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EDITED BY
Johann G. Zaller,
University of Natural Resources and Life Sciences Vienna, Austria

REVIEWED BY
María José Marqués Pérez,
Autonomous University of Madrid, Spain
Tamara Isabel Tamara Franco,
University of Santiago de Compostela, Spain

*CORRESPONDENCE
Florian Thomas Payen
✉ florian.payen@sruc.ac.uk

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# Why do French winegrowers adopt soil organic carbon sequestration practices? Understanding motivations and barriers

Florian Thomas Payen[1,2,3]*, Dominic Moran[3], Jean-Yves Cahurel[4], Matthew Aitkenhead[5], Peter Alexander[2,3] and Michael MacLeod[1]

[1]Rural Economy, Environment and Society, Scotland's Rural College (SRUC), Edinburgh, United Kingdom, [2]Global Change Institute, School of Geosciences, University of Edinburgh, Edinburgh, United Kingdom, [3]Global Academy of Agriculture and Food Security, The Royal (Dick) School of Veterinary Studies, University of Edinburgh, Midlothian, United Kingdom, [4]Pôle Bourgogne—Beaujolais—Jura—Savoie, Institut français de la vigne et du vin, Villefranche-sur-Saône, France, [5]Information and Computational Sciences, James Hutton Institute, Aberdeen, United Kingdom

Soil carbon sequestration (SCS) practices on French agricultural land are part of the portfolio of actions available to policymakers in the field of climate change mitigation and are central to the success of the "4 per 1,000" initiative, launched by France in 2015. To date, there has been limited research considering their applicability to vineyards. A survey was circulated to 506 French winegrowers to identify the adoption rate of six SCS practices in the viticultural sector (applying organic amendments, using biochar, returning pruning residues to the soil, no-tillage, cover cropping, and introducing or preserving hedges in the vineyard) and to explore motives and barriers to adoption. The survey also investigated ways of overcoming barriers to adoption and winegrowers' perception of agri-environment measures. Differences in motivations and barriers between SCS practices were found, and winegrowers themselves suggested a need for improved communication of evidence about SCS practices and better-targeted policy incentives to support adoption.

KEYWORDS

**soil carbon sequestration (SCS), vineyards, farming practice, farmer attitudes, adoption behavior, agri-environment schemes**

## Highlights

- We examined the motives and barriers to the adoption of viticultural practices in France.
- We considered practices increasing soil organic carbon sequestration.
- A survey of 506 winegrowers investigated uptake of and attitudes toward the practices.
- Practices were adopted mostly to improve soil quality and agricultural productivity.
- Practices could not be adopted mainly due to their incompatibility with vineyard characteristics and a lack of resources.

# 1. Introduction

As is the case with many other developed nations, France has set ambitious greenhouse gas (GHG) emission reduction targets for the coming decades: reducing GHG emissions by at least 55% compared to 1990 levels by 2030 and achieving carbon neutrality by 2050 (European Commission, 2021). To achieve these targets, the country will need to implement technologies leading to a net removal of GHGs from the atmosphere in addition to GHG emission reduction strategies (Intergovernmental Panel on Climate Change (IPCC), 2018). In this context, in 2015, the French government launched the "4 per 1,000" initiative (4p1000, 2018), which aims to achieve an annual growth rate of 0.4% in the global soil organic carbon (SOC) stocks for climate and food security. The initiative has both a national and international focus and promotes the implementation of agricultural practices leading to SOC sequestration, a process that consists of transferring atmospheric carbon dioxide ($CO_2$) into the soil through plants, plant residues and other organic solids stored or retained in the soil as part of the soil organic matter (SOM) (Olson et al., 2014). This transfer allows for a decrease in GHG concentrations in the atmosphere.

SOC sequestration in agricultural soils has been identified as an effective mitigation tool, both at the global level (e.g., Smith, 2016; Fuss et al., 2018; Sykes et al., 2020) and in France more specifically (e.g., Pellerin et al., 2013, 2019). Several studies have evaluated the feasibility of the "4 per 1,000" objective in French soils (Minasny et al., 2017; Martin et al., 2021) and identified territories offering high SOC sequestration potential (Angers et al., 2011; Launay et al., 2021). Pellerin et al. (2019) showed that nine soil carbon sequestration (SCS) practices were of interest for agricultural land in France: the use of no-tillage, cover cropping, the introduction of temporary pastures in crop rotations, the use of organic amendments, the introduction of agroforestry, planting hedges, implementing a moderate intensification of extensive pastures, transitioning from hay meadows to pastures, and the introduction of cover crops in vineyards. These practices have different sequestration potentials and are associated with varying implementation and maintenance costs.

Despite many SCS practices being associated with low or negative costs, their adoption by farmers is part of a complex decision-making process, including agronomic, environmental, sociological, economic and ethical dimensions (Chenu et al., 2019). Improving our understanding of the enabling environment for these practices in the agricultural sector is crucial to designing effective policies to incentivize their adoption. It is also important to consider the motives of different categories of land users and, to date, there has been little consideration of SOC sequestration in vineyards, which account for 3% of the total agricultural land in France (Comité National des Interprofessions des Vins à appellation d'origine et à indication géographique (CNIV), 2019). This article investigates the motivations underlying the adoption of SCS practices by farmers in France, as well as the eventual barriers that may hinder the adoption of these practices, *via* an online survey circulated nationally to winegrowers. Viticulture was chosen as a case study due to the importance of traditions and elements of national culture inherent to viticultural and winemaking know-how. This research also explores how motivations and barriers correlate to the way winegrowers view agri-environment measures (AEMs), which are commonly applied by the French government in the viticultural sector to support the adoption of some SCS practices (e.g., cover cropping, no-tillage, maintenance of hedges, etc.).

The paper is structured as follows. The next section provides background information on agricultural measure adoption and policy instruments to incentivize behavioral change. Section 3 covers data collection and methods. Section 4 provides results from the survey, categorized by motivations and barriers for each SCS practice considered. Section 5 discusses differences in motivations and barriers between SCS practices and puts the results of this study within the broader context of the literature on farmer motivations for adopting agricultural practices. Section 6 covers conclusions.

# 2. Agricultural practice adoption and agri-environment schemes

There is extensive literature investigating, using mainly survey methods, the different factors (socio-economic, demographic, technical, etc.) associated with farmers and farms that influence the adoption of SCS practices on agricultural land (Ingram et al., 2014; Sánchez et al., 2016; Payen et al., 2022). However, psychological factors, such as farmers' motivations for undertaking various environmental activities, and constraints faced by farmers, whether they are structural or environmental, have received less attention. Motivations, more specifically, are important elements explaining farmer behavior. Mills et al. (2013) identified a variety of extrinsic (i.e., financial incentives, risk minimization, profit maximization, capital investment, regulation, respect among peers and recognition in wider society) and intrinsic (i.e., personal sense of environmental responsibility, interest in the environment and personal sense of enjoyment) motivations involved in changes in farmer behavior toward more environmentally-friendly practices. The strength of these motivations and the way they interact with each other can have a profound effect on farmer behavior: changes in behavior motivated by intrinsic reasons, for instance, tend to be more persistent than changes triggered by extrinsic motivations (Mills et al., 2018), while economic factors (i.e., household income, land tenure, family labor, and farm business structure) appear to be particularly influential determinants of participation (Lastra-Bravo et al., 2015). Additional studies are, thus, needed to refine our knowledge of the conditions that foster or perpetuate the use of SCS practices on agricultural land (Soussana et al., 2019).

A number of policy approaches can be used to incentivize behavioral change in the agricultural sector, including economic incentives, regulatory and control approaches, information schemes, and voluntary actions and agreements (Intergovernmental Panel on Climate Change (IPCC), 2014). In the European Union (EU), agri-environment schemes (AESs) have been introduced as a key tool for the integration of environmental concerns into the Common Agricultural Policy (European Commission, 2017). AESs provide financial support for the Member States to implement AEMs. In France, as in many other Member States of the EU, AEMs serve as the main policy instrument to instigate a change toward more sustainable practices in the agricultural 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. Each AEM has a specific environmental objective, such as climate change mitigation, climate change adaptation, biodiversity protection, soil quality improvement, etc. (European Commission, 2017). A core principle of AEMs is that participation is voluntary; farmers' willingness to participate in AEMs is, therefore, central to achieving policy objectives (Espinosa-Goded et al., 2010).

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. This lack of success is due partly to a poor understanding of farmers' attitudes toward AEMs and individual reasons for participating or not (de Snoo et al., 2013; Schroeder et al., 2015). If AEMs are to be used to incentivize the uptake of SCS practices on agricultural land in France, a better knowledge of how French farmers perceive them would be central to the development of improved AEMs for SOC sequestration (Hammes et al., 2016). Farmers, like other people, may also not simply prioritize financial gain above all else; they can, on the contrary, gain equal or greater utility from actions benefiting society or the environment (Wynne-Jones, 2013). Increasing our understanding of what motivates farmers to adopt SCS practices may provide valuable insight to assess whether AEMs, under their current form, are the best policy instrument to incentivize the uptake of SCS practices.

# 3. Data collection

## 3.1. Soil organic carbon sequestration practices

Six SCS practices were included in this study: the use of organic amendments (OA), the use of biochar amendments (BC), returning pruning residues to the soil (PR), no-tillage (NT), cover cropping (CC), and planting and maintaining hedges in the vineyard (HG). These practices have been identified as having the potential to participate in climate change mitigation *via* SOC sequestration on viticultural land, with SOC sequestration rates ranging from 1.22 Mg $CO_2$-eq. $ha^{-1}year^{-1}$ for HG to 8.96 Mg $CO_2$-eq. $ha^{-1}year^{-1}$ for BC (Pellerin et al., 2017, 2019; Payen et al., 2021a,b). Except for PR, the adoption rate of these practices at the national level in France is low (Agreste, 2017).

