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Organic viticulture leads to lower trade-offs between agroecosystem goods but does not improve overall multifunctionality

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HIGHLIGHTS

- Farming sytems were compared using fourteen indicators, five agroecosystem goods and three ecosystem services
- We found similar levels of multifunctionality but organic systems showed lower trade-offs between agroecosystem goods
- Organic farming favored regulating and supporting services but reduced provisioning service compared to conventional farming
- Despite contrasted performance profiles, organic and conventional systems had similar economic margins

GRAPHICAL ABSTRACT

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ABSTRACT

CONTEXT: Assessing the multifunctionality of agroecosystems is crucial to design more sustainable farming systems. While it is known that organic farming benefits biodiversity and ecosystem services, how organic farming affects their multifunctionality, including agronomical, ecological as well as economic dimensions, remains poorly explored.

OBJECTIVE: In this study, we investigated how individual indicators regrouped into agroecosystem goods of vineyards respond to farming systems and landscape composition. We also explored how ecosystem services resulting from agroecosystem goods respond to farming systems and landscape composition. In addition, we evaluated trade-offs and synergies between agroecosystem goods as well as between ecosystem services for each farming systems.

METHOD: We quantified 14 indicators corresponding to five agroecosystem goods (biodiversity conservation, soil organic matter decomposition, pest control, wine production, margin) in 20 pairs of organic and conventional vineyards.

RESULTS AND CONCLUSION: Our study reveals that organic farming did not improve agroecosystem multifunctionality compared to conventional farming but led to lower trade-offs between agroecosystem goods. We found that organic systems increase supporting and regulating services but had lower provisioning service compared to conventional systems. Indeed, organic vineyards had multiple beneficial effects including higher pest control, lower production costs but produced less wine. Our results indicate a strong trade-off between pest control and wine production in both systems. In addition, conventional systems supported a negative trade-off between biodiversity conservation and wine production which was not the case of organic systems.

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SIGNIFICANCE: Our study provides key information to further design farming systems that combine ecological, economical and agronomical performances. Further investigations are now needed to identify which combined management options maximize multiple performance of agroecosystems independently of certifications and across scales.

1. Introduction

Agriculture is one of the main drivers responsible for environmental degradation (e.g. greenhouse gas emissions, soil health and biodiversity) (Foley et al., 2011) although food security is a major issue for human health (FAO, 2015). Agroecology has been proposed as a pathway to face the challenge of conciliating commodity production with reduced environmental footprint (Bommarco et al., 2013; Kleijn et al., 2019). Among the diverse forms of agriculture that agroecology encompasses, organic farming is usually presented as a prototype for agroecology (Reganold and Wachter, 2016; Tittonell, 2014). However, the agronomical, environmental and socio-economic performances of organic farming are still under intense debate and some aspects remain poorly studied (Reganold and Wachter, 2016; Muller et al., 2017; Eyhorn et al., 2019; Muneret et al., 2018; Seufert and Ramankutty, 2017).

Multifunctionality refers to overall functioning of an ecosystem or the ability of ecosystems to simultaneously provide multiple ecological functions or ecosystem services (Garland et al., 2021). Such approach has been initially developed for natural ecosystems (Maestre et al., 2012) but is a promising tool to design and monitor crop production systems (Allan et al., 2015; Herzog et al., 2019; Garland et al., 2021). Assessing multifunctionality of organic farming systems by considering socio-economic context as well as agronomical and environmental performances is therefore of major importance to design agricultural landscapes that better balance multiple sustainability goals.

Organic farming is a certification guideline that differs between countries and represents multiple types of farming systems (Seufert et al., 2017). These guidelines usually share the ban of synthetic pesticides and mineral fertilizers but have no obligations in terms of ecological processes or environmental impacts (Reganold and Wachter, 2016; Seufert et al., 2017). Numerous studies have found that organic farming at the field scale benefits biodiversity on average (Hole et al., 2005; Bengtsson et al., 2005; Tuck et al., 2014). This suggests that organic farming systems are more likely to support ecological functions provided by biodiversity such as biological pest control, pollination or soil organic matter decomposition (Mader, 2002; Kennedy et al., 2013; Seufert and Ramankutty, 2017; Muneret et al., 2018). However, the consequences of such beneficial effects on agroecosystem functioning remains unknown for several ecological processes. Moreover, many studies revealed that not all components of biodiversity are positively affected by organic farming and that some taxonomic groups are even negatively affected by organic farming practices (e.g., soil tillage, copper use) (Mackie et al., 2013; Tuck et al., 2014; Birkhofer et al., 2014; Ostandie et al., 2021a, 2021b). Beyond certification schemes, identifying how farming practices impact multitrophic biodiversity in agricultural landscapes is therefore a major topic in the present context.

