified, is inspiring to describe winegowers' knowledge, and the way it hybridizes with the knowledge constructed during EVS approach. Interviews indeed allow to identify three types of knowledge which are hold by winemakers:

-A *formal* knowledge, such as quantified data produced by robust physical or chemical soils' analysis, or general knowledge about soils or plants. This knowledge is characterized by its genericity, in the sense that it comes from widely used analytical technics, or well-established scientific knowledge.

-An *experiential* knowledge, coming from winemakers' observations of their own soils and ecosystems. This knowledge may derive from tests or experiments or direct observations. This knowledge is mainly local: for instance, it deals with the types of plants specifically adapted to local environmental conditions, or with the way the local soils react to mechanized works.

-An *ethical* knowledge, which guides action without being necessarily justified by well-identified empirical data. This form of knowledge is mobilized to produce value judgement: for instance, one winegrower may value ‘‘plants diversity'', or no-tillage practice in order to let ‘‘soils' life to flourish''.

The two first form of knowledge may be understood as refinements of Gorman's (2002) ‘‘knowing what''. The third one is similar to Gorman's (2002) ‘‘knowing why''. Obviously, winemakers also expressed elements of ‘‘knowing when’’ and ‘‘knowing how’’, for instance, when describing in details their technical itineraries and its evolutions. However, in our cases, these two last forms of knowledge, which are more related to action, were always justified by (or grounded on) formal, experiential or ethical knowledge. These three forms of knowledge indeed continuously interact in local agronomic situations. For instance, for one winegrower from Group C, valuing cover crops (*ethical* knowledge) confront with *formal* knowledge about water drainage in sandy soils, which is itself confirmed by *experiential* knowledge coming from previous efforts at developping cover crops. We then argue than these three categories are necessary and sufficient to describe how EVS interacts with winegrowers’ own knowledge.

Our empirical data first suggests that participants hybridize EVS-related knowledge (individual diagnostic as well as general information on microbiology and soils) with their factual, experiential and ethical knowledge to produce an *interpretation* of EVS global and individual results. These interpretations then depend on winegrowers’ representations of their current agronomic situation and planned trajectory (since these representations depends on winegrowers’ formal, experiential and ethical knowledge). Reciprocally, EVS results may enrich or justify winegrowers’ experiential or ethical knowledge. For instance, one winegrower from Group A which values plants’ diversity interpreted global and his individual (‘‘green’’) EVS diagnostic as an empirical justification of his ethical knowledge. By doing so, he also established a link between plants diversity and microbiological diversity. More globally, we found in various cases that EVS results enriched winegrowers’ representation of biodiversity, which was often (before that) restricted to macrofauna and flora. Another winegrower from Group A which had observed the positive effects (on vine productivity and vigor) of massive organic waste inputs interpreted his ‘‘green’’ diagnostic as a scientific justification of his experiential knowledge of the positive effects of his practices on vine vigor. In Group C, EVS results are seen as confirmations of winegrowers’ agronomic difficulties: globally, winegrowers from this group are not surprised from their (‘‘orange’’ or ‘‘red’’) individual diagnostics, which are interpreted through the lens of their experiential knowledge (e.g difficulties to develop cover crops in sandy soils, or under hydric stress conditions). In some cases, EVS results confronted with other sources of formal knowledge: for instance, one winegrower from Group A found his individual EVS’ diagnostic contradictory with other microbiological analysis he had previously performed in other plots from his wine estate. In this case, interpretation focused on comparing measurements methods in terms of sampling and analytical strategy.

Importantly, this is through this interpretation activity that EVS may have concrete effects on agronomic practices of winegrowers from Group B. For instance, winegrower n°1 from Group B (see table 1) interpreted his individuel results, as well as global EVS' scientific inputs, through the filter of his own agronomic preoccupations (the low level of organic matter in his soils): he then insisted, during the interview, on the importance of organic matter to foster soil's microbiological life. Consequently, he decided (after his participation in EVS) to increase organic amendments. Similarly, winegrower n°3 (see table 1) interpreted global EVS results from the perspective of his soil compaction problem, by concluding than soil compation is detrimental to microbiological life. The same observation was done for all winegrower from Group B: the agronomic problems which create instabilities of the technical itineraries directly determine the interpretations of individual and/global EVS' results. Reciprocally, EVS results enrich the descriptions winegrowers made of their agronomic problems, by introducing the notions of microbiological mass and diversity. It is worth noting that, in coherence with our results regarding agronomic changes (section 2-b), these interpretations (and the related agronomic changes) are formulated even when the diagnostic is ''green'', which means that the existence of a pre-identified agronomic problem is more determinant than EVS data to induce winegrowers' willing to change agronomic practices.