## 3.2. Mixed-methods approach

A survey was created to understand the drivers of and barriers to the adoption of SCS practices by winegrowers in France. It was developed using a literature review and expert consultations and was piloted with a small group of winegrowers. The survey consisted of a combination of both close-ended and open-ended questions to gather a mix of quantitative and qualitative data. It was divided into four sections (Appendix A in Supplementary material). Section one collected information used for classifying respondents according to their role in the viticultural farm (e.g., farm manager, head of cultivation, etc.) and the geographical location of their vineyard (*département* and winegrowing region). The second section asked winegrowers, for each SCS practice, the reasons that motivated their adoption of the practice, in case they had adopted it, or the barriers that prevented them from adopting the practice, in case they had not adopted it. It also investigated specific actions that the winegrowers believed could alleviate some of the identified barriers. These questions were open-ended to allow winegrowers to express what they felt were the most important motivations and barriers without leading their answers with pre-selected options. For each practice, winegrowers were free to mention as many motivations and barriers as they felt like; the aim was to grasp all the different types of motivations and barriers that would be mentioned by the respondents and to assess which would be more prevalent. Answers were analyzed and categorized using thematic analysis, which is a particularly effective method to facilitate the organization of qualitative data and determine common perspectives among respondents (Creswell and Guetterman, 2020). The third section was designed to collect data on winegrowers' received subsidies and participation in AEMs. The last section aimed at understanding winegrowers' attitudes toward AEMs: winegrowers were asked to evaluate four statements created to reveal their attitudes toward AEMs using a 5-point Likert scale.

An online survey was conducted between July 2020 and January 2021. It was administered *via* Google Forms, using a random method. Responses were anonymous and handled in accordance with the General Data Protection Regulation. The survey targeted winegrowers who had an active decision-making role regarding how to conduct viticultural activities on their vineyard; only the responses of farm managers (*chefs d'exploitation*), co-managers (*co-exploitants*), heads of cultivation (*chefs de culture*) and technical directors (*directeurs techniques*) were accepted. 1,635 winegrowers were contacted by email using personal contacts, viticultural databases and wine shops. The French Institute of Vine and Wine and several regional inter-professional councils of wine (e.g., the *Syndicat des vignerons des Côtes-du-Rhône*) were contacted and circulated the questionnaire to their members. A total of 506 full responses were received from across France, giving a return rate of 31%, which is in line with the average response rate of online surveys in published research, estimated to reach 36.7% for surveys using a random selection of participants (Wu et al., 2022). Most winegrowers who responded were farm managers (84%), with the remainder being either co-managers (10%), heads of cultivation (5%) or technical directors (1%). Responses covered each of the fourteen French winegrowing regions, though the number of responses from regions with large viticultural land (e.g., Languedoc-Roussillon and the Rhône Valley) was higher than that from regions with small viticultural land (e.g., Bugey and Burgundy).

# 4. Results

## 4.1. Viticultural practices and participation in agri-environment measures

The adoption rate of SCS practices among French winegrowers was high, overall: almost all winegrowers surveyed (99.6%) have adopted at least one SCS practice; only two of the 506 respondents have not adopted any SCS practice at all. Most winegrowers (91%) return pruning residues to the soil, either simply leaving them on the ground or crushing them with a woodchipper to facilitate their incorporation into the soil. The use of organic amendments and cover cropping is practiced by a high number of surveyed winegrowers (73% for both). More than half the respondents (57%) maintain hedges in their vineyard, while a bit less than half (48%) practice no-till viticulture. Only very few winegrowers (2%) use biochar amendments in their vineyard.

Winegrowers' participation in AEMs was low, with around 24% of respondents stating that they were involved in an AEM. Not all respondents indicated which AEM they were participating in, but the most commonly cited were COUVER_06 (Creation and management of a permanent grass cover or strip in zones of high environmental interest), COUVER_11 (Creation of a naturally grown soil cover on the inter-rows of grapevines by preventing herbicide use), PHYTO_02 (No use of synthetic herbicides) and PHYTO_10 (No use of synthetic herbicides on the inter-rows of perennial crops). COUVER_11 targets viticultural systems specifically, whereas the other AEMs were developed more broadly for perennial systems (PHYTO_10) or all types of agricultural systems in France (COUVER_06 and PHYTO_02).

According to the responses, 47% of the winegrowers surveyed received subsidies as part of the National Programme of Support to the Viticultural and Wine Sector. Developed by FranceAgriMer,[1] this programme gets a fund of €280 million every year to support vineyard restructuration and conversion, investments in viti-vinicultural businesses, wine promotion abroad, and the distillation of wine by-products (FranceAgriMer, 2020).

## 4.2. Motivations for and barriers to the adoption of SCS practices

### 4.2.1. Organic amendments

Of the 506 respondents to the survey, 341 indicated one or several drivers that motivated the use of OA in their vineyard. The motivations behind the adoption of OA were mostly to achieve biophysical and economic outcomes (Figure 1A). The most commonly given motivation was the wish to return organic matter (OM) to the soil to improve SOM and enhance soil quality, which corresponded to 58% of all identified motivations for OA and was given by 276 respondents out of the 341 who answered this question. Fertilizing grapevines to increase vine vigor and maintain yields was also an important motivation for using OA in vineyards (19% of all identified motivations). Several other motivations were mentioned by winegrowers, but their frequency was considerably lower.

The number of respondents who identified eventual barriers that prevented them from using OA in their viticultural farm was lower than for motivations ($n = 107$). This was to be expected based on the adoption rate of OA, which was high. The barriers to the adoption of OA were mainly economic, biophysical and technical (Figure 1B). The total count was more homogeneously distributed between each barrier, which suggests that the reasons behind the non-adoption of OA were context-specific. Two barriers, in particular, were very often given by winegrowers: the fact that costs associated with the use of OA (mainly the costs of purchasing organic amendments) were too high (31%) and that the use of OA was not needed in the vineyard since winegrowers achieved expected yields without them, there was a good C/N balance in the soil without them, or there were risks of disrupting grape quality by increasing yields too much (26%). The rest of the barriers mentioned by winegrowers were less commonly observed in the sample.

1 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 agricultural sector.

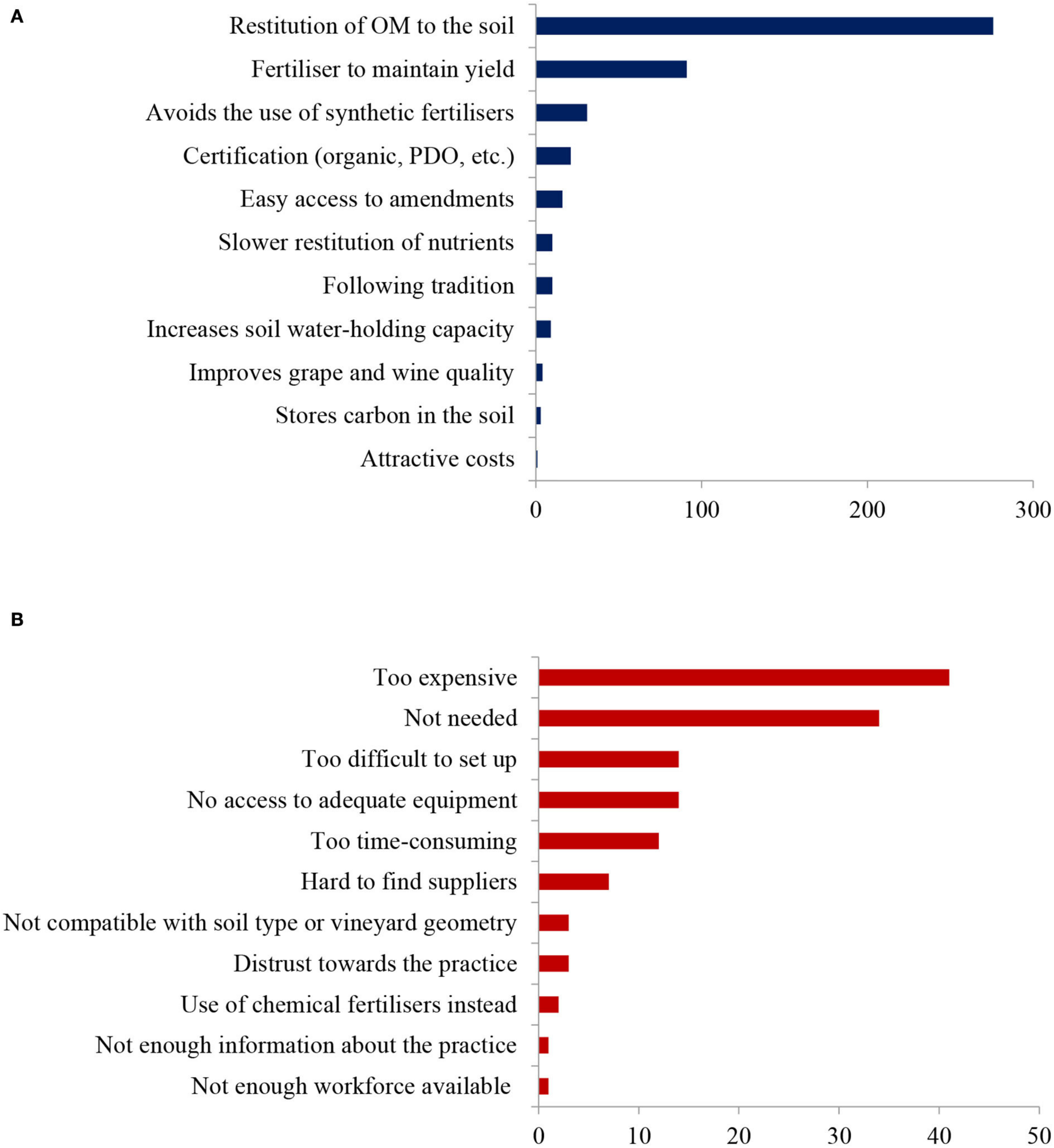


FIGURE 1
Motives **(A)** and barriers **(B)** to the adoption of organic amendments in viticulture in France ($n = 341$ and 107, respectively). Several responses were possible for each respondent. OM, organic matter; PDO, protected designation of origin.