The expected better ecological performances of organic farming might cascade to better economic performances. On the one hand, organic farming might be more profitable for farmers by favouring some ecological processes that reduce agrochemical inputs and production costs (Seufert and Ramankutty, 2017). On the other hand, organic farming is known to exhibit lower yields and lower yield stability (Knapp and van der Heijden, 2018) that might limit profitability (Kirby and Granatstein, 2014; Wheeler and Crisp, 2009; Gong et al., 2022). In addition, better valuation of products by the market and consumers might contribute to increase the benefit/cost ratio of organic farming (Crowder and Reganold, 2014; Hough and Nell, 2003). However, the synergies and trade-offs between profitability, commodity production and environmental footprint of organic farming remains poorly explored at field or farm scales (but see Wittwer et al., 2021) and we lack of a good understanding of the farming practices that favour synergies and limit trade-offs.

In addition, major context-dependency and large variability in the multiple performance of organic farming systems has already been reported (Tuck et al., 2014; Seufert and Ramankutty, 2017; Muneret et al., 2018). Among several environmental factors, landscape context, including the amount and the spatial arrangement of natural or semi-natural habitats, has been found to modulate the local effects of farming systems on biodiversity and ecosystem functions (Winqvist et al., 2011; Tuck et al., 2014; Muneret et al., 2019a, 2019b; Smith et al., 2020). Indeed, while local farming practices act as filters on communities, large-scale effects due to metacommunity processes determines community composition and associated functions (Henckel et al., 2015; Petit et al., 2020; Gallé et al., 2020). Moreover, the expansion of organic farming in the landscape has been suggested as a potential key aspect that might modulate the local performance of organic farming systems (Muneret et al., 2019b; Petit et al., 2020). As organic farming covers almost 1.5% of global agricultural land, there is a large potential for an increase in farmland area under organic farming (FiBL et IFOAM, 2017). The increasing amount of land under organic farming in the landscape brings important questions about robustness of the documented effects of organic farming across scales (Gabriel et al., 2010). However, how landscape context mitigates the multiple performances of organic farming, including ecological, agronomical, and economic performances, remains largely unknown (but see Smith et al., 2020). Studies investigating how landscape context affects multifunctionality of agroecological farming systems are now crucially needed to identify optimal strategies to maximize agroecosystem multifunctionality.

The aim of this study is to analyse the effects of organic farming on vineyard multifunctionality by quantifying agronomical, environmental as well as economic goods of organic systems compared to conventional ones. In addition, we investigated how landscape context modulates the level of multifunctionality measured at the field scale. To do so, we included performances related to aboveground and belowground biodiversity conservation, biological pest control, soil organic matter decomposition, crop productivity, production costs and profitability. We hypothesized that although organic farming benefits ecological performance such as a more efficient biological pest control and biodiversity conservation, it may also decrease commodity production such as wine production. In addition, we expected that organic farming would lead to higher production costs compared to conventional farming but higher profitability due to better products valuation that might compensate for lower yields (we meant that consumers from regions where wine production shares a larger proportion of the regional economy are willing to pay more for organic wine). We hypothesized that despite lower agronomic and economic performances, organic systems benefit from very high ecological performances which in turn lead to higher overall multifunctionality compared to conventional systems. Finally, we also hypothesized synergistic effects of organic farming across scales with higher levels of multifunctionality expected in landscapes dominated by organic farming.

2. Material and methods

2.1. Study site and experimental design

We constructed an experimental design to investigate how organic farming expansion and the amount of semi-natural habitats modulate the local effects of organic and conventional systems on agroecosystem multifunctionality. Our study site is located in a vineyard-dominated region in southwestern France (44°48′N, 0°14′W). The design consisted of 20 pairs of organic and conventional vineyards (40 fields, one organic vineyard and one conventional vineyard in the same landscape recorded as one pair). The pairs were selected along two uncorrelated landscape gradients (Pearson correlation $r = -0.33$, $P > 0.05$): a gradient of proportion of organic farming (ranging from 0.1% to 24.2%) and a gradient of proportion of semi-natural habitats (ranging from 0.4% to 75.1% and composed of forests (65%) and open habitats (35%) such as meadows and shrublands) in a 1 km radius which is the spatial extent usually found to affect biodiversity and ecosystem services (Petit et al., 2020) (See supplementary materials, Table S1). Such an experimental design makes possible to disentangle the relative effects of local farming practices from the proportion of semi-natural habitats and organic farming at the landscape scale. Landscape variables were calculated using QGIS 2.18.1 (QGIS Development Team, 2016).

2.2. Data collection to assess agroecosystem goods and services

We measured 14 primary variables that are used as proxies for five agroecosystem goods themselves corresponding to three types of ecosystem services (namely regulating, supporting and provisioning services) as well as economic performance (See Fig. 1). The 14 primary variables quantified were: the abundance and taxonomic richness of aboveground and soil arthropods communities as proxies for biodiversity conservation; the predation rates of grape moth eggs as well as abundance of leafhoppers and pathogen infestation as proxies for pest control services; the stabilisation and decomposition coefficients to characterize organic matter decomposition and yield per hectare to assess wine production. In addition, we measured production costs using three different cost types (labor, equipment and inputs) and sales of wine production. We provide details about data collection and measures for each variable below.