d-Impacts on winemakers' professional networks

Farmers are generally engaged in complex networks of professional interactions with heterogeneous sets of actors (Klerks and Proctor, 2013; Cerf et al. 2017): agronomists and advisors, representatives of farmer organizations, machinery manufacturers, suppliers of seeds, but also their pairs (in the context of professional organizations, or informally with neighbours). These networks, as supporting interactive learning and knowledge exchanges, strongly influence (positively or negatively) the development and diffusion of agronomic innovations (Skaalsveen et al. 2020 ; Thiollet-Scholtus et al. 2020). How does engagement into EVS impact existing winegrowers' professional networks? Even if we did not explore exhaustively participants' social interactions, our empirical data first suggests that winegrowers generally discussed EVS results with their usual professional contacts. These ones are variable depending on the individuals: suppliers of seeds or crop protection products; private advisors (mainly for biodynamic farming); animators of farmers organizations (such as so-called GIEE, that is groups of discussions about economic or environmental issues); analytical laboratories. More originally, our results show that EVS workshops were perceived as an opportunity to discuss with other winegrowers, especially neighbours, which seem to be fairly rare within the AOC Côtes-de-Provence region. In many cases, interviewees expressed their regret that this dynamics of exchanges was not maintained after the official end of the EVS project for the territory. This importance of peer group discussions was particularly highligthed by winegrowers working in areas with strong environmental specificities. It is the case for the southern zone of the Côtes-de-Provence vineyards, close to the sea (see figure 1), which is characterized by sandy soils and a relatively high number of ‘‘orange’’ of ‘‘red’’ diagnostics. Participation in EVS made them realize that, because of the environmental and physical specificities of their territory, peer groups discussions would be an efficient way to find solutions to their agronomic problems. As explained by one winegrower, ‘‘we have issues which are specific to our area, and exchanging with people working in the same area is interesting’’. One role of EVS was then to impulse the creation of these peers groups, where winemakers could compare their diagnostic with each others, to discuss about their agronomic practices, and (above all) to realize the value of this form of professional exhanges. As discussed in the next section, one central issue participatory research is to maintain these peer groups over time.

Box 1

Winegrower from Group A-Conventional farming-‘‘Green’’ EVS diagnostic

The interviewee (a man) is the head of a 36he wine estate. He is a member of an association gathering winegrowers from the area he lives in (*association des vignerons de la Sainte-Victoire*). With 16 other winegrowers from this association, he is engaged into a GIEE (a professional organization aiming to promote collective discussions and innovative practices) which develops the use of organic waste to fertilize soils. This GIEE also ensures soils monitoring through physical and chemical analysis. His technical itinerary is now well stabilized, after 10 years of tests. He sows cover crops (clover) on 1 inter-row over 4. Even if he was interested in EVS global insights, he does not plan to extend cover crops (he has concerns about water stress, even if he has never directly faced such a problem). The interviewee spreads massive quantities of organic waste on 12he of his wine estate (250t per he). He is very satisfied with the results: his soils better retain water during dry periods, and he has observed an increase of the number of earthworms. He interprets his (‘‘green’’) EVS diagnostic as a consequence of this use of organic waste. Besides, he disussed with the head of the GIEE in order to compare the results obtained by EVS in the area with the soils analysis performed by the GIEE.