### 4.2.2. Biochar amendments

As the adoption rate of BC was very low in the sample, only a very small number of respondents indicated motivations for the adoption of this practice ($n = 6$). However, because the use of BC is still more experimental in viticulture than the other SCS practices considered in this study, statements from these winegrowers were very valuable for understanding the rationale behind the use of BC in viticulture. The main motivation behind the use of BC was the restitution of OM to the soil to improve SOM and soil fertility (43%) (Figure 2A). One winegrower stated that they were using BC specifically to capture and store $CO_2$

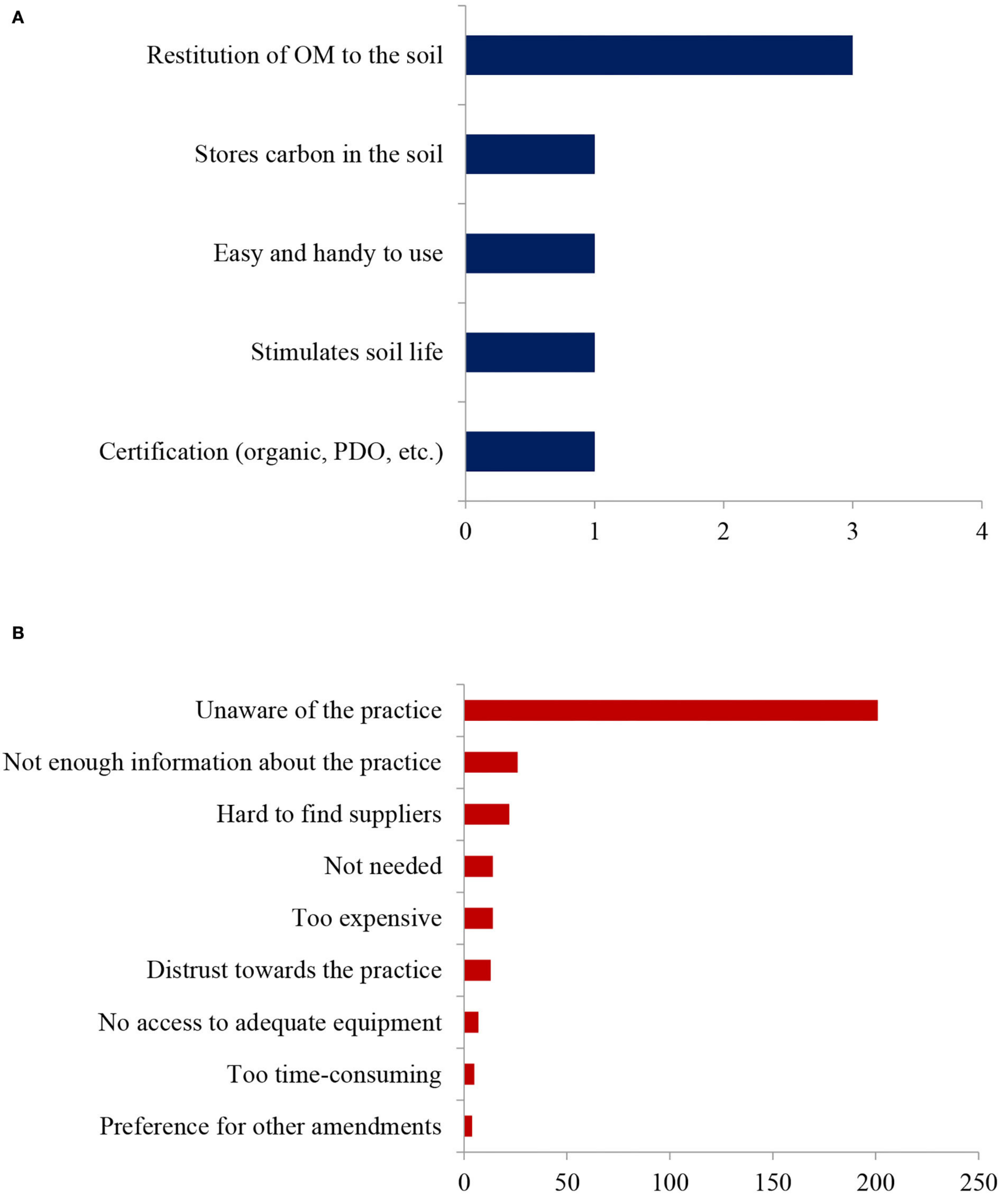


FIGURE 2
Motives **(A)** and barriers **(B)** to the adoption of biochar amendments in viticulture in France ($n = 6$ and 279, respectively). Several responses were possible for each respondent. OM, organic matter; PDO, protected designation of origin.

in the soil to help to mitigate climate change, and for no other reason.

Despite the non-adoption of BC by nearly all the respondents, almost half of them decided not to mention any barrier to adoption ($n = 221$), perhaps because they were unfamiliar with the practice. The mentioned barriers were mostly capacity-building barriers (Figure 2B). The main barrier to adoption comes from the fact that most winegrowers are unaware that BC exists: this reason corresponded to 66% of all barriers identified and was given by 201 respondents out of the 279 who answered this question. Even among winegrowers who are aware of BC, the practice is not well-understood, because not enough information about it is available to winegrowers, especially information on the benefits of using BC, how to implement the practice, and the long-term effects of the practice on the soil (8%).

### 4.2.3. Returning pruning residues to the soil

Contrary to BC, the adoption rate of PR was very high; as a result, a substantial number of respondents identified motivations behind the use of PR in their vineyard ($n = 421$). The motivations for the adoption of PR in viticulture were mainly to reach biophysical outcomes and technical reasons (Figure 3A). As for OA, the most important motivation for using PR was the wish to return OM to the soil to improve SOM and soil quality (48%). Of the 421 respondents, 283 mentioned the restitution of OM as one of the main drivers for the use of PR. The second two most important motivations for PR were that the practice is particularly easy and handy to conduct (20%) and leads to a gain of time for the winegrower (7%) since gathering and exporting residues out of the vineyard requires specific equipment and techniques and is quite time-consuming. The other motivations given by respondents were technical and environmental.

Only 42 of the 506 winegrowers in the sample responded to the question about barriers to the adoption of PR, which was predicted due to the high adoption rate of the practice. The barriers to the adoption of PR were mainly technical and biophysical (Figure 3B). Though several barriers were identified by winegrowers, one was prevalent: the fact that returning pruning residues to the soil could facilitate the propagation of wood diseases, such as mildew, to the soil (49% of all identified barriers). Other barriers were more sporadically given. An interesting barrier from a social perspective is the cultural aspect associated with the use of PR by some winegrowers, who have been using them traditionally for heating or cooking purposes.

### 4.2.4. No-tillage

The adoption rate of NT was more balanced between adopters and non-adopters than it was for other SCS practices. The number of respondents who provided motivations behind the adoption of NT in their vineyard ($n = 201$) was consistent with the number of winegrowers using the practice in the sample (245 out of 506). The motivations for the adoption of NT in viticulture were predominantly to reach specific biophysical outcomes (Figure 4A). Three important biophysical outcomes were mentioned by winegrowers: to preserve soil life (i.e., microorganism and earthworm activity), which may be disturbed and negatively impacted by tillage (19% of all identified motivations); to maintain soil structure and avoid mixing soils horizons (14%); and to reduce soil erosion, which may be aggravated by a deep and regular plowing of the soil, especially if left bare afterwards (13%). Other motivations were environmental and cultural; their frequency was lower than that of the motivations previously presented.

A similar number of respondents provided insights on barriers to the adoption of NT ($n = 186$). The barriers preventing the use of NT in viticulture were diverse, ranging from biophysical and technical to environmental and economic barriers (Figure 4B). Despite this diversity, two barriers were referred to more frequently than others: the fact that the use of NT is not successful in reducing the competition for water and nutrients between grapevines and plant activity in the soil enough for grapevines to thrive (24%) and that, in some vineyards, the use of tillage is required to control vegetation growth adequately—herbicides or reduced tillage not being effective enough (18%).

A distinguishing result observed for NT was that the soil-bearing capacity was mentioned both as a motivation and a barrier: this highlights the fact that the effect of NT on the soil varies depending on the context, improving the soil-bearing capacity in some places, but damaging it in others. Another distinctive observation for NT was the strong influence of cultural habits and traditions on how winegrowers relate to the practice: some respondents felt strongly that viticulture did not require tillage at all to perform well and produce high-quality grapes, whereas others saw tillage as an obvious way to control vegetation growth and considered that their vineyard looked "dirty" if not tilled.