2.2.1. Biodiversity conservation

In order to measure the ability of farming systems to conserve biodiversity, we quantified arthropods biodiversity from two distinct compartments, above- and below-ground biodiversity, by considering pollinators, spiders, ground beetles as well as soil microarthropods.

2.2.2. Aboveground community

Pollinators were sampled between April and August 2018 using coloured pan traps and sweep netting. From April to May, pollinators were collected using pan traps on three sampling dates, with two sampling points per field and per date. The two sampling points were located 15 m apart and were active for 48 h. Each sampling point was composed of two sets of three coloured pan traps (blue, yellow and white), one set

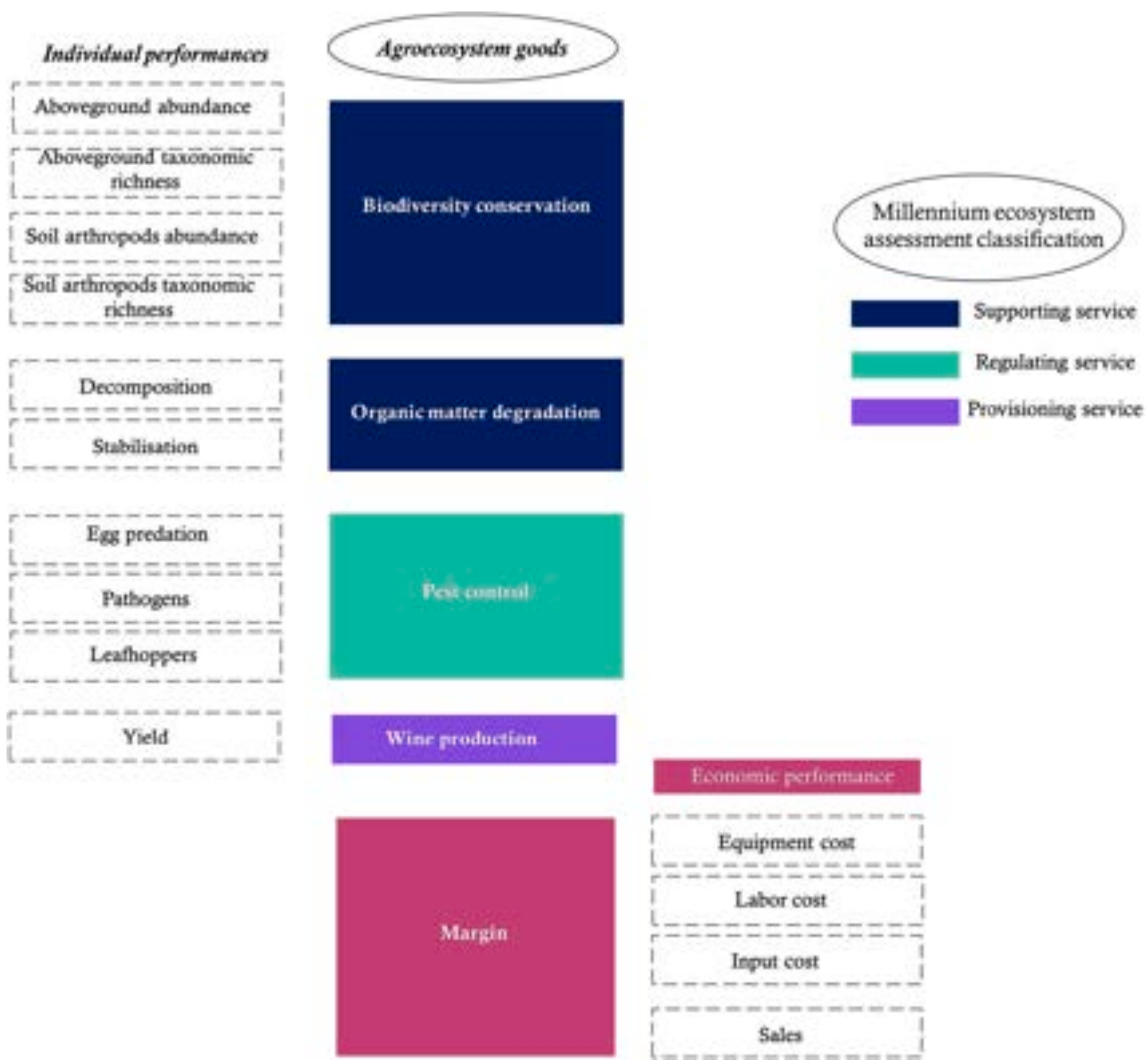

Fig. 1. Representation of the fourteen primary variables measured corresponding to five agroecosystem goods, themselves belonging to three ecosystem services or to economic performance.