Box 2

Winegrower from Group B-Biodynamic farming-‘‘Orange’’ EVS diagnostic

The interview is conducted with the two crop managers (women) of a 30he wine estate which is cultivated in biodynamic farming since 2018. They maintain self-growing cover crops in winter and spring, before to destroy it. They would like to delay cover crop destruction (later in spring), but (as many winegrowers in the area) they have concerns about water stress (while recognizing that ‘‘there is no scientific results behing these concerns, but only fears and habits that are hard to change’’). Because of the sandy-clay texture of their soils, they face soils compaction issues when using tractors. They interpret the ‘‘orange’’ EVS global diagnostic as the result of an excess of tractor passages in 2022 for antifungal treatments (due to important rainfalls). As a consequence, they will stop tillage (beginning in 2024 fall) under the vines in order to limit tractor use. During workshops, they appreciated to discuss with a neighbour which maintains permanent cover crop. They would like to follow up these peer groups discussions in the future.

Box 3

Winegrower from Group C-Organic farming-“Orange” EVS diagnostic

The interviewee (a man) is the technical manager (crop and wine production) of a 15h wine estate which is cultivated in organic farming since 2015. Before this date, soils were intensively tilled. For the past 4 years, he has tried to develop cover crops in order to improve soils structure (he faces soil leach and collapse issues). He faces a lot of difficulties in finding a technical itinerary which is adapted to his sandy soils (a central issue being water stress). He tested various solutions: sowing of cereal crops, or a mix of cereals and legumes (fever beans to ‘‘store water during summer’’) on all inter-rows or 1 inter-row over 2 ; he also tested different methods of cover crops management (tillage or mulching). He describes a form of contradiction between the need to preserve water ressources, and the attempt at developping cover crops; and EVS results do not offer him concrete solutions to overcome his difficulties. However, he was very interested in discussing with winegrowers from the same area (Gulf of Saint-Tropez, southern zone of the Côtes-de-Provence vineyards) during the EVS workshop: these peer groups discussions seem to have reinforced his awarness of the specifities of this area. He was also surprised by aggregated EVS results, which show that technical itinerary (in particular, tillage practices) is more determinant than modes of production (conventional, organic, or biodynamic farmin) for soils microbiological quality.

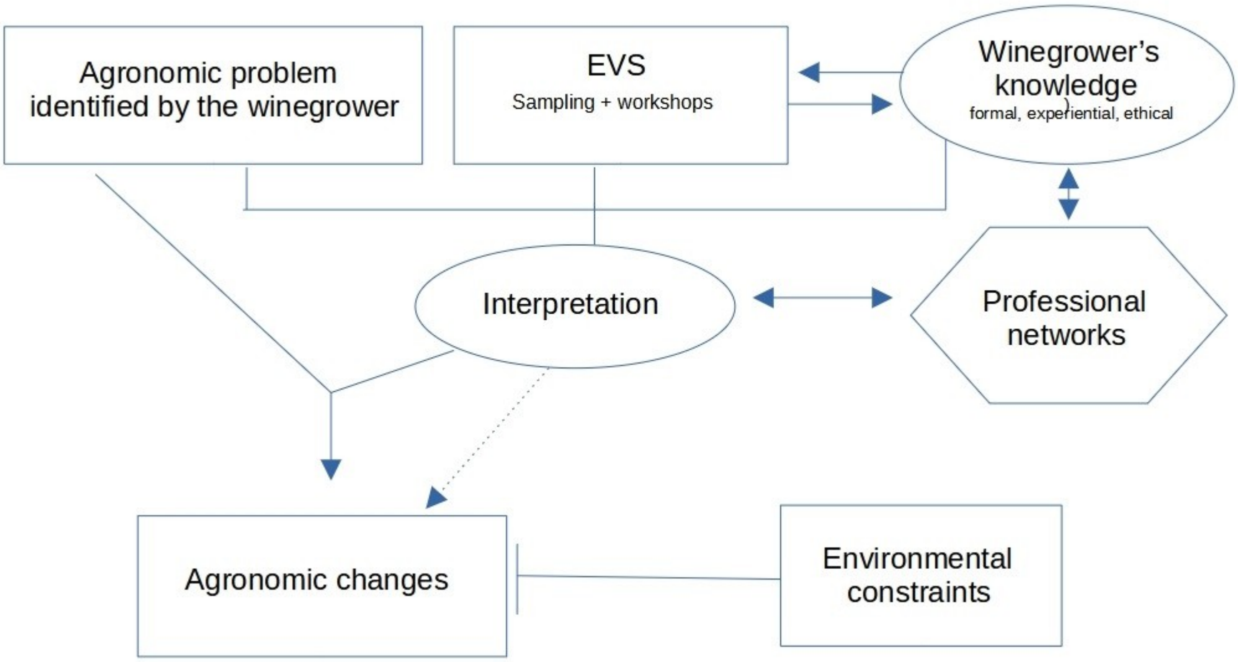

Figure 2-General model of EVS impact on practices, knowledge and professional networks. Full lines stand for short-terms effects which are clearly established from our empirical data. Dotted lines stand for hypothetical, long-term effects.