### 4.2.5. Cover cropping

Of the 506 winegrowers in the sample, 341 provided motivations that played a positive role in their adoption of CC, which is in line with the adoption rate of this practice. A surprisingly high number of motivations were given by winegrowers, many of them being to achieve biophysical and environmental outcomes (Figure 5A). The three most frequent biophysical outcomes identified by winegrowers were: to return OM to the soil to improve SOM and soil quality (23%); to reduce soil erosion by ensuring that the soil is not left bare, especially in the inter-rows (20%); and to improve the soil-bearing capacity, which in turn facilitates the passage of tractors in the vineyard, particularly after a heavy rainfall event,

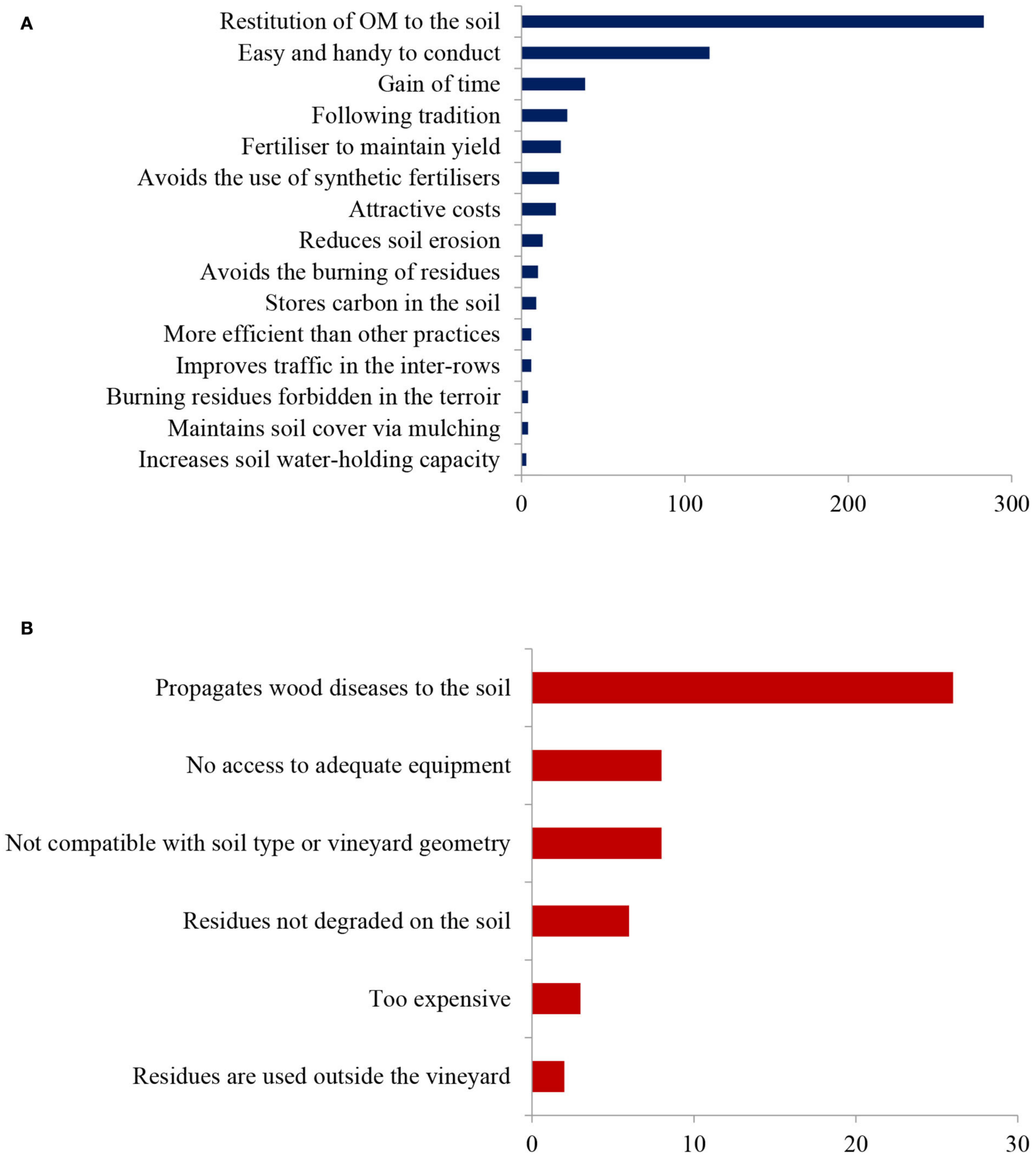


FIGURE 3
Motives **(A)** and barriers **(B)** to returning pruning residues to the soil in viticulture in France ($n = 421$ and 42, respectively). Several responses were possible for each respondent. OM, organic matter.

and reduce soil compaction (12%). The use of CC was also motivated by the will to increase biodiversity in the vineyard both *via* the cover crop and by attracting insects and birds into the vineyard (10%). Some respondents viewed implementing cover cropping as a way to avoid the use of synthetic fertilizers since cover crops can be used as green manure in vineyards in lieu of chemical fertilizers (3%).

The number of respondents who discussed barriers to the adoption of CC ($n = 108$) was expected based on the adoption rate of the practice in the sample. Most barriers to the adoption

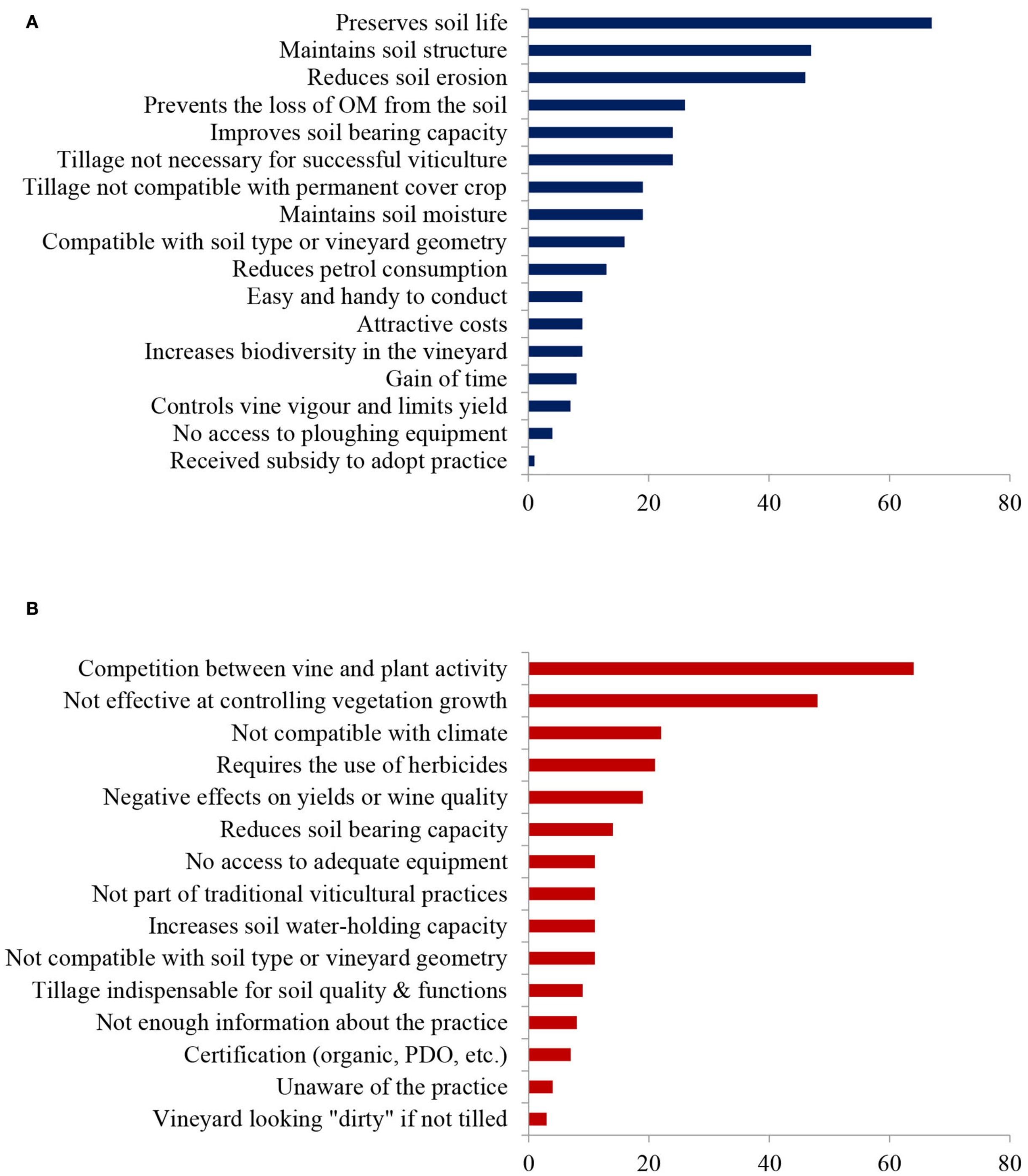


FIGURE 4
Motives **(A)** and barriers **(B)** to the adoption of no-tillage in viticulture in France ($n = 201$ and 186, respectively). Several responses were possible for each respondent. OM, organic matter; PDO, protected designation of origin.

of CC in vineyards were biophysical, though technical and economic barriers were not negligible (Figure 5B). The too-high competition for water and nutrients between the grapevines and the cover crop was one of the most important obstacles for winegrowers in using CC in their vineyard (42% of all identified barriers). In winegrowing regions with water scarcity during the summer (e.g., the Mediterranean coast) or with poor soils, the use of CC was completely impossible as the

