Factors influencing winegrowers' adoption of soil organic carbon sequestration practices in France

Florian Thomas Payen[a,b,*], Dominic Moran[c], Jean-Yves Cahurel[d], Matthew Aitkenhead[e], Peter Alexander[b,c], Michael MacLeod[a]

[a] Scotland's Rural College (SRUC), West Mains Road, Edinburgh, EH9 3JG, UK

[b] School of Geosciences, University of Edinburgh, Drummond Street, Edinburgh, EH8 9XP, UK

[c] Global Academy of Agriculture and Food Security, The Royal (Dick) School of Veterinary Studies, University of Edinburgh, Easter Bush Campus, Midlothian, EH25 9RG, UK

[d] Pôle Bourgogne – Beaujolais – Jura – Savoie, Institut français de la vigne et du vin, Villefranche-sur-Saône, 69 661, France

[e] James Hutton Institute, Craigiebuckler, Aberdeen, AB15 8QH, UK

[*] Corresponding author. E-mail address: florian.payen@sruc.ac.uk.

ABSTRACT

The adoption of soil organic carbon sequestration (SCS) practices on agricultural land offers the double advantage of offsetting greenhouse gas (GHG) emissions and improving soil quality. However, little is known about the drivers that might influence winegrowers to adopt these practices, whose uptake remains low on viticultural land. Better understanding these drivers will be crucial to evaluating the efficacy of current policies in the viticulture sector in promoting and incentivising soil organic carbon sequestration in vineyards. This paper identified factors influencing the adoption of SCS practices by winegrowers in France. A survey of 400 winegrowers investigated current rates of adoption and winegrowers' perceptions of the practices. A binary logistic model suggested that winegrower's age, being an independent winegrower, farm size, the number of workers hired, vine's age, being certified High Environmental Value (HVE), being certified organic, practising irrigation, receiving subsidies, and winegrower's perceived resources, attitude towards SCS practices and confidence significantly influenced the decision to adopt the practices, though their influence differed depending on the practice. The findings provide insights for GHG mitigation planning targeting the viticulture sector.

Keywords: soil carbon sequestration; vineyards; farmer behaviour; farming practices; adoption; logistic regression.

1. Introduction

Soil organic carbon sequestration (SCS) practices are management practices that aim to sequester soil organic carbon (SOC) in agroecosystems to offset greenhouse gas emissions. SCS practices can also increase soil quality; as a result, their implementation represents an important strategy for both climate change mitigation and sustainable food production (Smith et al., 2019; Sun et al., 2020). However, how much the mitigation potential of SCS practices will have an impact at the farm, territorial and landscape levels depends largely on the adoption of the practices by farmers. This is why it is important to further our understanding of the factors influencing the adoption of these practices.

An extensive literature on farmer decision making regarding the adoption of agronomic practices and innovations (*e.g.*, Garini et al., 2017; Barnes et al., 2019; Despotović et al., 2019) shows that a diverse range of interacting social, economic and cultural factors influence farmers' adoption decisions. Tradition, self-opinion and conflicts of interest are important considerations in explaining why farmers and stakeholders of the agricultural industry may not adopt measures, even in potential win-win scenarios (Moran et al., 2013).

Farmer behaviour with respect to adopting SCS practices on agricultural land has been widely researched over the past decade (*e.g.*, Knowler and Bradshaw, 2007; Calatrava and Franco, 2011; Ingram et al., 2014; Sánchez et al., 2016; Paul et al., 2017). These studies showed that financial incentives play a major role in adoption decisions (Sánchez et al., 2016), along with the cost associated with practice implementation and adequate information about the practice (Paul et al., 2017). Low awareness of SCS practices and variations in how well farmers and stakeholders understand the processes involved in SOC sequestration are also reasons for non-adoption at the European level (Ingram et al., 2014).

Compared to arable land and grasslands, there are relatively few studies considering viticultural land, where adoption rates of SCS practices are low. Garini et al. (2017) evaluated winegrowers' motivations to adopt agro-ecological practices (such as drip irrigation, reduced herbicide application, etc.) but did not focus specifically on SCS practices. Schütte and Bergmann (2019) investigated the attitudes of French and Spanish winegrowers towards the adoption of cover cropping, but their study was limited to a very specific area at the local level in each country. Accordingly, there is limited information on the factors affecting the adoption of SCS practices in vineyard agroecosystems. Yet, promoting the uptake of SCS practices in vineyards is important, especially in countries with large viticultural areas (*e.g.*, Spain, France, Italy, etc.), due to the substantial SOC sequestration potential of these practices in viticultural soils (Payen et al., 2021a; Payen et al., 2021b). Understanding farmer behaviours and practice adoption is arguably more complex in vineyard agroecosystems than in other agricultural systems, due to the strong traditions and cultural know-how embodied in the concept of *terroir*[1] in Europe. This implies that European winegrowers might face even greater cognitive barriers in their perceived need to observe specific intergenerational practices.

In the European Union (EU), agri-environment schemes have been introduced as a key tool for the integration of environmental concerns into the Common Agricultural Policy

[1] A vitivinicultural *terroir* refers to an area where a collective knowledge of the interactions between the biophysical environment and the applied vitivinicultural practices has developed over time, giving distinctive characteristics to products originating from this area (OIV, 2010).

(European Commission, 2017). Agri-environment schemes provide financial support for the Member States to implement agri-environment measures (AEMs). In France, as in many other Member States of the EU, AEMs serve as the main policy instrument to instigate a change towards more sustainable practices in the agriculture sector by providing payments to farmers who undertake specific agricultural practices aiming at protecting the environment on the farmland or reducing GHG emissions from agricultural activities (European Commission, 2017). However, research (*e.g.*, Hammes et al., 2016) showed that AEMs have not been as effective as intended, which is illustrated by the insufficient participation of farmers in these measures. Increasing our understanding of the drivers motivating farmers to adopt SCS practices may provide valuable insight to assess the effectiveness of AEMs in incentivising the uptake of SCS practices on viticultural land.

This study identifies the factors influencing the adoption of SCS practices by French winegrowers. France, whose viticultural area is the third-largest worldwide, with 0.793 Mha in 2018 (OIV, 2019), and includes different soil types, climates, grapevine varieties and viticultural practices, was chosen as a case study. A survey covering all winegrowing regions of France was administered online to determine the current use of SCS practices by winegrowers and their perceptions of these practices. A binary logistic regression was used to evaluate the influence of twenty predictors on the adoption of SCS practices. Findings from this study could be used to draw more generalised recommendations to facilitate the adoption of SCS practices in the viticulture sector, particularly in other countries with large viticultural land.

The paper is structured as follows. The next section covers data collection and methods. Section 3 provides results from the binary logistic regressions, organised per SCS practice modelled. Section 4 discusses the significance (or absence of significance) of the different factors tested in the study and establishes comparisons between SCS practices. Finally, section 5 covers conclusions.

2. Materials and methods

2.1. Soil organic carbon sequestration practices

Six SCS practices were considered in this paper: the use of organic amendments (OA), the use of biochar amendments (BC), incorporating pruning residues to the soil (PR), no-tillage (NT), cover cropping (CC) and planting or maintaining hedges in the vineyard (HG). Existing research and evidence proved that the implementation of these practices leads to SOC sequestration on agricultural land (Sykes et al., 2020). Pellerin et al. (2017) and Pellerin et al. (2019) analysed the SOC sequestration potential of these SCS practices (excluding BC) more specifically in the context of French soils and showed that they could play a crucial role in reaching the target of the '4 per 1000' initiative[2] at low (*e.g.*, NT and HG) or even negative (*e.g.*, OA and CC) costs at the national level.