4-Discussion

To what extent can engagement of farmers in ecological research foster agroecological transitions? In this study, we propose to tackle this issue by taking as a case study a participatory research project dealing with soil ecological quality in viticulture. EcoVitiSol® (EVS) engages winemakers in close collaborations with ecology researchers in order to evaluate physical, chemical and microbiological quality of vineyards' soils, for three different farming system (conventional, organic, biodynamic). Our results suggest that participation in EVS does have impacts on agronomic practice, but that these impacts are mediated by individual, contextual agronomic situations: the existence of agronomic problems already identified by the winegrower, environmental constraints, and winegrowers' formal, experiential and ethical knowledge. Figure 2 proposes a general model describing EVS ways of impact. Participant winegrowers interpret EVS results through the filter of the (potential) agronomic problem they face and the knowledge they hold. In cases where they are currently unsatisfied with their technical itinerary, participation in EVS may accelerate or trigger the implementation of solutions to their agronomic problems — in cases where they do not face limiting environmental constraints. Interestingly, this short-term impact is independent from the individual EVS diagnostics. In cases where technical itinerary is stabilized, we were not reported in interviews any short-term planned agronomic changes — even when individual EVS diagnostic is not optimal. To sum up, our study highlights that the expected impacts of participatory research in ecology for agroecological transition are heavily dependent on individual agronomic and environmental situations: in particular, the degree of stability of the technical itinerary appears to be the main factor which determines the motivation to conduct agronomic changes after collaborating with researchers in ecological sciences. Obviously, if such a study were replicated in others wine regions, collective characteristics of the vineyards (such as economic situation) could also enter our global scheme as another determinant of participatory research's impact on agronomic changes. A second important output of our study consists in a clarification of *what* exactly is important, in participatory research, to drive agronomic changes. It appears that the individual information provided to winegrowers (carbon, microbial biomass and biodiversity and global diagnostics) is not (at least at short term) determinant for winegrowers' motivations to implement new practices. Winegrowers seem to give more importance to the results at the scale of the whole territory, as well as to the general inputs on soil microbiology presented and discussed during the sampling campaign and the workshops. Besides, by driving the formation of peer groups to discuss agronomic issues, EVS workshops may constitute a lever for long-term changes, notably for winegrowers sharing some common environmental constraints.