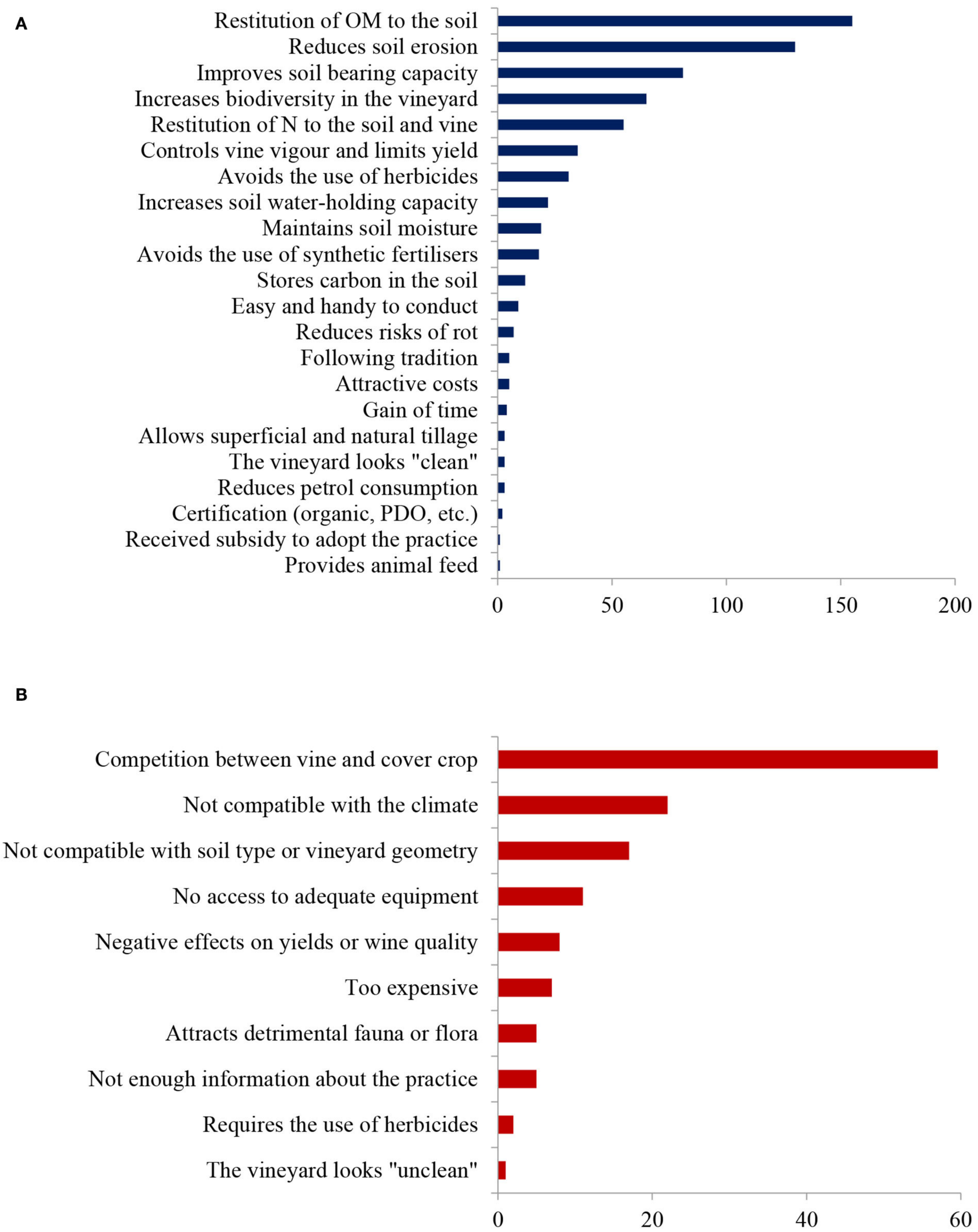


FIGURE 5
Motives **(A)** and barriers **(B)** to the adoption of cover cropping in viticulture in France ($n = 341$ and 108, respectively). Several responses were possible for each respondent. OM, organic matter; N, nitrogen; PDO, protected designation of origin.

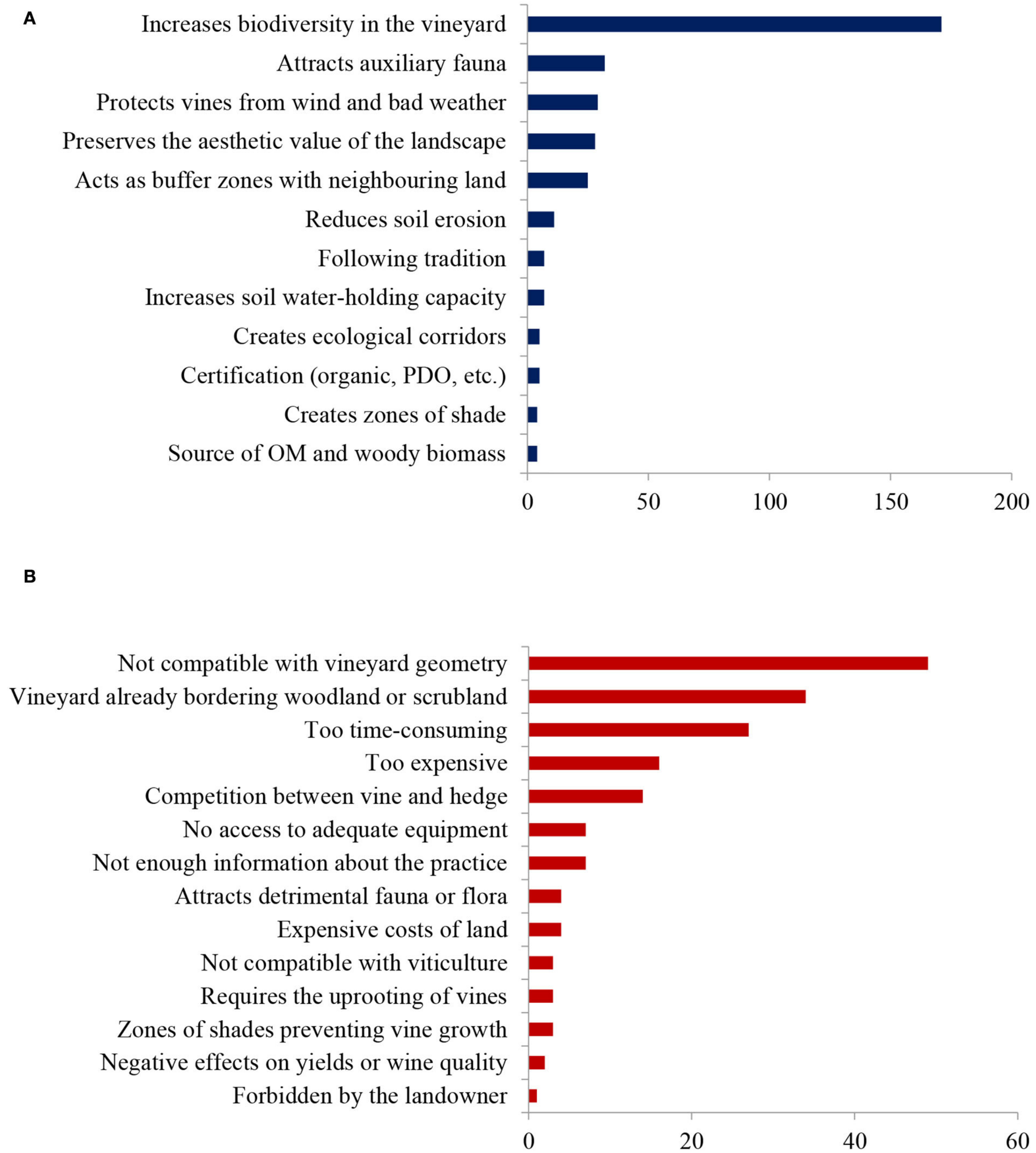


FIGURE 6
Motives **(A)** and barriers **(B)** to the adoption of hedges in viticulture in France ($n = 220$ and 136, respectively). Several responses were possible for each respondent. PDO, protected designation of origin; OM, organic matter.

negative impacts on grapevines were too important (16%). The use of CC was also impossible in vineyards with too stony or too sandy soil types or with peculiar geometries, such as vineyards with high density or located on steep slopes (13%).

It was interesting to notice that CC generated contrasting views among certain respondents who gave opposite reasons why they would or would not implement the practice in their vineyard. CC was mentioned as a way to control vine vigor and limit grape yields in some places but also as potentially

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TABLE 1 Actions proposed by winegrowers to overcome the barriers to the adoption of soil carbon sequestration (SCS) practices ($n = 30$).

| Actions to overcome barriers | Count | Category of action |
|---|---|---|
| Improve the communication of information on SCS practices in viticulture | 11 | Communication |
| Increase subsidies for the purchase of adequate equipment | 9 | Political; economic |
| Develop marketing strategies for SCS practices in viticulture | 4 | Economic |
| Set up additional payment schemes for the adoption of SCS practices | 4 | Political; economic |
| Accompany the search for qualified workforce at the local level | 3 | Social |
| Replant vines to increase vineyard compatibility with SCS practices | 3 | Technical |
| Develop training on SCS practices | 2 | Capacity building |
| Accompany the change of opinions about winemaking practices and culture | 1 | Social |

Several responses were possible for each respondent.

creating too much competition for water and nutrients with the vines in others. This shows that the suitability of cover crops for viticulture may vary at the local and regional levels based on climatic conditions, soil characteristics, vineyard density, etc. In addition, some respondents viewed cover crops as making their vineyard look "clean," while others saw them as making their vineyard look "dirty." Socio-cultural differences may explain why winegrowers perceived the practice in such opposite ways: while maintaining soil cover is something that is done traditionally by farmers in some winegrowing regions, the practice is not commonly spread in others and might not be associated, in the minds of winegrowers, with 'proper' ways of conducting viticulture.