[2] The '4 per 1000' is an international initiative gathering public and private stakeholders under the Lima-Paris Action Plan framework. It aims to achieve an annual growth rate of 0.4% in the global SOC stocks (to a depth of 40 cm) for food security and climate (4p1000, 2018).

2.2. Study area: France

Vineyards are widely distributed throughout France (Fig. 1), covering a variety of agro-ecological zones with notably different climates: Mediterranean in the southeast, continental in the east, and temperate oceanic in the rest of the country. Viticultural practices differ between winegrowing regions, each having its own, traditional methods of cultivation (Agreste, 2017). This is due to the strong socio-cultural history associated with winemaking in the country, embodied in the concept of *terroir*. Age-old viticultural management practices at the regional or local levels have evolved across centuries and are crucial elements of distinct regional *terroirs* (OIV, 2010).

The adoption rate of SCS practices on viticultural land is low at the national level in France, except for PR (Fig. 2). Uptake varies, however, at the regional level, with specific winegrowing regions displaying higher or lower adoption of certain practices. The use of OA, for instance, is as low as 3% in Roussillon and 4% in Beaujolais but reaches 19% in Champagne and 20% in Alsace (Agreste, 2017). The adoption of NT also varies between winegrowing regions, ranging from 9% in Provence to 65% in Champagne (Agreste Primeur, 2016). There is no existing data on the adoption rates of BC and HG on viticultural land in France.

2.3. Survey design

To understand the adoption of SCS practices by winegrowers, a survey was conducted between April and September 2019. The survey data was collected using a structured questionnaire developed after a literature review, expert consultations and a pilot study. The final questionnaire was divided into five sections (Appendix A). The first section was designed to collect data on winegrowers' socio-economic profiles (*e.g.*, age, education, workforce hired, etc.). The second section enquired about vineyard structure and characteristics (*e.g.*, vineyard size, vine's age, organic certification, etc.). The third section collected information on winegrowers' incentives for adopting new viticultural practices, such as subsidy or participation in AEMs. Section four addressed the adoption or otherwise of SCS practices. The last section asked winegrowers to evaluate various statements to reveal their beliefs and attitudes towards SCS practices.

The survey targeted farm managers (*chefs d'exploitation*) and co-managers (*co-exploitants*) who cultivate grapes. It only considered vineyards categorised as "viticultural farms", *i.e.* when grape production represents more than two-thirds of the revenues of the farm (Legouy, 2014). The survey was administered online via SurveyMonkey, using a simple random sampling method. A total of 1,380 winegrowers were contacted by email using viticultural databases, wine shops and personal contacts. The French Institute of Vine and Wine, the French Confederation of GPI Wines (*Confédération des vins IGP de France*) and several regional inter-professional councils of wine (*e.g.*, the *Bureau interprofessionnel des vins de Bourgogne* and the *Conseil interprofessionnel du vin de Bordeaux*) were contacted and agreed to circulate the questionnaire through their networks or to publish the link to the questionnaire on their website and newsletter. A total of 400 fully completed responses were collected across France, giving a return rate of 29%. The sample size margin of error was determined by the methods of Iarossi (2006). Responses were anonymous and handled in accordance with the General Data Protection Regulation.

2.4. Principal component analysis

Statements included in the questionnaire assessed winegrowers' attitude towards SCS practices both from an economic and environmental point of view, their perception of the resources needed to implement the practices, and their confidence towards adoption. Respondents were asked to choose the extent to which they agreed with the statements using a five-point Likert scale, from strongly disagree (–2) to strongly agree (2). A principal component analysis (PCA) was used to condense the information contained in the statements. PCA is a data reduction technique that converts a given number of correlated variables into a smaller number of uncorrelated components, with a minimum loss in information (Jolliffe, 2002). The components created, or principal components, account for most of the variation in the responses.

Before conducting the PCA, the suitability of the statements for this type of analysis was checked using the Kaiser-Meyer-Olkin (KMO) test and Bartlett's test of sphericity. The KMO test, which provides a measure of the adequacy of the data for PCA, yielded a value of 0.74, which was considered acceptable (*i.e.* > 0.6). Bartlett's test of sphericity was used to assess whether the correlation matrix of the statement variables was different from an identity matrix. The test was statistically significant (p = .000), which means that the correlation matrix of the statements was significantly different from an identity matrix, which is consistent with the assumption that the correlation matrix should be treated as factorable.

The PCA was conducted using an eigenvalue higher than one to extract components. The varimax rotation was employed to simplify component interpretation. A total of three components were kept (Table 1). The value of 0.4 was chosen as a loading threshold for retaining statements in components. A total of ten statements loaded onto the components (Table 1). Once the PCA was completed, a Cronbach's Alpha was carried out for each component to assess internal consistency and reliability. Values higher than 0.6 are commonly considered acceptable for this test; the three components were, therefore, retained as explanatory variables for the rest of the analysis (Table 1).

The first component, 'resources', consisted of statements reflecting the adequacy of the respondents' current resources to implement SCS practices. These related mostly to time (*e.g.*, "I have enough time to implement SCS practices") and tools (*e.g.*, "My current tools and technologies are sufficient to implement SCS practices"). The second component, 'attitude', measured the respondents' beliefs towards SCS practices. Statements with the highest loadings towards this component included "SCS practices increase viticultural productivity" and "SCS practices enhance soil quality". The final component, 'confidence', assessed the respondents' confidence in the implementation of SCS practices, with statements such as "I have a clear understanding of how to implement SCS practices" and "I trust my skills to implement SCS practices".

2.5. Explanatory variables

Table 2 presents the explanatory variables used in the qualitative choice modelling. Three types of variables were chosen to explain the adoption of SCS practices, based on the literature about the adoption of new practices in the agriculture sector, and interviews with experts from the French Institute of Vine and Wine as well as members of regional Chambers of Agriculture. The first category of variables related to winegrowers' socio-economic characteristics, such as gender, age, education (general or viticultural) and landownership, and vineyard attributes, including farm size, workforce hired, certification labels – High Environmental Value[3] (HVE) and organic agriculture (European label 'AB') – and irrigation use. Age is commonly used in studies investigating farmers' adoption of new practices, as older farmers are prone to being more conservative towards the adoption of alternative farm practices (Prokopy et al., 2008). Farm size is also considered to be an important factor in the adoption of new practices, since smaller farms cannot benefit from the same cost advantages as larger farms when implementing management practices (Knowler and Bradshaw, 2007; Tambo and Abdoulaye, 2012). The second category of variables concerned respondents' access to information and involvement in policy instruments. These types of variables have proved to be crucial in the adoption of innovative measures and their diffusion (Luo et al., 2014). A policy variable (AECM) was created to assess the participation of respondents in AEMs. Some AEMs in France set up specifically for viticultural land (*e.g.*, COUVER_11, which provides financial support to winegrowers for the implementation of cover cropping in the inter-rows of vineyards) are likely to influence the adoption of SCS practices. The third category of variables was linked to specific aspects of viticultural production systems, such as the date when the majority of vines was planted, and whether the respondent is an independent winegrower[4]. The three components 'resources', 'attitude' and 'confidence' resulting from the PCA were also used as explanatory variables in the modelling.

[3] The High Environmental Value (*Haute Valeur Environnementale* in French) label is a French certification awarded to farmers using sustainable and environmental-friendly practices on their farms (IFV, 2019).

[4] An independent winegrower is a winegrower who grows grapevine, harvests grapes, makes wine and directly sells it (Vignerons indépendants de France, 2020).