localized at ground level and the other set localized at vegetation level (60 cm from the ground level). Each coloured trap was made of 500 ml plastic bowls. From July to August, two sweep netting sessions, with a sweep net of 35 cm in diameter, were performed in all fields. For each session, sweep netting was conducted along two 30 m transects, one in the grassy inter-row and one in the inter-row under tillage. Each transect were spaced by 15 m and starting at 15 m from the edge and were sampled using one sweep per footstep. For each field and session, we repeated this operation twice during the same day: in the morning (before 12 p.m.) and in the afternoon (after 2 p.m.). Samplings occurred on dry and sunny days with low wind speeds. All collected individuals were stored in 70% ethanol, and individuals were identified to the lowest possible taxonomic resolution. Only wild pollinators (bees, bumble bees and hoverflies) were considered for the analyses, while honeybees (*Apis mellifera*) were removed from the analyses to avoid bias due to the presence of beehives around some fields. To calculate taxonomic richness, we used taxonomic units based on the lowest level of identification bees, bumblebees and hoverflies. For bees of the genus *Lasioglossum*, due to the difficulty of identification at the species level, we considered subgenera, and based on the strength of the distal veins of the forewing, we divided the bees into two groups under the same subgenus.

Spiders and ground beetles were sampled on three different dates in June, July and October 2018 with pitfall traps. Pitfall traps were made of 750 ml plastic bowls with a 11.5 cm diameter. On each date, three pitfall traps were placed along a transect under a vine row starting 15 m from the field border and were located 15 m from each other. The transect was located towards the middle of the field. The pitfall traps were half filled with soapy water and were left open for 10 days. Spiders and ground beetles were collected and stored in 70% ethanol. Individuals were identified to the lowest possible taxonomic resolution: the species level for carabids, but for spiders, 77% of individuals at the species level (11% to the family level, e.g. Lycosidae; and 12% to the genus level, e.g. *Pardosa* sp.).

Aboveground biodiversity was composed of pollinators, spiders, and ground beetles. As we had multiple sampling dates, we considered the abundance of each taxon as the total sum of individuals collected per field and taxonomic richness was assigned considering the number of species at the year scale per field.

2.2.2.1. Soil arthropods community. Soil arthropods were collected from the topsoil (0–15 cm) in October 2018 to characterize belowground biodiversity. In each of the 40 fields, 500 ml of soil was constituted by mixing 9 subsamples extracted using soil cores (5 cm in diameter) spaced at 15 m intervals in all rows and interrows. Soil arthropods were directly extracted using a Berlèse-Tullgren extractor for five days (ISO 23611-2:2006 norm), with a light and associated temperature gradient over the soil core (48 h without light and 72 h with light), which was crumbled into a 2 mm plastic sieve suspended over a collecting vessel containing 70% alcohol. All arthropods collected were counted and identified to the order or family levels (i.e. Coleoptera, Chilopoda, Symphyla, Pauropoda, Isopoda, Diptera, Diplopoda, Diplura, Protura, Aranea, Acari and Hymenoptera) and to species level for springtails (38% of individuals were from the specie *Cryptopygus thermophilus* and 12% from *Folsomides parvulus*).

2.2.3. Pest control services

Pest control was quantified by measuring predation rates of grape moth eggs, the number of leafhoppers and the level of pathogen infestation. Egg predation was measured during two sessions (in May and July 2018) using sentinel cards measuring rates of predation of grape moth (*Lobesia botrana)* eggs (Muneret et al., 2019a, 2019b). The two sessions corresponded to the reproduction period of L. *botrana* which is the main grape berry moth species in our study region. An egg-laying waxed paper was placed in a L. *botrana* breeding box overnight in cages with adults free to mate. The egg laying paper was collected and groups of 10 eggs were cut out then glued on cards made of plastic-strips for field exposure. Nine cards were dispatched across three interrows (3 cards per interrow) in each vineyard fields 15 m from the start of each row and with each card being separated by 15 m. The cards were positioned on one of each two arms of the vine as close as possible to a bunch of grapes (on which *L botrana* normally oviposit). After 72 h, the cards were retrieved, and the number of missing eggs was counted. We estimated predation rates as the total number of missing eggs for each field.

In addition to predation rates of grape moth eggs, we quantified the actual levels of insect pest and pathogen infestation. Vineyards are exposed to many pests including pathogens and insects that cause severe damage to vineyards. We focused on one pathogen, *Plasmopara viticola*, which is known to generate significant yield losses (Jermini et al., 2010) in south-west of France, and one leafhopper, *Scaphoïdeus titanus*, known to be a major vector of the “flavescence dorée” phytoplasma, which induced irreversible decline of infected vines (Chuche and Thiéry, 2014).

We assessed the frequency of pathogen attacks as well as the severity of pathogen attacks in July 2018 at the closing bunch stage. In each field, we selected 100 bunches of grapes distributed over five plots located 15 m from each other (three plots in one row and two plots in another row distant from 15 m). Each plot was made up of five vine stocks and four bunches of grapes per vine stock were used for pathogen assessment. The severity of attacks of *P. viticola* was estimated using a scale ranging from 1 to 5 corresponding to the proportion of each bunch infected by the pathogen (1: 0 to 20%, 2: 20 to 40%, 3: 40 to 60%, 4: 60 to 80% and 5: 80 to 100%). We estimated the frequency of pathogen attacks as the proportion of bunches with at least one spot of *P. viticola* and pathogen infestation levels as the mean severity level at field scale. As the two variables were strongly correlated (See fig. S1 in the supplementary materials), we kept the mean severity index in following analysis.