#### 4.2.6. Hedges

Of the 506 respondents, 220 provided elements of response to the question about drivers that motivated the implementation of HG in their vineyard. The motivations for the adoption of HG in viticulture were mainly environmental and to achieve specific biophysical outcomes (Figure 6A). The most frequently given motivation was to increase biodiversity in the vineyard (52% of all identified motivations): of the 220 winegrowers who mentioned motivations for the adoption of HG, 171 wrote that biodiversity was the primary reason why they decided to plant hedges on their viticultural farm. Their responses took into account biodiversity *via* the species of hedges planted, but also how hedges attract auxiliary fauna (e.g., birds or insects) that interact positively with grapevines by fulfilling roles of predators against harmful species or by helping to pollinate grapevines (10%). Other motivations related to the ecosystem services provided by hedges, namely protecting vines from wind (e.g., mistral) and bad weather (9%), preserving the aesthetic value of the landscape (9%), and acting as buffer zones with neighboring lands, avoiding, for instance, the run-off of phytosanitary products (8%).

The number of respondents who answered the question about barriers against the adoption of HG in their vineyards was lower ($n = 136$), which aligns with the number of non-adopters of HG in the sample. The types of barriers named by winegrowers were heterogeneous, with biophysical, environmental, technical and economic barriers being discussed by respondents (Figure 6B). The three most important obstacles to the adoption of HG in viticulture were the incompatibility of the practice with the geometry of the vineyard, which was either too dense, lacking enough space to set up hedges (which would hinder the use of tractors) or split into lots of small, unconnected parcels (28%); the proximity of the vineyard to woodland or scrubland (20%); and the fact that the practice is too time-consuming to set up or maintain (16%). Some respondents also mentioned the high competition for resources (mainly water and nutrients) between the hedges and the vines that they border, especially in times of drought or in nutrient-poor soils, as a barrier to implementation (8%). An interesting barrier mentioned by a few winegrowers is the belief that hedges are not compatible with viticulture and are more relevant for grasslands or annual croplands (2%).

### 4.3. Actions to overcome the barriers to the adoption of SCS practices

The question asking winegrowers about the potential actions that they believe could help to alleviate some of the barriers to the adoption of SCS practices that they had identified throughout the survey was answered by only a few respondents ($n = 30$). However, those who answered provided a high and diversified number of strategies that could overcome some of the barriers that they identified. Most of these actions were economic (46%), political (35%) and communication-based (30%) (Table 1). They included developing marketing strategies on SCS practices particularly in viticulture to increase their profitability and added value; increasing subsidies to allow for the purchase of the appropriate equipment and techniques required to conduct SCS practices efficiently; and improving the communication of evidence and information about the effectiveness of SCS practices to winegrowers. The majority of responses presented in Table 1 reflected on SCS practices as a whole and did not target specific practices, except for a few of them, which mentioned BC as an example of practice for which winegrowers were lacking proper information and adequate equipment.

### 4.4. Winegrowers' attitudes toward agri-environment measures

The statements on AEMs were answered by a fifth of the respondents ($n = 106$). Responses to these statements provided insight into the attitudes of French winegrowers toward such measures (Figure 7). Overall, the attitude of winegrowers toward AEMs was positive: most winegrowers stated that they were interested in AEMs (63%) and agreed with the fact that they were important elements to fight against climate change (56%). This is reflected in the fact that 70% of the respondents try to participate in AEMs as much as possible, while only 5% of them do not; the rest have a neutral opinion toward this statement.

## 5. Discussion

### 5.1. Differences in motivations and barriers between SCS practices

Findings from this study highlight the role played by extrinsic and intrinsic motivations in undertaking SCS practices in viticulture, showing that motivations were heterogeneous and overlapping (Figures 1A, 2A, 3A, 4A, 5A, 6A). Despite this heterogeneity, winegrowers were mainly motivated to undertake SCS practices to achieve biophysical outcomes, i.e., to overcome the biophysical degradation of the soil caused by conventional management, which negatively affected the agronomic soil characteristics required to conduct viticulture and produce high-quality grapes for winemaking. For all SCS practices (except HG), achieving biophysical outcomes represented more than 50% of all the motivations mentioned for the practice (Figure 8A). HG was the exception to this trend, for which the motivations were predominantly of environmental nature (71%).

There were economic motivations at play for each practice, though they were second to other categories of motivations (e.g., to achieve biophysical or environmental outcomes). Only in the case of OA were economic reasons important motivations in the adoption of the practice (20%), due mainly to the use of organic amendments as fertilizers to increase yields (Figure 8A). This shows that winegrowers do not simply react to financial opportunities and imperatives but, conversely, make decisions within a care-based ethic and have a strong sense of stewardship over the land and the soil. This stewardship ethic has also been observed by Greiner and Gregg (2011) in their study on the adoption of conservation practices by farmers in northern Australia. They found that environmental and lifestyle motivations (e.g., the will to look after the environment or to live and work on a grazing property) were more important than economic and social motivations (e.g., the wish to maximize company profit or to be appreciated by colleagues or society) in the adoption process of grazers, suggesting a strong altruistic motive. In addition, Mills et al. (2018) highlighted the greater importance of agronomic and environmental motivations over financial ones in the adoption of sustainable practices by English farmers. However, this was only true for unsubsidized activities; financial drivers were of greater importance in the adoption process for subsidized actions.

The barriers to the adoption of SCS practices were diverse and varied depending on the practice (Figures 1B, 2B, 3B, 4B, 5B, 6B). Overall, winegrowers were mainly constrained from adopting SCS practices by biophysical and technical barriers, i.e., by the incompatibility of the practice with specific biophysical features of the vineyard (such as soil type, vineyard slope, and climate) or farm characteristics (such as vine density, vineyard size, and vine age) and by a lack of technical resources required to conduct the practice (e.g., access to adequate equipment, not enough additional time, etc.). The biophysical barriers accounted for 71 and 50% of all the barriers to the adoption of CC and NT, respectively, and the technical barriers represented 64% of all the barriers to the use of PR (Figure 8B).

A few practices were an exception to these observations. The main barriers preventing the use of OA by winegrowers in France were economic (36%), related to the high costs associated with the purchase of organic amendments and the difficulty to find suppliers at the regional scale. The most important barriers to the adoption of BC were capacity-building barriers (74%), linked to the low or non-awareness of biochar as a potential amendment for viticultural soils among winegrowers and to the lack of experiments and trials on biochar conducted in viticulture, making the effects of biochar on soil, vine and grape quality uncertain (though some evidence is starting to emerge). For these practices, the barriers preventing their adoption were more related to the winegrowers' enabling environment (i.e., lack of economic incentive, lack of training and proper information, and governance) than to technical issues. Therefore, overcoming these barriers is not really under the control of winegrowers themselves, or at least not only, and more holistic actions would be needed to target other stakeholders from the agricultural sector (e.g., viticultural advisors) beyond winegrowers (Demenois et al., 2020).

Based on these observations, it seems that AEMs are a useful policy instrument to incentivize the uptake of SCS practices in the viticultural sector. AEMs may help winegrowers to overcome economic barriers (such as the high costs or the decrease in yields associated with some SCS practices) by providing them with financial compensation for adopting SCS practices. They may also play a role in surmounting biophysical and technical barriers by giving winegrowers more resources to undertake restructuring operations in the vineyard to make it

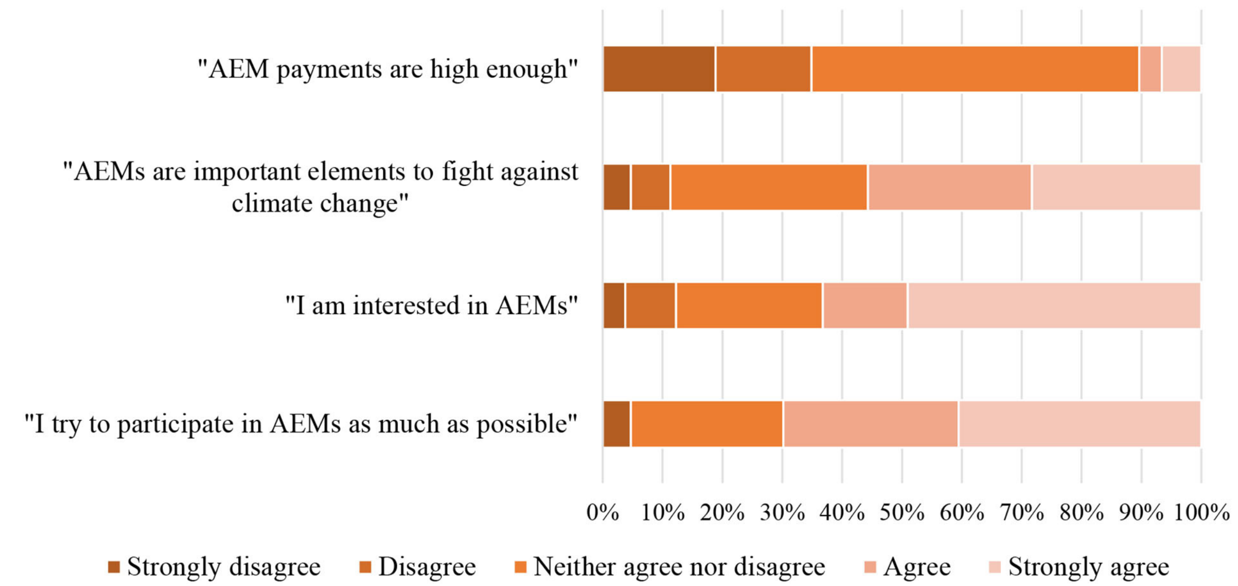


FIGURE 7
Agreement of surveyed winegrowers to statements on agri-environment measures (AEMs) ($n = 106$). Five-point Likert scale: −2 = strongly disagree, 2 = strongly agree.

more compatible with the use of SCS practices (e.g., pulling grapevines up and replanting them with a lower density or on a more adapted soil) and to invest in new equipment or hire more workforce. However, considering the suggestions made by winegrowers to increase subsidies for the purchase of adequate equipment and to set up supplementary payment schemes (Table 1), it seems that the amount of money given to winegrowers participating in AEMs has not been sufficient over the 2014–2020 period. The budget allocated to AESs post-2020 may need to be increased to provide financial incentives suitable to farmers' needs.