2.6. Qualitative choice model

The interest of this paper was in modelling the binary choice of SCS practice adoption (1 = adoption of the practice, 0 = non-adoption of the practice). A binary logistic regression was used for each of the six SCS practices to assess the contribution of the explanatory variables to the adoption process of the practice without considering the adoption of the other practices. This type of econometric model is commonly used to assess the factors influencing the adoption of agricultural practices by farmers (*e.g.*, Tey et al., 2014; Timprasert et al., 2014; Paul et al., 2017; Daxini et al., 2018). In the logit model (Equation (1)), P_i corresponds to the probability of adoption of a SCS practice, $(1 - P_i)$ to the probability of non-adoption of the practice, α to the intercept, and $\beta_1, \beta_2, ..., \beta_{20}$ to the regression coefficients of variables $X_1, X_2, ..., X_{20}$, respectively. i refers to the values of respondent i.

$$\ln \frac{P_i}{(1-P_i)} = \alpha + \beta_1 X_{1i} + \beta_2 X_{2i} + \cdots + \beta_{20} X_{20i} \qquad (1)$$

The parameters in the logit model were estimated using the maximum likelihood method. The sign of the β coefficients represents how the variables influence the likelihood of adoption of SCS practices: if β is positive, when the value of the associated variable increases, the likelihood of adoption of the SCS practice increases as well, and vice versa.

The model was run with all the explanatory variables presented in Table 2; however, some variables (*e.g.*, gender or education) were not significant predictors of adoption for any of the SCS practices. A likelihood-ratio test was carried out to see whether the goodness of fit of the model was altered when removing these variables. The test was significant, which implies that permuting these variables significantly alters the model fit. All the explanatory variables were, therefore, integrated into the model.

3. Results

3.1. Descriptive statistics

The overall sample size of French winegrowers was 400. Considering that the population size of viticultural farms was 85,000 in 2019 (CNIV, 2019), the sample size margin of error was 4.89% with a confidence level of 95% (Iarossi, 2006). Margins of error lower than 5% are considered acceptable for samples with a majority of categorical data (Barlett et al., 2001). Sample summary data for all the variables used in the regressions are presented in Table 2. The mean age of respondents was 50 years. The majority of respondents had a higher education degree (78%), while 20% stopped after secondary education, and only a small percentage of respondents did not have secondary education (2%). Most respondents also had a viticultural degree (74%). 12% of the viticultural farms in the sample were less than 5 ha, 37% between 5 and 15 ha, 26% between 15 and 30 ha, 12% between 30 and 50 ha, and 13% higher than 50 ha. Most vines were planted between 1970 and 1989 (35.25%) and between 1990 and 1999 (29.75%). Fewer were planted between 2000 and 2010 (19.75%). A few were planted between 1950 and 1969 (8.5%) and between 2011 and 2020 (4.5%). The sample included a small number of vines planted before 1950 (2.25%). 33% of viticultural farms were certified organic and 17% were certified HVE. 16% of the respondents were involved in an AEM. Awareness of the ‘4 per 1000’ initiative was, overall, very low, with only 7% of the respondents stating that they were familiar with the initiative.

3.2. Adoption of soil organic carbon sequestration practices in the sample

The adoption rate varied considerably between practices. PR was the most commonly adopted practice, with 91% of respondents incorporating pruning residues into the soil of their vineyard. The adoption of OA and CC was lower (73% and 69%, respectively). NT and HG were adopted by about half the respondents (50% and 52%, respectively). The adoption of BC was exceptionally low, with only 2% of the respondents stating that they use biochar amendments. Most respondents were not familiar with BC.

There were also variations in the adoption rate of SCS practices at the regional level. For instance, in Languedoc-Roussillon, the adoption rate of CC (57%) was lower than at the national level (69%). This may be due to the high competition for water and nutrients between the vine and the cover crop during the growing period of the vine in this region, which is characterised by dry summers and soils that are low in humus. Inversely, CC was used by 88% of respondents in Alsace-Lorraine, which is more than at the national level and substantially more than in Languedoc-Roussillon. This higher adoption rate in Alsace-Lorraine can be explained by the lower competition between vines and cover crops in the vineyard during the important stages of the vine cycle compared to Languedoc-Roussillon.

3.3. Factors influencing the adoption of soil organic carbon sequestration practices

The significance of the model fit was assessed for each practice using model chi-square. The chi-square values were significant at the 0.1% level for OA, PR, NT and HG and at the 5% level for CC, which indicates that the model fit for these practices is significantly better than a null model (*i.e.* without any predictors). However, the chi-square was not significant (p = .430) for the adoption of BC; BC was, therefore, excluded from the analysis. The goodness of the model fit was assessed for each practice using the Nagelkerke R^2 and the level of accuracy (*i.e.* the percentage of respondents classified correctly between adopters and non-adopters by the model). The Nagelkerke R^2 was 0.23 for OA, 0.25 for PR, 0.22 for NT, 0.13 for CC and 0.20 for HG. These were reasonable values for this type of regression and study (Barnes et al., 2019), though the explanatory power was lower for CC than for the other practices. The level of accuracy (75% for OA, 91% for PR, 65% for NT, 70% for CC and 66% for HG) was considered acceptable for all the practices. Collinearity between the predictors was controlled by calculating the variance inflation factor (VIF). The VIFs were between 1.05-1.71 for all the variables, which suggests low multicollinearity in this study (James et al., 2017).

3.3.1. Organic amendments

Only four explanatory variables significantly influenced the decision to adopt OA, holding the other variables constant: independent winegrower, vine planting, AB and irrigation (Table 3). The effect of independent winegrower and AB was positive, while that of vine planting and irrigation was negative. The variables AB and independent winegrower exerted the strongest impact on the adoption process of OA, with an odds ratio of 3.02 and 2.52, respectively.

3.3.2. Pruning residues

Age, farm size, workforce hired and HVE had a significant impact on the decision to adopt PR (Table 4). The effect of farm size and HVE was positive, while that of age and workforce hired was negative. HVE was, by far, the predictor with the highest impact on the decision to adopt PR: respondents whose vineyard is certified HVE are extremely more likely, by a factor of 7.29, to adopt PR than respondents whose vineyard is not certified HVE.

3.3.3. No-tillage

The decision to adopt NT was influenced significantly and in a positive way by resources, attitude and confidence but negatively by workforce hired, AB and irrigation (Table 5). Irrigation was the predictor with the greatest effect on the decision to adopt NT: respondents practising irrigation in their vineyard are notably less likely, by a factor of 0.31, to adopt NT than respondents not practising irrigation.

3.3.4. Cover cropping

Farm size, vine planting, resources and confidence were the key predictors affecting the decision to adopt CC, while the other variables were not significant (Table 6). The effect of vine planting, resources and confidence on the decision to adopt CC was positive, whereas that of farm size was negative. The variable with the strongest effect on the decision to adopt CC was resources, with an odds ratio of 1.6.

3.3.5. Hedges

The decision to adopt HG was positively influenced by the predictors vine planting, HVE, AB, resources and confidence, and negatively influenced by the variable subsidy (Table 7). HVE had a particularly powerful effect on the decision to adopt HG compared to the other five variables: respondents whose viticultural farm is certified HVE are considerably more likely (by a factor of 4.38) to adopt HG than respondents whose farm is not certified HVE.

4. Discussion

4.1. Influence of the predictors on the decision to adopt soil organic carbon sequestration practices

Twelve predictors out of twenty had a significant effect on the decision to adopt at least one SCS practice: age, independent winegrower, farm size, workforce hired, vine planting, HVE, AB, irrigation, subsidy, resources, attitude and confidence (Table 8). However, there were variations in the significance of the explanatory variables between SCS practices.