We estimated population levels of *S. titanus* by trapping adults from early July to mid-September 2018. We placed three yellow sticky traps in the middle row of each field, 15 m from the edge and located 15 m from each other. Sticky traps were fixed on the highest wire line (about 1.5 m from the ground). The traps were weekly collected and replaced with new ones during ten consecutive weeks corresponding to the period of activity of the species. Once the traps were collected, we identified and counted the number of *S. titanus*. For each field we considered the abundance of leafhoppers as the total sum of individuals collected per field.

2.2.4. Organic matter degradation

Organic matter degradation in soils was measured using the Tea Bag Index TBI (Keuskamp et al., 2013). One teabag session was carried out in November 2018 to February 2019. Two types of teas were used to estimate the degradation of organic matter, red tea (Lipton Rooibos, EAN: 8722700188438) and green tea (Lipton green tea Sencha, EAN: 8714100770542) (Keuskamp et al., 2013). In each field, six pairs of green and red tea bags were buried (three pairs were placed in two different rows). The pairs were placed 15 m from the edge, and a space of 15 m was left between each pair. The tea bags were buried to a depth of 8 cm, with a distance between the bags of the same pair of 4 cm minimum. Tea bags were left in the soil for 90 days. Before planting, the whole bags (string, label, tea and container) were weighed dry (48 h in an oven at 40 °C). After 90 days, tea bags were taken out of the ground. After removing the roots and pebbles, the tea was weighed dry (72 h at 60 °C). During the two pre-planting weighing sessions, twenty bags of each type of tea were used to weigh the string and the label as well as the weight of the empty bag. The average weight of these twenty measurements was used to calculate the initial tea weight before incubation in soil and to calculate the final weight after incubation. We calculated two variables related to organic matter degradation, the degradation index, indicating the soil capacity to release stable organic matter (k), and the stabilisation index (S), providing information on the capacity of the soil to humify fresh organic matter (Keuskamp et al., 2013). Averaged values of k and S per fields were used for the analyses.

2.2.5. Wine production, production costs, sales and margin

For each field, the yield (hl/ha) as well as the farming practices were collected through farmers' interviews during winter 2018–2019. Each farming practice implemented was recorded by type (i.e., tillage, cover crop management, vegetation management, pesticide use, pruning and harvesting). For each practice, the type of tractor and related tools composing the equipment, the type of labor and time allocated, as well as the inputs associated to applied doses were recorded. We calculated the production costs for each of the three factors of production (labor, equipment and inputs) using the standardized OBC method (Ugaglia, 2009). For labor and equipment, the production costs were estimated using the standardized costs corresponding to the type of equipment and labor force used (Bureau de Coordination du Machinisme Agricole, 2018) multiplied by the time allocated to the farming practice. The standardized costs used for tractors and related tools include depreciation, insurance, maintenance, fuel and lubricant costs, and depend on annual usage (hours) and on the number of drive wheels. For inputs, we multiplied the standardized cost of input (IFV, 2018) by the dose applied in the field. Concerning sales, we gathered data based on the selling price of the wine as averaged during the last five years. We then calculated the average theoretical income by multiplying the mean yield across the period by the average price corresponding to the sales along this period. Finally, we calculated the margin by subtracting the production costs from the average selling price.

2.3. Calculation of agroecosystem multifunctionality

For variables where null or lower values indicated higher levels of agroecosystem goods (e.g. pest infestation levels), values were inverted ($-fi + \max(fi)$) where fi are the measures of the function i, to appear on the same scale before averaging and standardization (leafhoppers, pathogens, stabilisation index, productions costs) (Byrnes et al., 2014). Before the calculation of the multifunctionality indices, we calculated z-scores of the fourteen indicators using their maximum and minimum values to standardize variables expressed on different scales (Maestre et al., 2012). We calculated two multifunctionality indices, one based on agroecosystem goods, and one based on ecosystem services and economic performance. To assess the multifunctionality index on agroecosystem goods, we first averaged the individual indicators, after standardization, corresponding to each good category. We then standardized each good and assessed the multifunctionality indices by averaging the five agroecosystem goods. As the margin reflects the agroecosystem performance resulting from sales and production costs, we directly used it to assess the economic performance of the systems. We also assessed the multifunctionality at the service level using the same approach, but ecosystem services were weighted by the number of agroecosystem goods considered (we used a weight of 0.5 for biodiversity conservation and organic matter degradation to inform supporting service). Wine production was measured through only one variable: yield estimation that was directly used as a proxy for this agroecosystem good and provisioning service.

2.4. Statistical analysis

We first examined how local farming practices and landscape context affect each of the 14 individual indicators. The outputs of these models are not presented in the result section but can be find in table S2 in supplementary materials. We explored how local farming and landscape composition affect multifunctionality indices based on agroecosystem goods and ecosystem services, respectively considering the five agroecosystem goods and the three ecosystem services. Finally, we explored trade-offs or synergies between agroecosystem goods and ecosystem services.