The current design of AEMs also does not encompass all the barriers at play in restricting the adoption of SCS practices by French winegrowers. In addition, because the desire of winegrowers to achieve biophysical and environmental outcomes is more important than economic motivations for adopting SCS practices, providing financial incentives may not be enough to trigger winegrowers' participation in AEMs. Further policy mechanisms would be needed as complementary approaches to AEMs to tackle the other types of barriers refraining action in the viticultural sector, mainly barriers relating to capacity building and cultural norms, and to appeal to the sense of stewardship expressed by winegrowers. Information and education schemes, such as government-provided information and reporting, could improve the communication of proper evidence supporting the feasibility, benefits and impacts of using SCS practices in vineyards to French winegrowers. This may better winegrowers' understanding of the effects of SCS practices on soil characteristics (e.g., OM, structure, bearing capacity, water-holding capacity, agronomic potential, etc.) and promote the environmental dimensions associated with SCS practices (e.g., climate change mitigation, biodiversity increase, landscape improvement, etc.). Information and education schemes could also help to attenuate the weight of tradition and cultural habits, which may lead winegrowers to develop negative attitudes toward practices or strong beliefs that they are incompatible with the art of winemaking, in preventing the adoption of SCS practices.

## 5.2. Motivations and barriers in the literature

Studies analyzing what drives and prevents the adoption of SCS practices are few in the context of France and viticulture, though this research topic is gaining increasing attention. Reasons behind the adoption of CC, along with obstacles preventing adoption, were studied specifically in vineyards located in the Languedoc-Roussillon winegrowing region by Frey et al. (2017), who surveyed 334 winegrowers. The similarities in the findings observed for motivations comparatively to our study were striking, both in terms of motivations given by winegrowers overall and the importance of each motivation in the sample. The four most frequent motivations mentioned by winegrowers in the study by Frey et al. (2017) were identical to these given by winegrowers in our study: to increase biodiversity, to return OM to the soil,

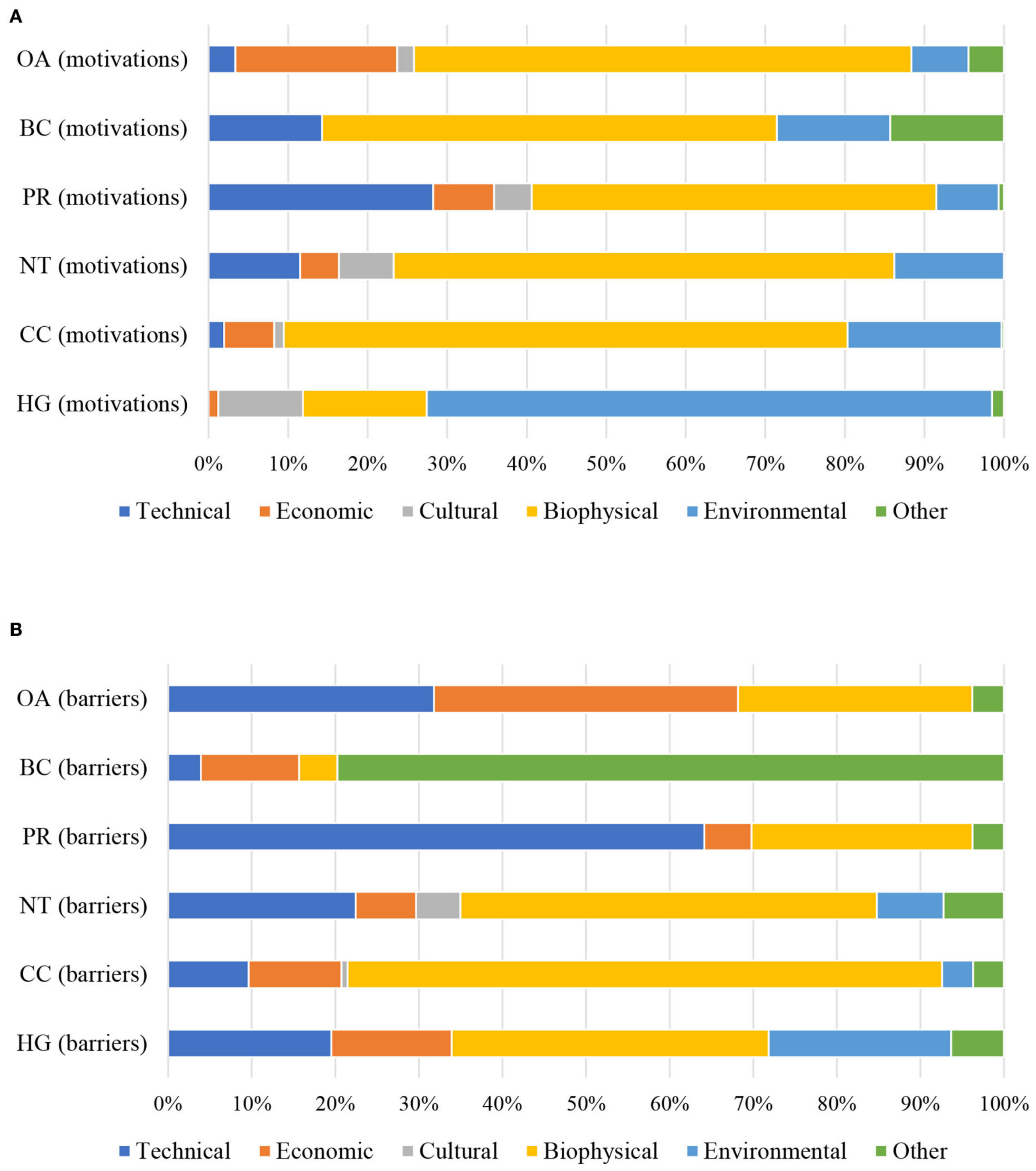


FIGURE 8
Categories of motivations for **(A)** and barriers to **(B)** the adoption of soil carbon sequestration practices by winegrowers in France. OA, organic amendments; BC, biochar amendments; PR, returning pruning residues to the soil; NT, no-tillage; CC, cover cropping; HG, hedges.

to help to prevent soil erosion, and to improve soil-bearing capacity, with a slight difference being the order of importance of each motivation. The barriers to the adoption of CC were also similar in both studies, though to a lesser extent than for the motivations. Water and nutrient competition, a decrease in yields and the lack of adequate equipment were the three most important barriers mentioned by respondents in the study by Frey et al. (2017); in our study, competition for water and nutrients between vines and cover crops were also the most frequent barriers given, but the incompatibility of the practice with the climate and the soil type or vineyard geometry came second and third, before concerns for yields and a lack of adequate equipment. These similarities may be due to the high representation of winegrowers from Languedoc-Roussillon in our sample (29%), which is in line with the fact that the viticultural land of Languedoc-Roussillon represents 30% of the total viticultural land in France (Ministère de l'Economie et des Finances (MEF), 2018). Findings from our paper confirm previous analyses observed in French vineyards regarding CC; they also broaden the understanding of the factors at play in the adoption process of winegrowers to the national scale and for a more comprehensive set of SCS practices.

The barriers to the adoption of SCS practices were investigated by Demenois et al. (2020) in France for different agricultural systems, including vineyards located in Beaujolais. In their study, the barriers were not categorized per SCS practice but given as a whole for the entirety of the SCS practices considered by the stakeholders participating in the workshops. Of the seven SCS practices identified by these stakeholders, four were similar to those considered in our study: OA, CC (in the form of grass cover or legume crop) and agroforestry (*via* hedges). There were strong similarities between the barriers identified by Demenois et al. (2020) and our study in the fact that biophysical and technical barriers were two of the most important categories of barriers preventing the adoption of SCS practices in both studies. More particularly, the biophysical barriers reported by Demenois et al. (2020) correspond to some of the main barriers mentioned in our study, namely the poor quality of viticultural soils and the competition for water between vines and cover crops or trees/hedges. One point of divergence, however, was social barriers, which were few in our study, but prevalent in the study by Demenois et al. (2020). Increased difficulty of work and workload was mentioned by Demenois et al. (2020) as one of the key barriers by participants, which is in opposition with the fact that winegrowers in our study mostly mentioned the easiness and handiness of implementing SCS practices as a reason that motivated them to use the practices. This highlights how the reality of adopting SCS practices may vary at the regional and local levels (winegrowers from Beaujolais represented only 5% of the respondents in our sample) or depending on the practices considered. The eventual complexity of implementing SCS practices is linked to the way viticulture is conducted (e.g., planting density, vineyard slope, soil characteristics, vine pruning, etc.); for instance, specific vineyards may prevent the mechanization of viticultural practices (due to a high planting density or a too steep terrain), which may, in turn, increase the difficulty of implementing SCS practices. Adopting a more territorial approach, based on the specificities of winegrowing regions and *terroirs*, could be more relevant to discussing and planning the dissemination of SCS practices in viticultural land in France.