Age had a significant, negative effect only on the decision to adopt PR. This confirms the results of previous studies analysing the role of farmer age in the adoption process of new practices (*e.g.*, Lambert et al., 2015; Sánchez et al., 2016; Paul et al., 2017). Several reasons explain why younger farmers are, in general, more likely to adopt management practices than older farmers. Younger farmers have a longer planning horizon than older farmers, which makes them more inclined to adopt new management practices, especially if they maintain or increase production on the farm (Knowler and Bradshaw, 2007). Younger farmers are also more exposed to information about new practices and are, therefore, more knowledgeable about innovations (Barnes et al., 2019). They are also more willing to face learning curves (Roberts et al., 2004). Long et al. (2016) observed in several European countries (the Netherlands, France, Switzerland and Italy) that older farmers may be reluctant to change traditional agricultural practices, even if new practices are tried and tested. The difficulty in overcoming traditions makes it harder to incentivise training in new agricultural practices among older farmers.

Farm size had a significant effect on the decision to adopt PR and CC but was not significant for the other SCS practices; however, the effect of the variable was positive for PR but negative for CC, which means that winegrowers with larger vineyards are more likely to adopt PR but less likely to implement CC than winegrowers with smaller vineyards. Literature on the influence of farm size on the adoption of new management practices by farmers reports mixed effects of the variable. Lambert et al. (2015) and Barnes et al. (2019) both found that farmers with larger farms are more likely to be adopters of precision agriculture technologies. Goldberger and Lehrer (2016) also found that walnut growers with larger orchard farms were more likely to adopt biological control practices in the western USA, and Prager and Posthumus (2010) observed greater uptake of soil conservation practices in larger farms in Europe. This positive influence can be explained by the fact that, in larger farms, the costs of adopting a new practice are spread over more hectares (Lambert et al., 2015) and that when more land is being cultivated, farmers become less vulnerable to failure from the new practice (Mariano et al., 2012). Conversely, Despotović et al. (2019) showed that with increasing farm size, farmers become less willing to adopt integrated pest management practices, because they are less ready to take a risk by reducing pesticide use. This suggests that the effect of farm size on the adoption of new management practices is context-specific, and this applies to the adoption of SCS practices by French winegrowers.

The size of the workforce hired had a significant, negative effect on the decision to adopt PR and NT (but had no significant effect on the decision to adopt other SCS practices). This finding is consistent with that of Tey et al. (2014), who noticed that the number of hired workers was one of the most important factors in the adoption of conservation tillage and crop rotation in Malaysia and that its effect was negative. It could be explained in the case of French viticulture by the important costs associated with hiring workforce on a full-time basis, which could reduce winegrowers' willingness to adopt PR and NT, due to the capital investment in new equipment necessary for both practices (Posthumus et al., 2015; Garcia et al., 2018). Conversely, as soil tillage requires more qualified workers, such as tractor drivers, than NT (especially when NT takes the form of chemical weeding), viticultural farms with a high number of workers are more likely associated with the use of tillage than of NT. This goes against the results of other studies, which found a positive effect of hired (Barnes et al., 2019) or family (Paul et al., 2017) labour on the adoption of new management practices. The positive effect of family workforce observed by Paul et al. (2017) is, however, due to the fact that an increased number of family members working on the farm leads to a reduction in labour intensity, particularly in smaller farms where labour is more often manual than on larger farms, but at lower costs than when labour is hired outside of the household.

Being an independent winegrower had a significant effect on the decision to adopt OA but not any other SCS practice. This effect was positive, probably because independent winegrowers often have more capital and equipment than other winegrowers and would have a higher capability to adopt OA. The year of vine planting also significantly influenced the decision to adopt OA, CC and HG. The effect of the variable was negative for OA but positive for CC and HG.

Being certified HVE had a strong, positive effect on the decision to adopt PR and HG (by a factor of 7.29 and 4.39, respectively). This is coherent with the restrictions of the label, which require the use of practices that limit as much as possible inputs coming from outside the agricultural system and that help to increase biodiversity on the farm (IFV, 2019).

Being certified AB had a significant influence on the decision to adopt OA, NT and HG; however, this effect was positive in the case of OA and HG but negative for NT. The strong positive effect (by a factor of 3.02) obtained for the adoption of OA was anticipated, since organic agriculture forbids the use of synthetic fertilisers, which are replaced by organic amendments (Council of the European Union, 2007). Under organic viticulture, winegrowers use OA to increase soil properties and quality and to ensure that grape yields are sufficient. However, organic fertilisers are used cautiously on viticultural land (often according to soil testing), as too much vine vigour could lead to a decrease in grape quality for winemaking. The positive effect of AB on the adoption of HG could be explained by the important role hedges play in agroecosystems under organic farming, mainly by providing shelter for beneficial organisms, which act as pest control in lieu of pesticides, and by improving soil quality and water infiltration (Holden et al., 2019). The negative effect of AB on NT can also be explained by the fact that, under organic certification (Council of the European Union, 2007), winegrowers cannot use herbicides treatments to control weed growth in vineyards; a majority uses tillage instead to ensure that weed does not compete too much with the vine.

The use of irrigation by winegrowers had a negative impact on the decision to adopt OA and NT. This could be due to the lower evapotranspiration associated with the use of NT, which may reduce the need for irrigation. It is also related to the bio-climatic conditions of the winegrowing regions where irrigation is used. Irrigation in viticulture is mostly practised in the southeast of France, where precipitations are low. Tillage is commonly used under such conditions as a way to mitigate the water and nitrogen competition between weed and vine. The negative effect of irrigation on the adoption of OA is surprising, however, as irrigation is often used on viticultural soils with low OM content, where the use of organic amendments could improve soil water retention and quality. It goes against the findings by Sánchez et al.

(2016), who noted a positive effect of irrigation on the adoption of intercropping practices in Spain.

Receiving subsidies was, surprisingly, only significant in the decision to adopt HG and in a negative way. Previous studies observed, inversely, a positive effect of subsidies on the adoption of new management practices such as CC and intercropping (Sánchez et al., 2016) or precision agriculture technologies (Barnes et al., 2019). The negative effect of subsidies on the adoption of HG in viticulture might be due to the specific nature of subsidies that respondents were asked about: set up in the context of the vitivinicultural common market organisation and developed by FranceAgriMer[5], these subsidies aim at incentivising vineyard restructuration that would improve productivity, mainly by modifying vine row density, training the vine or implementing irrigation practices (FranceAgriMer, 2020), but they do not target non-productive investments such as hedgerows. Other types of financial incentives targeting more specifically the implementation or maintenance of hedgerows exist at the regional or *département* level, but respondents were not asked about them in the survey.

The variable resources had a significant and positive effect on the decision to adopt NT, CC and HG, which means that winegrowers who believe that they have the necessary resources (*i.e.* time and appropriate equipment) to adopt SCS practices are more likely to adopt NT, CC and HG than winegrowers who do not. This is in line with previous studies that analysed the effect of this variable on the adoption process of new agricultural practices (*e.g.*, Tey et al.,

[5] FranceAgriMer is a French agricultural agency whose aim is to implement the measures set up by the Common Agricultural Policy at the national level and to undertake actions to support the agriculture sector. It receives a fund of €280 million every year to support vineyard restructuration and conversion, investments in vitivinicultural businesses, wine promotion abroad, and the distillation of wine by-products (FranceAgriMer, 2020).

2014; Daxini et al., 2018; Barnes et al., 2019). These studies concluded that farmers who believed that their current machinery was able to support the new technology were more likely to adopt it. This finding is relevant to the fact that the implementation of SCS practices may require new tools and be time-consuming. Although the adoption of NT may reduce fuel and time costs associated with tillage, it is likely to require capital investment in new equipment (Posthumus et al., 2015) and to generate costs associated with weed control such as herbicides (Maillard et al., 2018). These costs, however, vary depending on the planting density of the vineyard: the costs of tillage are considerably higher than those of NT in vineyards with a high planting density but tend to be similar to those of NT in vineyards with a low planting density. The implementation of CC is associated with additional inputs and time costs (Sykes et al., 2020). Planting hedges requires capital investment for appropriate tools and increases time costs for maintenance (Lasco et al., 2014).