To explore the relative effects of local farming practices and landscape context on agroecosystem multifunctionality and individual variables, we constructed Generalized Linear Mixed Models (GLMMs) with a Gaussian error distribution. Models used local farming systems (organic or conventional systems), landscape variables (proportions of organic farming and semi-natural habitats in a 1 km radius) as well as their interactions as fixed effects. All models included "pair" as a random effect to take into account the paired-experimental design. We fitted different models for each of the five agroecosystem goods and the three ecosystem services. In addition, we fitted models that explained the averaged multifunctionality indices based on agroecosystem goods and ecosystem services. Model selection and parameter estimations were performed under a multimodel inference approach using the MuMIn package (Bartoń, 2019). We reported estimation and confidence intervals based on full average. The residuals of all final models were checked for normality and homoscedasticity using the "DHARMa" package (Hartig, 2017). Collinearity between explanatory variables was assessed using the variance inflation factor (all VIFs were lower than 3). All continuous explanatory variables were scaled by the mean and standard deviation. GLMMs were fitted using the "lme4" (Bates et al., 2015), "MASS" packages (Ripley, 2002). We detected no spatial autocorrelation among the residuals using bubble plots and Moran's test. All analyses were performed using R (R Core Team). In order to identify trade-offs between agroecosystem goods and services, we performed pairwise comparisons considering Pearson's correlations among goods and among services respectively within each farming system and across the two farming systems.

3. Results

3.1. Multifunctionality analysis

We have found a significant effect of organic farming on two agroecosystem goods, namely pest control and wine production. Systems under organic farming had higher pest control (+77% on average) and lower yields (−39% on average) compared to conventional systems. No differences between farming systems were found for biodiversity conservation, organic matter degradation and the margin (see Fig. 2 and Fig. S2 in the supplementary materials). Overall, the aggregated multifunctionality index based on the five agroecosystem goods indicated no difference between organic and conventional faming (Table S2 and Fig. S4 in supplementary materials). The averaged value of agroecosystem multifunctionality was 0.37 ± 0.08 (mean ± SD) for organic and 0.37 ± 0.05 for conventional systems.

At the ecosystem services level, we found that organic farming benefitted to supporting services (+17% of supporting service in organic systems compared to conventional systems) and regulating services (+ 77% in organic systems), while provisioning services were 39% lower in organic systems compared to conventional ones. No effect of farming system was found on the economic performance. As for the average multifunctionality index based on agroecosystem performance, we did not find a significant effect of the farming system on the multifunctionality index calculated on ecosystem services and economic performance. Overall, the averaged multifunctionality index was of 0.30 ± 0.07 (mean ± SD) for organic systems and 0.32 ± 0.06 for conventional systems (see Fig. S4 in the supplementary materials).

No effects of the landscape variables (proportions of organic farming and semi-natural habitats in a 1 km radius) and their interactions with local variables were found on agroecosystem goods, ecosystem services or agroecosystem multifunctionality. However, we found a significant effect of the proportion of semi-natural habitats in the individual indicator approach (See supplementary materials Appendix 1).