These results should be replaced in the abundant literature which has studied, over the last decades, the factors that influence farmers' adoption of environmentally sustainable innovations (see review by Rizzo et al. 2024) or ecological practices (see review by Thomson et al. 2024). In these two recent reviews, the authors analyzed respectively 44 articles and 70 articles published after 2010 in order to elicit the different categories of variables which explain farmers' (lack of) propension (in developed countries) to change their practices towards more sustainable models (including organic farming, regenarative agriculture, agroecology...) for pest management, fertilization and soil management. They both find out the same categories of relevant factors, which are finely intertwined: psychological or behavioral features (general attitudes towards the environment, degree of risk aversion, degree of resistance to innovation); socio-demographic features (farmer's age, income, education); farm structural features (size, income, type of production); institutional or social factors (rules, legislation, professional networks). In the case of viticulture, these factors are highlighted in some recent studies which tackle this same issue of the drivers of change under different perspectives. Zacchman et al. (2023) explore the effects of providing personalized or general information about environmentally toxic fungicides to 436 grapevine growers in Switzerland. They find no effect of information on winegrowers' intentions to plant fungus-resistant varieties, and show that this result reflects the role of environmental ‘‘noncompliant’’ perceptions as an obstacle to change. Studying winegrowers’ decision-making process regarding adaptation to climatic change in the Loire Vally, Thiollet et al. (2020) demonstrate the role of winegrowers’ socio-cultural profiles (including their social network) as determining levers and obstacles to changing viticulture practices. By conducting 16 interviews with winegrowers from the Napa Valley in California, USA, Gonzalez-Maldonado et al. (2024) establish a link between winegrowers’ perceptions and attitudes about soil health and soil management practices. They interpret their results under the conceptual framework of the diffusion of innovation theory (see e.g Rogers et al. 1995), which classifies individuals as a function of their *inherent* dispositions to adopt a new practice. Similarly, Chen et al. (2022) suggest that winegrowers general attitudes and beliefs towards viticultural practices is the main drivers of decision making regarding pesticide use and inter-row management (including type of vegetation, duration of vegetation cover, and soil tillage). Without being exhaustive, these references suggest that literature studying the factors that influence famers’ adoptions of ecological practices (in general or in the specific case of viticulture) primarily focuses on factors which are *inherent to individuals* (attitudes, beliefs, social networks) or *to the farm* (type, size, income). By contrast, this literature rarely considers more contextual factors, such as the existence of specific agronomic problems or local environmental constraints. Interestingly, our study precisely allows to enter into these considerations. One reason is that winegrowers have engaged in EVS in a voluntary basis. As a consequence, we can assume that our sample is biaised towards individuals who share some common (positive) values, beliefs and attitude towards the environment and ecological practices. Because of this form of homogeneity of the cases we studied, we were able to consider other kinds of factors influencing the adoption of new agronomic practices – such as the stability of the technical itinerary or the existence of strong environmental constraints. Besides, we were also able to describe the interactions between scientific information provided to winegrowers, and their formal, experiential and ethical knowledge.

With that in mind, let us finally try to deduce from ou results some insights on how to optimize the impacts for agroecological transitions of participatory research in ecology engaging winegrowers – and, more generally, farmers. Contrary to more applied sciences such as agronomy, ecological sciences, when dealing with agricultural ecosystems, does not aim to directly offer concrete agronomic solutions. They may only allow to formulate some general recommendations (such as limiting tillage or developing cover cop). Two questions then rise from our study: (i) How can participatory research projects in ecology such as EVS help winegrowers facing specific environmental constraints? (ii) How could programs such as EVS also impact those winegrowers who are not spontaneously interested in developping a better knowledge of their soils? Our results suggest a common answer to these two questions: out of providing and discussing scientific information, EVS creates the conditions for the constitution of peer groups. During workshops, we observed the spontaneous constitutions of small groups of winegrowers exchanging about their results, their current practices, and the changes they plan. Interviews have confirmed the interest, for winegrowers, of peer discussions: this aspect was notably highlighted by winegrowers from Group C, which are actively searching for solutions to their agronomic problems while being submitted to strong environmental constraints. This result echoes Rust et al. (2022) analysis of the role of expertise (compared to peer group) in adopting soil management innovations for two groups of farmers in UK and Hungary. The authors show that farmers tend to trust more other farmers than agricultural researchers from academic and government institutions; one of the reasons is that these last ones would not be empathetic towards farmers' problems and needs. In our case, we can suppose that participation to EVS may attract winegrowers with a good level of trust in ecological research and scientists; and indeed, interviewees all manifested their trust towards EVS results and EVS consortium. However, Rust et al. (2022)'s results, coupled to our own conclusions, may indicate that the constitution of such peer groups could be a major output of participatory research approaches, including for those winegrowers who are *a priori* less interested (or trustful) in ecological sciences. Participatory approaches could then serve as a starting point to structure such peer groups. For instance, workshops such as those organized by EVS could be used to identify groups of winegrowers facing similar agronomic problems, or willing to test a new practice. These peer groups could then be maintained in time, and engage other (initially non-participant) farmers in order to collectively find innovative solutions to common issues, or implement together new (more sustainable) practices. This suggestion points to the importance of professional organizations, such as *syndicats*, as animators of these spaces of discussions. Their strong engagement in participatory research projects could then be a crucial factor to ensure a long-term impact of the collaborations between farmers and researchers in ecological sciences.

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