The variable attitude had a significant and positive effect on the decision to adopt NT, which is in line with the strong positive relationship between attitude and behaviour found by previous studies (*e.g.*, Wauters et al., 2010; van Dijk et al., 2016; Rezaei et al., 2018; Despotović et al., 2019). The positive effect of attitude on the decision to adopt was to be anticipated considering the important role attitude plays in behavioural modelling, and particularly in the theory of planned behaviour: it is generally admitted that the more favourable an attitude is towards a behaviour, the higher the possibility that an individual will perform the behaviour (Ajzen, 1991). For this reason, it was quite surprising that winegrowers' attitudes towards SCS practices did not have a significant effect on the adoption of the other SCS practices. This might be because the statements used to create the principal component 'attitude' considered SCS practices as a whole, but respondents may have answered with specific SCS practices in mind.

The variable confidence influenced significantly and positively the decision to adopt NT, CC and HG, suggesting that farmers who are confident in their capability to adopt SCS practices are more likely to adopt these practices. This is in line with the findings of Daxini et al. (2018) and Despotović et al. (2019), who noted a positive effect of the variable on farmers' intention to adopt specific management practices. It highlights the fact that if winegrowers do not adopt NT, CC and HG, it is not necessarily because they lack the motivation to do so but instead because they lack suitable levels of confidence in their understanding and skills to take action (Wilson et al., 2018).

It was surprising that the variable viticultural advisor was not significant for any of the practices. Most studies investigating the factors influencing the adoption of new agricultural practices reported a positive effect of being in contact with an agricultural advisor on adoption (*e.g.*, Ingram, 2008; Baumgart-Getz et al., 2012; Daxini et al., 2018; Barnes et al., 2019). Such a positive effect can be explained by the important support role of advisors, who provide knowledge and technical expertise, which encourages adoption (Busse et al., 2014). The effectiveness of this support role depends, however, on the advisors' knowledge and understanding of management practices, which, in the case of SCS practices, tends to be low at the European level (Ingram et al., 2014). SOC sequestration is not currently an objective in viticulture, which may explain why the variable viticultural advisor was not significant in this study. Nevertheless, SCS practices are in agreement with what is generally advised by viticultural advisors (*e.g.*, in the context of agroecology).

4.2. Uncertainty and further research

A sampling error was detected, which implies that the sample used in this study was not representative of the entire population of French winegrowers. Firstly, the adoption rate of some SCS practices in the sample was higher than at the national level as established by the latest national survey undertaken by the French Government (Agreste, 2017). The adoption rate of PR in the sample (91%) was similar to that estimated at the national level (87%), but this was not the case for the adoption rate of OA (73%), NT (50%) and CC (69%), which were considerably higher than at the national level (9%, 21% and 45%, respectively). This suggests that there is an overrepresentation of winegrowers who have adopted SCS practices in the sample, which may be because these winegrowers might have higher concerns about soil quality and climate change and would, therefore, be more inclined to answer the questionnaire. This overrepresentation may have skewed some of the results of the logistic regressions, since adopters of SCS practices are more likely, on average, to have positive attitudes towards the practices than non-adopters. However, it is important to notice that the data reported by Agreste (2017) is expressed in percentage of viticultural land where a practice has been implemented and not in percentage of winegrowers who have implemented the practice, which may also explain some of the differences observed between our sample and the national survey. Secondly, winegrowers whose viticultural farm is certified organic were overrepresented in this study: they represented 33% of the sample, while only 8% of the total viticulture at the national level is conducted under organic farming (Agreste, 2017). This could explain, for instance, the higher adoption rate of OA in the sample, since the use of organic amendments is encouraged under organic agriculture as an alternative to synthetic fertilisers.

The adoption intensity in the sample averaged 3.3 practices, ranging from 0 (n = 1) to 6 (n = 1) practices adopted by a single respondent. Most respondents to the questionnaire implemented three or four practices (31% and 30%, respectively). 17% of respondents implemented two practices and 16% implemented five practices. Only 5% of the respondents implemented one practice, overall. This shows that winegrowers do not adopt just one SCS practice but, conversely, several at the vineyard level. The adoption intensity was not taken into account in this study; however, there is room for further research to investigate the factors influencing the adoption intensity of SCS practices and whether having already adopted one or several SCS practices incentivises winegrowers to implement more on their viticultural farm. This would be of great importance to better understand the role viticultural land could play in sequestering SOC, since the adoption of several SCS practices at the vineyard level (*e.g.*, OA+NT) is associated with higher SOC sequestration rates than the adoption of a single SCS practice (*e.g.*, only OA or only NT), based on field experiments (Payen et al., 2021a). Questions regarding the adoption intensity of SCS practices in French vineyards could be added to the surveys on viticultural practices conducted by Agreste at the national level, which rely on sample groups representative of each winegrowing region of France.

5. Conclusions

This paper aimed to investigate the different factors influencing the adoption process of SCS practices by winegrowers in France. Results showed that socio-economic and behavioural characteristics were important factors in the decision to adopt SCS practices. Specific aspects of viticultural production (*e.g.*, vine age or being an independent winegrower) were also significant drivers of the decision to adopt the practices. The use of a binary logistic model proved to be adequate to evaluate the impact of the different variables tested in the study, except in the case of BC, whose adoption rate in the sample was too low for the model to be significant. These results add to the existing literature relating to farmers' decision-making behaviour and adoption of new agricultural practices. They also address a gap in the literature, as vineyard agroecosystems have not been considered for analysis by any study dealing with the adoption process of SCS practices.

Findings from this study could help to improve policy targeted at the viticulture sector in France and potentially in the EU. The current subsidies received by French winegrowers do not incentivise effectively the adoption of agricultural practices with SOC sequestration elements, since subsidies did not play any significant role in the adoption of OA, PR, NT and CC in this paper. The same could be said of AEMs: even though a relatively large number of winegrowers from the sample were involved in a measure directly incentivising the adoption of a SCS practice (mostly OA, CC and HG), being involved in an AEM did not have any significant effect on the adoption of these practices. This suggests that many winegrowers who implement SCS practices are not necessarily involved in the corresponding AEM, which represents a potential loss of earnings for these winegrowers. Further research would seek to understand the reasons behind this, and whether it is because payments are not high enough or winegrowers are not sufficiently aware of AEMs. Overall, results from this paper provide insights into the decision-making behaviour of winegrowers, which could be useful in the context of the '4 per 1000' initiative, of which France is a founding member.

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Competing interests

Declarations of interest: none.