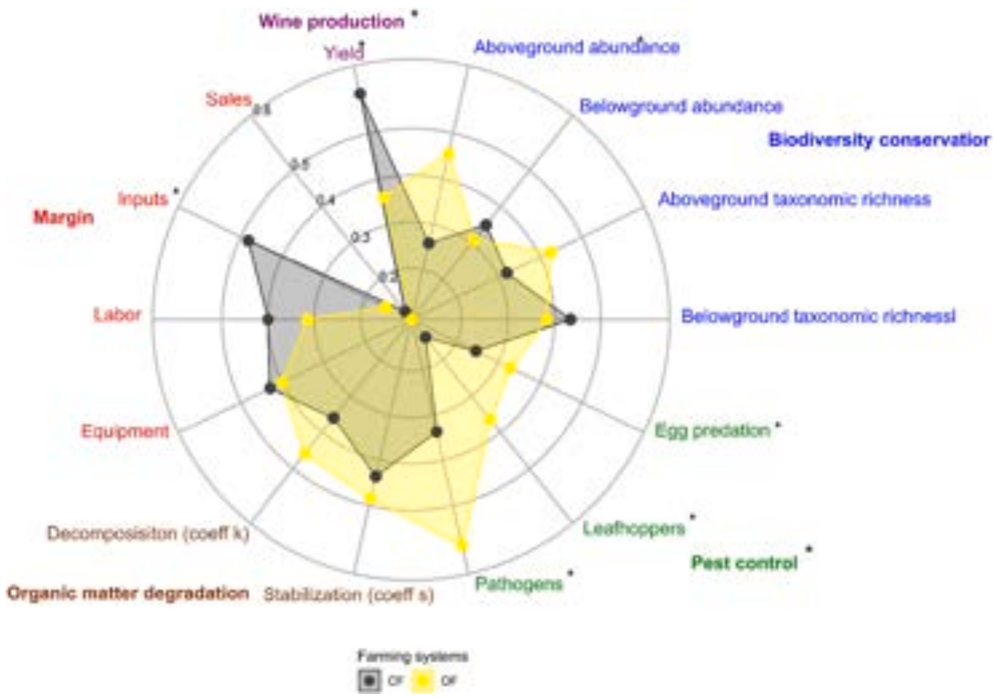

Fig. 2. Radar plots showing the averaged standardized values of the 14 primary indicators belonging to five agroecosystem goods for organic and conventional farming systems. The surface and dots in yellow represent systems under organic farming and surface and dots in grey, systems under conventional farming. (*) indicates significant differences between organic and conventional farming as obtained by multimodel inference for individual performances and agroecosystem performances. All performances are standardized, number represents values scaled, and primary indicators were not reflected. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.2. *Trade-off and synergies between agroecosystem goods and services*

Overall, irrespectively of farming systems our global pairwise comparison on agroecosystem goods revealed a trade-off between wine production and pest control as well as a synergy between pest control and biodiversity conservation (Fig. S5 in the supplementary materials). The trade-off between pest control and wine production held also within each type of farming system but with a higher intensity in conventional systems (Fig. 3). In addition to this trade-off, a negative trade-off between biodiversity conservation and wine production was also found in conventional systems.

At the ecosystem service level, our global pairwise comparison revealed a negative trade-off between regulating and provisioning services as well as a synergy between regulating and supporting services. As for agroecosystem goods, our analysis within each farming system revealed a trade-off between regulating and provisioning services but that differ in the magnitude of the correlations. The strength of the negative correlation was higher for conventional systems compared to organic systems.

4. Discussion

Our study reveals that vineyard multifunctionality does not differ between farming systems but that organic farming tends to minimize trade-offs between agroecosystem goods. The similar value in multifunctionality between farming systems is supported by very contrasted performance profiles. Overall, our results indicate that organic systems enhances supporting services and regulating services while decreasing the levels of provisioning services compared to conventional farming. Interestingly, we found that despite lower wine production, organic farming have lower production costs, leading to similar margin for farmers. In addition, our analyses clearly indicate that farming practices at the field scale are the main factors shaping vineyard multifunctionality as landscape context very rarely affected agroecosystem goods and services.

Surprisingly, no differences in terms of biodiversity conservation were found between organic and conventional systems. This result is not in line with our initial hypothesis or several meta-analyses demonstrating an overall positive effect of organic farming on biodiversity conservation (Bengtsson et al., 2005; Tuck et al., 2014). However, several empirical studies reported that differences between organic and conventional systems in perennial crops regarding biodiversity conservation are less pronounced or even non-existent compared to annual systems (see for instance Bruggisser et al., 2010; Muneret et al., 2019a, 2019b). In addition, a large variability in the effects of organic farming has been reported between functional groups, indicating that communities of organisms respond differently to organic farming practices (Tuck et al., 2014; Birkhofer et al., 2014; Ostandie et al., 2021a, 2021b). For instance, positive effects of organic farming on plants and pollinators have been reported while neutral effects have been found on decomposers or ground-dwelling arthropods (Verbruggen et al., 2010; Tuck et al., 2014; Lichtenberg et al., 2017; Ostandie et al., 2021a, 2021b). Our analysis of individual indicators of biodiversity conservation revealed that organic farming enhanced abundance of aboveground organisms while no differences in taxonomic richness above and belowground as well for belowground abundance were detected (See Fig. S6 in supplementary materials). This strongly supports the idea that organic farming does not benefit to all components of biodiversity, resulting in an overall neutral effect of organic farming on biodiversity conservation. In addition, our study also suggests that considering the farming practices actually performed within broad type of farming systems is more relevant to understand biodiversity responses in agricultural landscapes. For instance, several studies have now highlighted that agricultural practices, such as copper use or insecticide use, which are not related to farming system, play a key role in shaping community assemblages in vineyards (Pfingstmann et al., 2019; Ostandie et al., 2021a, 2021b; Karimi et al., 2021).

Beside no differences for biodiversity conservation, our analysis revealed that organic farming enhanced biological pest control, which is a major ecosystem function associated to biodiversity (Bengtsson et al., 2005; Tuck et al., 2014; Seufert and Ramankutty, 2017; Muneret et al., 2019a, 2019b). A recent meta-analysis at the global scale including a large diversity of crop types indicated that organic farming enhances biological pest control potential while showing contrasted performances in terms of pest infestation levels between pathogens, insects and weeds (Muneret et al., 2018). Our results are in line with the conclusions of this