Claessens et al. (2019) conducted a global survey to understand how barriers to the adoption of SCS practices vary at the global level and, more particularly, at the EU level. They also reflected on potential solutions that could be implemented to alleviate some of these barriers. Though their study was conducted for all types of agricultural systems, it allows for the findings from our paper to be put within the broader context of EU agriculture and to assess how viticulture in France may differ from other agricultural systems in the EU. EU farmers in the study by Claessens et al. (2019) ranked the fact that SOC sequestration is not rewarded financially (no subsidies nor carbon credits available) as their primary barrier to the adoption of SCS practices, followed by the fact that SOC management is not a political priority, and that farm extension services do not have the knowledge nor the capacity to train farmers on technical solutions. This shows that, overall, economic barriers play a much more important role in preventing the adoption of SCS practices on agricultural land at the EU level than they do more specifically in the context of viticulture in France, reflecting the fundamental difference in commodities and supply chains between viticulture, where grapes are not the final product, and other types of cropping systems (e.g., wheat). Furthermore, the solutions discussed by EU farmers in the study by Claessens et al. (2019) had similar implications to those mentioned by French winegrowers in our study in the fact that the majority of solutions ranked as most important by EU farmers dealt with improving capacity building to allow for better communication on how to increase SOC stocks on farmland and improved awareness among the public about SCS practices. Economic solutions were also identified as central in facilitating the adoption of SCS practices by EU farmers in the study by Claessens et al. (2019) and by French winegrowers in our paper. This shows that solutions focusing on improved capacity building coupled with economic actions (e.g., increasing subsidies for the purchase of adequate equipment or setting up additional payment schemes to reward the adoption of SCS practices) would be effective approaches to policy design for the EU agricultural sector and more specifically for the French viticultural sector.

## 5.3. Attitudes toward agri-environment measures and winegrower participation

Despite the overall positive attitude of French winegrowers toward AEMs highlighted by this study (Figure 7), the respondents' participation in AEMs was low. This discrepancy may be because only 106 respondents out of the total 506 that composed the sample answered the statements on attitude toward AEMs. Among those who answered the statements, the participation rate was much higher (52%; $n = 106$) than among the whole sample (24%; $n = 506$). This suggests that the observations on attitudes toward AEMs made in our study may be skewed by an overrepresentation of participants within the respondents, even though a positive attitude toward AEMs does not automatically lead to participation in AEMs (Hammes et al., 2016).

However, conclusions based only on respondents who answered the statements on attitude ($n = 106$) can still be drawn and inform winegrowers' participation in AEMs. As shown by Figure 7, the proportion of winegrowers who try to participate in AEMs as much as possible was higher than that of winegrowers who believe that AEMs are important in climate change mitigation; this tends to suggest that there would be other reasons behind the involvement of winegrowers in AEMs than only climate-related ones. This is coherent with the fact that AEMs are not only designed as mitigation strategies but can also aim at improving other ecosystem services such as biodiversity, water quality, landscape quality, etc. (European Commission, 2017).

It is also interesting to notice that only 10% of the 106 respondents thought that the payments that they would receive if they participated in AEMs would be high enough, which could be due to AEM payments not compensating winegrowers adequately for the costs associated with practice change (e.g., equipment purchases, vineyard restructuration, opportunity costs, etc.). Hammes et al. (2016) found similar results in northern Germany, where 30% of the surveyed farmers stated that AEM payments were too low. Too low financial incentives provided by AEMs may be one of the reasons why only 52% of the 106 respondents participated in AEMs, though 70% stated that they try to participate in AEMs as much as possible. This is in line with the findings of Mills et al. (2018), who showed in their study that the primary motivation of farmers for participating in subsidized AEMs was financial.

### 5.4. Gaps and uncertainty

The survey questions allowed respondents, for each SCS practice, to identify the motivations behind the adoption of the practice or the barriers that may have prevented them from adopting the practice. As a result, the number of respondents providing answers for motivations and barriers was correlated to the adoption rate of each practice in the sample: for example, because the adoption rate of PR was very high in the sample (91%), most respondents discussed the reasons that motivated them to use PR in their vineyard and only a few mentioned the barriers to the use of PR. The adoption rate of SCS practices in our sample was, overall, higher than that at the national level, with the exception of BC and PR: for instance, at the national level, OA is used on only 9% of the viticultural land (Agreste, 2017), while in the sample 73% of winegrowers used OA yearly; CC is used in the inter-rows of vineyards on 46% of the viticultural land at the national level and under the rows on 8% (Agreste, 2017), whereas the adoption rate of CC reached 73% in the sample. This suggests that there was an overrepresentation of adopters in our sample and, due to the way the survey was designed, motivations were more frequently mentioned by respondents than barriers. This overrepresentation could be linked to the fact that adopters might have higher concerns about environmental problems than non-adopters, which would make adopters more inclined to respond to surveys about climate change mitigation and soil quality (Payen et al., 2022). If the results from our study provided a strong overview of the barriers at play in the viticultural sector, further research should be led to understand why non-adopters participated less, on average, in the survey and to investigate more in detail the barriers that prevent them from adopting SCS practices. Increasing the overall participation of winegrowers in surveys such as this one, and more specifically the participation of winegrowers who are not aware of or interested in environmental problems, would allow for better capturing the global motives and barriers to the adoption of SCS practices in the viticultural sector.

This study took viticulture in France as a case study; therefore, respondents to the survey were all winegrowers. Though it provides insights into the reasons motivating winegrowers to adopt SCS practices and the obstacles preventing them from doing so, it does not consider other types of agricultural land (e.g., arable land, pastures, other perennial croplands, etc.), which represent a substantial share of the total agricultural land in France. Viticultural land accounts for only 3% of the French total agricultural land; most agricultural land in France (63%) is classified as arable land (Food and Agriculture Organisation (FAO), 2019). Understanding the enabling environment for SCS practices in different agricultural systems is paramount if SOC sequestration is to be used effectively as a $CO_2$ removal technology in France and to reach the target of the "4 per 1,000" initiative. Further research into the motivations for and barriers to the uptake of SCS practices in arable land, pastures and perennial croplands is needed to make our understanding of the factors influencing the adoption of SCS practices by farmers exhaustive.

## 6. Conclusion

Our survey of French winegrowers on SCS practices provided valuable inputs on the adoption of these practices in the viticultural sector, despite the overrepresentation of practice adopters in our sample. Results showed that most SCS practices were adopted to achieve biophysical outcomes, while the barriers to their adoption were mainly biophysical and technical. Economic motivations and barriers tended to be secondary to these factors, though they did play an important role in motivating or preventing the adoption of SCS practices by winegrowers in France. This may explain why the rate of adoption of some SCS practices (e.g., OA and NT) in the viticultural sector in France is limited at the national level, even though the adoption of these practices is estimated to have a low cost or even generate benefits for farmers (Pellerin et al., 2017). However, the costs estimated by Pellerin et al. (2017) need to be taken with care for viticultural land, as their calculations were based on low planting density; the costs of implementing SCS practices are expected to be higher in cases of high planting density.

A few winegrowers in our sample reflected on possible actions that could be undertaken to facilitate the adoption of SCS practices in their vineyard: the majority of their recommendations suggested increasing the communication of adequate and quantified information on the benefits of SCS practices at the local level and setting up further financial incentives (such as subsidies or payment schemes) to facilitate or reward the adoption of SCS practices in vineyards. These propositions indicated that the current AEMs used by the EU to incentivize the uptake of SCS practices by farmers, though useful in providing financial compensation, may have to be complemented by information and education schemes. Such schemes would need to underline the GHG mitigation potential of SCS practices, which are not seen by French winegrowers as mitigation strategies, but rather as practices allowing for an improvement in soil quality or an enhancement of biodiversity in the vineyard. In addition, France has recently launched the Low Carbon Label (*Label bas-carbone*), which provides funding from public bodies, companies and private individuals for projects aiming at reducing or offsetting GHG emissions (Ministère de la Transition Ecologique (MTE), 2021). The methodology for applying the label to viticulture is currently being developed. It will be of interest to investigate whether these additional financial incentives facilitate the adoption of SCS practices in vineyards in the future.

## Data availability statement

The data that support the findings of this study are available from the corresponding author, upon reasonable request.

## Ethics statement

The studies involving human participants were reviewed and approved by the University of Edinburgh. The patients/participants provided their written informed consent to participate in this study.

## Author contributions

FTP: conceptualization, methodology, investigation, formal analysis, data curation, writing—original draft, and visualization. DM and MM: conceptualization, validation, supervision, and writing—reviewing and editing. J-YC: validation, resources, and writing—reviewing and editing. MA and PA: supervision and writing—reviewing and editing. All authors contributed to the article and approved the submitted version.

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## Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.994364/full#supplementary-material

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