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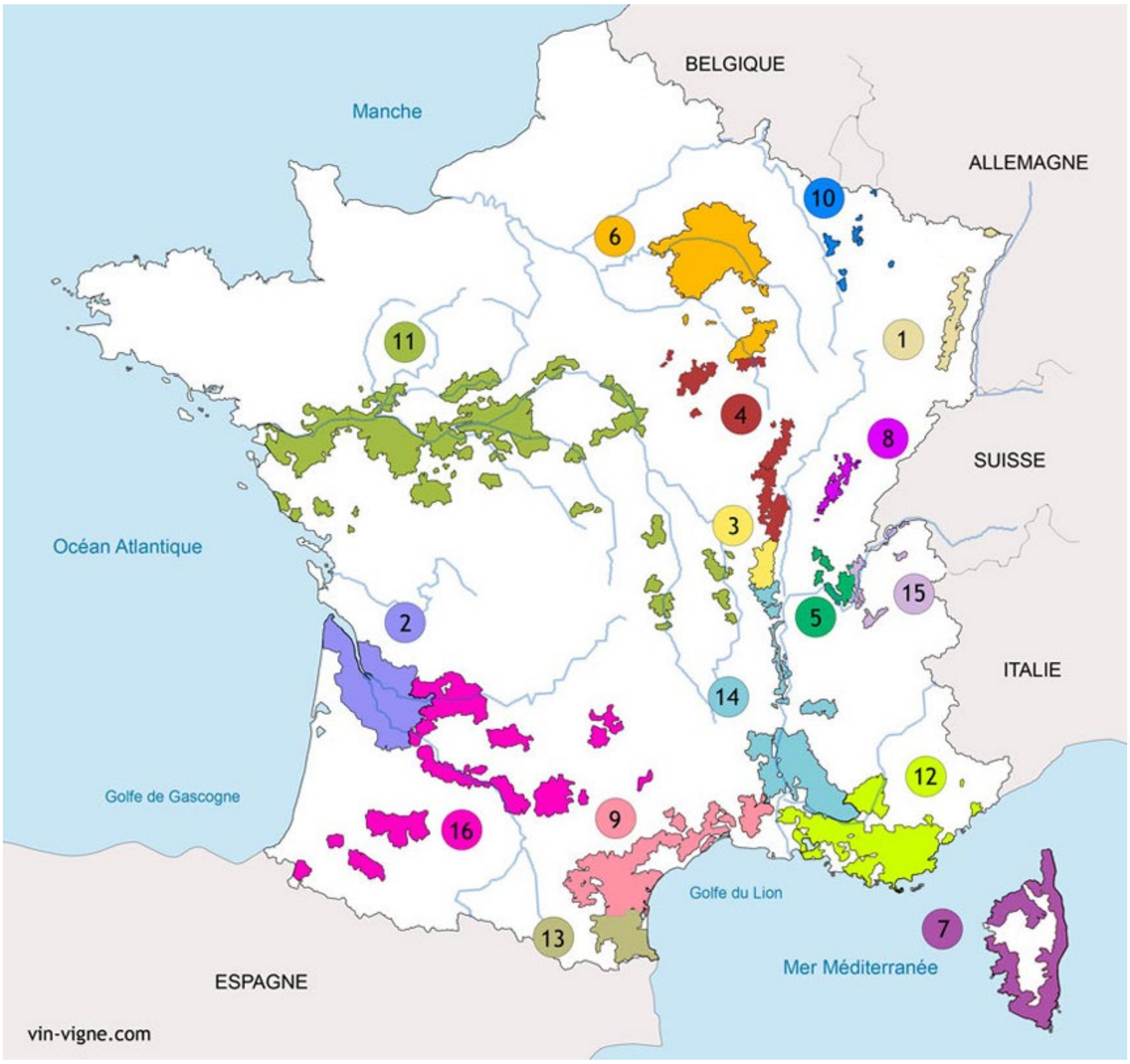

Fig. 1. French winegrowing regions (Vin-Vigne, 2015). (1), Alsace; (2), Bordeaux; (3), Beaujolais; (4), Burgundy; (5), Bugey; (6), Champagne; (7), Corsica; (8), Jura; (9), Languedoc; (10), Lorraine; (11), Loire Valley; (12), Provence; (13), Roussillon; (14), Rhône Valley; (15), Savoy and (16), South-West.

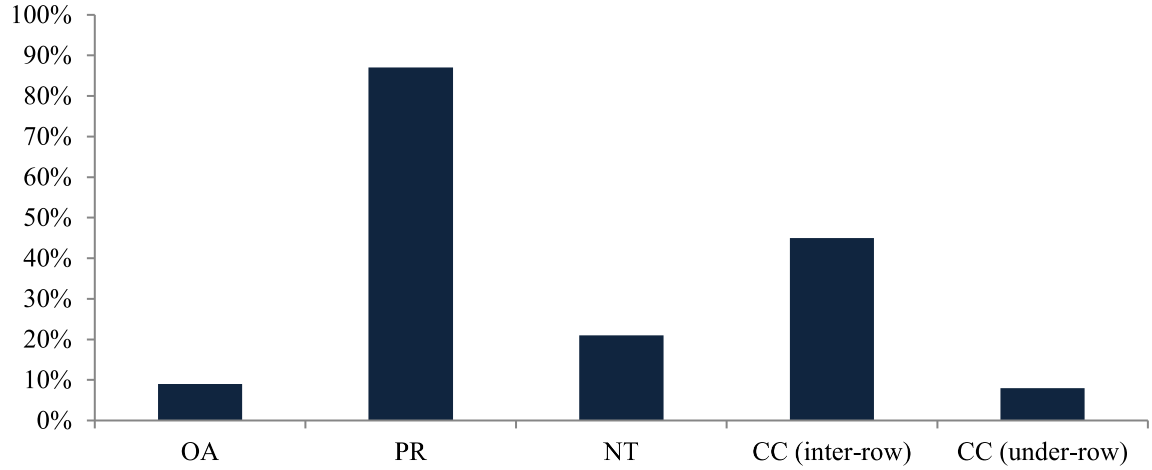

Fig. 2. Percentage of France's viticultural land where SCS practices are implemented (Agreste, 2017). OA, applying organic amendments; PR, returning pruning residues to the soil; NT, implementing no-tillage; CC, cover cropping.

Table 1. Results of the PCA for winegrowers' intentions to adopt SCS practices.

Statements	**Resources**	**Attitude**	**Confidence**
SCS practices increase viticultural productivity	0.070	**0.693**	0.054
SCS practices increase wine quality	0.225	**0.694**	0.038
SCS practices save time	**0.640**	0.095	-0.165
SCS practices enhance soil quality	0.083	**0.694**	0.233
SCS practices increase vineyard resilience	0.021	**0.624**	0.096
I have enough time to implement SCS practices	**0.770**	0.098	0.221
My current tools and technologies are sufficient to implement SCS practices	**0.609**	0.068	0.219
I have a clear understanding of how to implement SCS practices	0.109	0.169	**0.886**
I trust my skills to implement SCS practices	0.175	0.178	**0.879**
My current tools and technologies make it easy to implement SCS practices	**0.722**	0.116	0.129
Eigen value	3.096	1.393	1.207
Cronbach's Alpha	0.655	0.637	0.835

Table 2. Explanatory variables used in the modelling for the full sample of respondents (n = 400).

Variable	**Description**	**Mean**	**SD**	**Min**	**Max**
Gender	Gender of the farm manager (1 = male, 0 = female)	0.82	0.38	0	1
Age	Age of the farm manager (continuous)	49.94	11.47	24	86
Education	Level of formal education received by the farm manager (1 = primary education, 2 = secondary education, 3 = higher education)	2.76	0.47	1	3
Viticultural education	Farm manager has a viticultural degree (1 = yes, 0 = no)	0.74	0.44	0	1
Landowner	Farm manager owns (at least partially) their vineyard (1 = yes, 0 = no)	0.81	0.39	0	1
Inherited vineyard	Farm manager inherited the vineyard from a family member (1 = yes, 0 = no)	0.46	0.50	0	1
Independent winegrower	Farm manager is an independent winegrower (1 = yes, 0 = no)	0.67	0.47	0	1
Farm size	Size of the viticultural farm (1 = < 5 ha, 2 = 5-15 ha, 3 = 15-30 ha, 4 = 30-50 ha, 5 = > 50 ha)	2.77	1.20	1	5
Workforce hired	Number of regular labour (working part- or full-time) employed (continuous)	3.94	9.01	0	92
Vine planting	Date when the majority of vine was planted (1 = 2011-2019, 2 = 2000-2010, 3 = 1990-1999, 4 = 1970-1989, 5 = 1950-1969, 6 = before 1950)	3.30	1.09	1	6
HVE	Vineyard is certified High Environmental Value (1 = yes, 0 = no)	0.17	0.38	0	1
AB	Vineyard is certified organic (1 = yes, 0 = no)	0.33	0.47	0	1
Irrigation	Irrigation is used in the vineyard (1 = yes, 0 = no)	0.13	0.33	0	1
AECM	Farm manager participates in an agri-environment measure (1 = yes, 0 = no)	0.16	0.37	0	1
Subsidy	Farm manager receives subsidies (1 = yes, 0 = no)	0.49	0.50	0	1

Viticultural advisor	Farm manager is in contact with a viticultural advisor (1 = yes, 0 = no)	0.67	0.47	0	1
4per1000	Farm manager is familiar with the '4 per 1000' initiative (1 = yes, 0 = no)	0.07	0.26	0	1
Resources	Component variable built from ordinal responses (5-point Likert scale)	-	-	-	-
Attitude	Component variable built from ordinal responses (5-point Likert scale)	-	-	-	-
Confidence	Component variable built from ordinal responses (5-point Likert scale)	-	-	-	-

Table 3. Results of the binary logistic regression for the prediction of winegrowers' adoption of OA.

OA	Coefficient	Standard error	Wald	Odds ratio
Gender	-0.140	0.338	0.171	0.870
Age	-0.014	0.011	1.629	0.986
Education	0.075	0.273	0.076	1.078
Viticultural degree	0.144	0.291	0.246	1.155
Landowner	-0.126	0.382	0.108	0.882
Inherited vineyard	0.150	0.285	0.277	1.162
Independent winegrower	0.923***	0.274	11.311	2.516
Farm size	0.232	0.146	2.541	1.262
Workforce hired	0.050	0.037	1.782	1.051
Vine planting	-0.246**	0.121	4.120	0.782
HVE	-0.594	0.391	2.307	0.552
AB	1.104***	0.319	11.959	3.016
Irrigation	-0.797**	0.385	4.288	0.450
AECM	-0.001	0.346	0.000	0.999
Subsidy	0.395	0.290	1.863	1.485
Viticultural advisor	-0.258	0.285	0.817	0.773
4per1000	0.157	0.546	0.083	1.170
Resources	0.084	0.125	0.452	1.088
Attitude	0.012	0.134	0.008	1.012
Confidence	-0.012	0.126	0.009	0.988
Constant	0.928	1.222	0.576	2.529
Chi-square	70.509 (p = .000)			
Nagelkerke R^2	0.234			
Log-likelihood	400.026			
Accuracy	74.8%			

p < .1 = *; p < .05 = **; p < .01 = ***

Table 4. Results of the binary logistic regression for the prediction of winegrowers' adoption of PR.

PR	Coefficient	Standard error	Wald	Odds ratio
Gender	0.208	0.487	0.183	1.232
Age	-0.047***	0.018	6.578	0.954
Education	0.140	0.415	0.114	1.150
Viticultural degree	-0.724	0.471	2.359	0.485
Landowner	0.299	0.566	0.279	1.349
Inherited vineyard	0.062	0.435	0.020	1.064
Independent winegrower	-0.717	0.453	2.507	0.488
Farm size	0.771***	0.240	10.333	2.163
Workforce hired	-0.078***	0.023	11.636	0.925
Vine planting	-0.220	0.183	1.456	0.802
HVE	1.987*	1.063	3.496	7.293
AB	0.760	0.490	2.407	2.137
Irrigation	-0.707	0.631	1.256	0.493
AECM	-0.592	0.548	1.166	0.553
Subsidy	0.525	0.476	1.218	1.691
Viticultural advisor	0.180	0.410	0.193	1.197
4per1000	0.402	1.124	0.128	1.495
Resources	0.190	0.201	0.887	1.209
Attitude	0.319	0.209	2.330	1.376
Confidence	0.071	0.195	0.133	1.074
Constant	3.672	1.840	3.984	39.338
Chi-square	48.558 (p = .000)			
Nagelkerke R^2	0.248			
Log-likelihood	198.069			
Accuracy	91%			

$p < .1$ = *; $p < .05$ = **; $p < .01$ = ***

Table 5. Results of the binary logistic regression for the prediction of winegrowers' adoption of NT.

NT	Coefficient	Standard error	Wald	Odds ratio
Gender	-0.049	0.300	0.027	0.952
Age	0.006	0.010	0.299	1.006
Education	-0.368	0.259	2.025	0.692
Viticultural degree	0.049	0.271	0.032	1.050
Landowner	-0.443	0.340	1.699	0.642
Inherited vineyard	-0.167	0.255	0.428	0.846
Independent winegrower	0.198	0.255	0.606	1.219
Farm size	-0.147	0.122	1.441	0.863
Workforce hired	-0.039**	0.018	4.738	0.962
Vine planting	0.013	0.108	0.014	1.013
HVE	0.460	0.353	1.698	1.585
AB	-0.521**	0.254	4.212	0.594
Irrigation	-1.172***	0.394	8.865	0.310
AECM	0.110	0.307	0.128	1.116
Subsidy	-0.119	0.252	0.222	0.888
Viticultural advisor	0.334	0.249	1.798	1.397
4per1000	0.442	0.474	0.869	1.555
Resources	0.433***	0.119	13.291	1.541
Attitude	0.506***	0.123	16.868	1.659
Confidence	0.319***	0.113	7.936	1.376
Constant	1.556	1.117	1.941	4.742
Chi-square	71.827 (p = .000)			
Nagelkerke R^2	0.219			
Log-likelihood	482.681			
Accuracy	65.3%			

$p < .1$ = *; $p < .05$ = **; $p < .01$ = ***

Table 6. Results of the binary logistic regression for the prediction of winegrowers' adoption of CC.

CC	Coefficient	Standard error	Wald	Odds ratio
Gender	0.058	0.308	0.035	1.060
Age	0.003	0.011	0.075	1.003
Education	0.325	0.256	1.618	1.385
Viticultural degree	-0.175	0.278	0.396	0.839
Landowner	0.043	0.349	0.015	1.044
Inherited vineyard	-0.040	0.263	0.023	0.961
Independent winegrower	-0.113	0.260	0.190	0.893
Farm size	-0.252**	0.125	4.052	0.777
Workforce hired	0.029	0.023	1.603	1.029
Vine planting	0.198*	0.112	3.092	1.218
HVE	0.189	0.351	0.289	1.208
AB	0.207	0.261	0.631	1.230
Irrigation	-0.173	0.349	0.247	0.841
AECM	-0.423	0.310	1.868	0.655
Subsidy	0.365	0.264	1.917	1.440
Viticultural advisor	0.002	0.258	0.000	1.002
4per1000	-0.141	0.472	0.089	0.869
Resources	0.467***	0.124	14.137	1.596
Attitude	0.128	0.123	1.094	1.137
Confidence	0.281**	0.116	5.891	1.325
Constant	-0.286	1.127	0.065	0.751
Chi-square	37.356 ($p = .011$)			
Nagelkerke R^2	0.125			
Log-likelihood	461.078			
Accuracy	69.5%			

$p < .1$ = *; $p < .05$ = **; $p < .01$ = ***

Table 7. Results of the binary logistic regression for the prediction of winegrowers' adoption of HG.

HG	Coefficient	Standard error	Wald	Odds ratio
Gender	0.065	0.295	0.049	1.067
Age	-0.013	0.010	1.489	0.988
Education	0.129	0.249	0.271	1.138
Viticultural degree	0.308	0.265	1.347	1.361
Landowner	0.479	0.339	2.001	1.614
Inherited vineyard	-0.333	0.253	1.734	0.717
Independent winegrower	0.231	0.251	0.848	1.260
Farm size	0.068	0.119	0.326	1.070
Workforce hired	-0.007	0.016	0.193	0.993
Vine planting	0.183*	0.107	2.905	1.200
HVE	1.478***	0.368	16.131	4.383
AB	0.627**	0.248	6.391	1.872
Irrigation	0.198	0.358	0.304	1.218
AECM	0.230	0.307	0.558	1.258
Subsidy	-0.482*	0.255	3.560	0.618
Viticultural advisor	-0.159	0.245	0.419	0.853
4per1000	-0.170	0.465	0.134	0.843
Resources	0.419***	0.117	12.739	1.520
Attitude	0.082	0.118	0.480	1.085
Confidence	0.305***	0.115	7.029	1.357
Constant	-1.264	1.090	1.346	0.282
Chi-square	65.610 (p = .000)			
Nagelkerke R^2	0.202			
Log-likelihood	488.547			
Accuracy	66%			

p < .1 = *; p < .05 = **; p < .01 = ***

Table 8. Summary of how the significant factors influence the decision to adopt SCS practices.

Factors	**OA**	**BC**	**PR**	**NT**	**CC**	**HG**
Age			–			
Independent winegrower	+					
Farm size			+		–	
Workforce hired			–	–		
Vine planting	–				+	+
HVE			+			+
AB	+			–		+
Irrigation	–			–		
Subsidy						–
Resources				+	+	+
Attitude				+		
Confidence				+	+	+

Appendix A. Questionnaire used in this study. (The questionnaire was administered in French.)

I. Winegrower characteristics

- Are you…?
  - Male
  - Female
  - Other
- Which year were you born in?
- What is your highest level of education?
  - Primary school
  - Secondary school
  - Higher education
  - Other
- Do you have a viticultural degree?
  - Yes
  - No
- Are you…?
  - The farm manager
  - The co-manager
  - The spouse of the farm manager (working on the farm)
  - Other
- Do you own your viticultural land in its entirety?
  - Yes
  - No, I rent my viticultural land

    - Other
- If you are the owner of your vineyard, did you inherit it?
    - Yes
    - No
- Are you…?
    - An independent winegrower
    - A winegrower working in a cooperative
    - Other

II. Farm characteristics

- In which *département* is your vineyard located?
- What is the surface area of your viticultural farm?
    - Lower than 5 ha
    - Between 5 and 15 ha
    - Between 15 and 30 ha
    - Between 30 and 50 ha
    - Higher than 50 ha
- How many people work on a permanent contract (whether full-time or part-time) on your viticultural farm?
- When was the majority of your vines planted?
    - Before 1950
    - Between 1950 and 1969
    - Between 1970 and 1989
    - Between 1990 and 1999
    - Between 2000 and 2010

- Between 2011 and 2019

- Which type of geographic indication does the wine you produce qualify for?
  - Protected Designation of Origin (PDO)
  - Protected Geographical Indication (PGI)
  - Wine Without Geographical Indication (WWGI)
  - Other
- Did your viticultural farm receive one or several of the following labels…?
  - High Environmental Value (label HVE)
  - Organic agriculture (label AB)
  - Biodynamic (label Demeter or Biodyvin)
  - My viticultural farm did not receive any of these labels
  - Other
- Do you practise irrigation on your viticultural farm?
  - Yes
  - No

III. Access to information and involvement in policy instruments

- Are you in contact with a viticultural advisor?
  - Yes
  - No
  - I do not know
- Have you ever heard of the ‘4 per 1000’ initiative?
  - Yes
  - No
  - I do not know

- Are you participating in one or several agri-environment measures?
    - Yes
    - No
    - I do not know
- If yes, please indicate all the measures that you are participating in:
- Did you receive subsidies as part of the National Programme of Support to the Viticultural and Wine Sector developed by FranceAgriMer?
    - Yes
    - No
    - I do not know

IV. Adoption of soil carbon sequestration practices

- Do you return pruning residues to the soil in your vineyard?
    - Yes
    - No
    - I used to, but I stopped
- Do you apply organic amendments (such as compost, mulch, manure, etc.) in your vineyard in-between harvests?
    - Yes
    - No
    - I used to, but I stopped
- Do you apply biochar amendments in your vineyard in-between harvests?
    - Yes
    - No
    - I used to, but I stopped

- Is there, from one year to the other, a cover crop (temporary or permanent) growing in your vineyard?
    - Yes, under the vine rows
    - Yes, in the inter-rows
    - Yes, under the vine rows and in the inter-rows
    - No
    - There used to be some, but I stopped
    - Other
- Are there hedges on the edge of or within your viticultural farm?
    - Yes
    - No
    - There used to be, but I removed them
- Have you implemented no-tillage practices in your vineyard (*i.e.* absence of ploughing or a very shallow and occasional ploughing of the soil)?
    - Yes
    - No
    - I used to, but I stopped

V. Statements about the use of soil carbon sequestration practices in viticulture

- Please, indicate whether you agree or not with the following statements:
    - “SCS practices increase viticultural productivity.”
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree

        - Strongly agree
    - “SCS practices allow for the production of better-quality wine.”
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
    - “SCS practices decrease profits.”
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
    - “SCS practices increase production costs.”
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
    - “SCS practices are less time-consuming.”
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree

- "SCS practices represent new economic opportunities."
    - Strongly disagree
    - Disagree
    - Neither agree nor disagree
    - Agree
    - Strongly agree
- "SCS practices reduce greenhouse gas emissions."
    - Strongly disagree
    - Disagree
    - Neither agree nor disagree
    - Agree
    - Strongly agree
- "SCS practices decrease soil quality."
    - Strongly disagree
    - Disagree
    - Neither agree nor disagree
    - Agree
    - Strongly agree
- "SCS practices increase vineyard resilience."
    - Strongly disagree
    - Disagree
    - Neither agree nor disagree
    - Agree
    - Strongly agree
- "SCS practices decrease grape yield."

        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
- Please, indicate whether you agree or not with the following statements:
    - "I have enough time to implement SCS practices in my vineyard."
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
    - "I need more workforce to be able to implement SCS practices in my vineyard."
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
    - "I have enough financial resources to implement SCS practices in my vineyard."
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree

        - Strongly agree
    - "My current agricultural tools and technologies are not enough to implement SCS practices in my vineyard."
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
- Please, indicate whether you agree or not with the following statements:
    - "I understand perfectly how to implement SCS practices in my vineyard."
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
    - "I trust my abilities and skills enough to implement SCS practices in my vineyard."
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
    - "Implementing SCS practices is not my responsibility."
        - Strongly disagree
        - Disagree

        - Neither agree nor disagree
        - Agree
        - Strongly agree
    - "SCS practices are difficult to set up."
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
- Please, indicate whether you agree or not with the following statements:
    - "Most people around me think that I should implement SCS practices in my vineyard."
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree
    - "Most people around me encourage me to adopt SCS practices in my vineyard."
        - Strongly disagree
        - Disagree
        - Neither agree nor disagree
        - Agree
        - Strongly agree

- “Most people around me would disapprove if I were to implement SCS practices in my vineyard.”
    - Strongly disagree
    - Disagree
    - Neither agree nor disagree
    - Agree
    - Strongly agree
- “Most winegrowers that I know have adopted SCS practices in their vineyard.”
    - Strongly disagree
    - Disagree
    - Neither agree nor disagree
    - Agree
    - Strongly agree