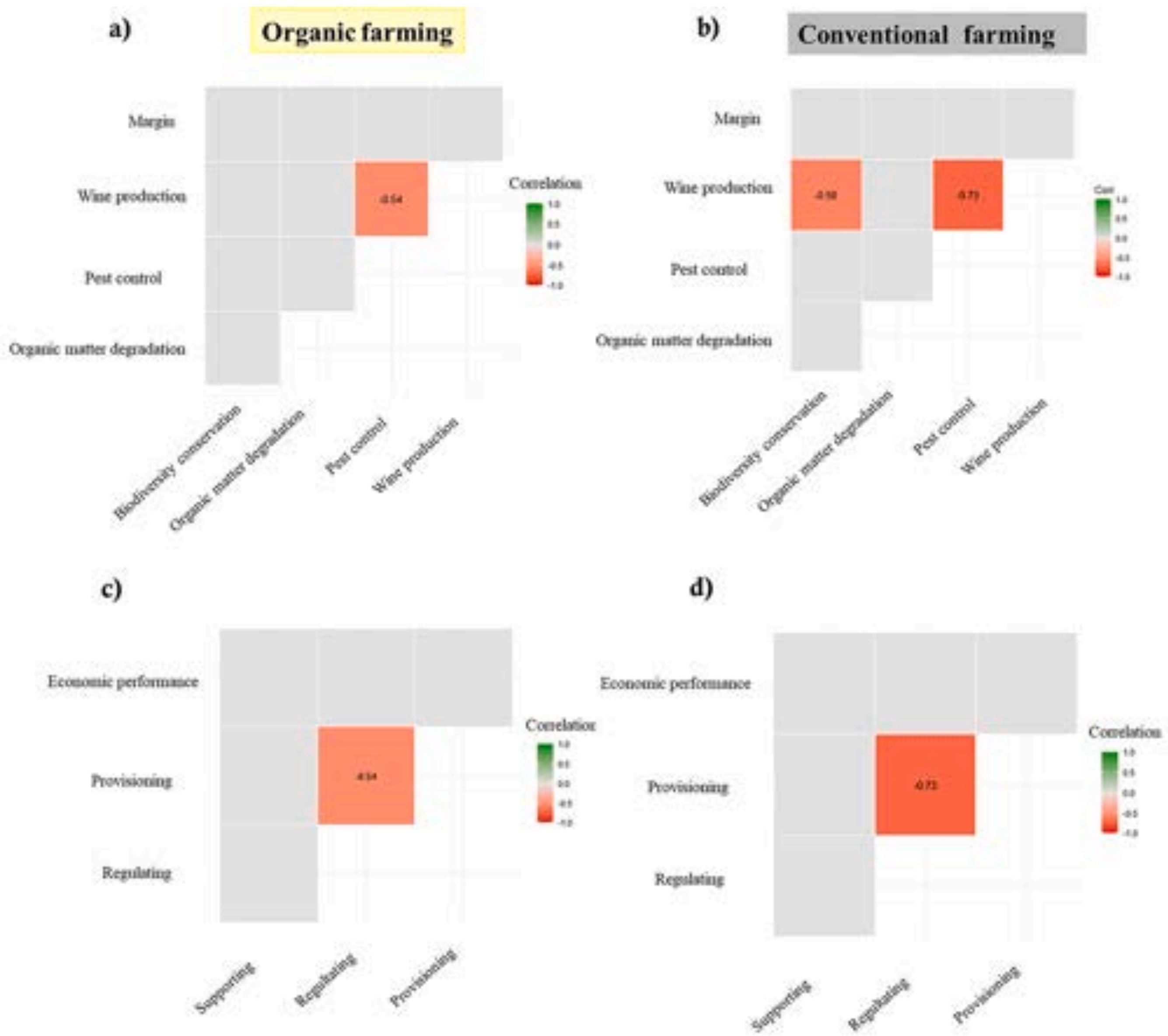

Fig. 3. Representation of the pairwise correlation respectively between the five agroecosystem goods (a and b) and the three ecosystem services as well as the economic performance (c and d), for the organic systems (yellow) and for the conventional systems (grey). Numbers represents Pearson's correlation values resulting from the pairwise approach. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

study as we found that organic farming supported higher levels of pest control potential but also higher levels of pest and pathogen infestations in the vineyard agroecosystem. Such result highlights the need to examine the mechanistic links between top-down control of pests control, pest infestation levels, crop injuries and yield losses.

Our results showing that organic farming does not benefit agroecosystem multifunctionality are not in line with a recent study (Wittwer et al., 2021) but are in line with the study of Herzog et al. (2019). Several reasons may explain this difference. First, the study by Wittwer et al. (2021) was performed in annual cropping systems while our study focuses on a perennial cropping system. In such a system, the contrast between organic and non-organic in terms of farming practices may be less pronounced than for annual crops (Bruggisser et al., 2010). In addition, very different sets of proxies were used to assess multifunctionality that may have led to different outcomes. For instance, Wittwer et al. (2021) considered a large number of proxies characterizing soil functioning for supporting services as well as water and air pollution for regulating services, while we aggregated aboveground and belowground communities for supporting services and focus on pest control for regulating services. We therefore advocate for further studies combining various set of indicators (e.g soil properties or water regulation) across multiple contexts to properly assess the effect of farming practices on agroecosystem multifunctionality.

Our study reveals that the similar margins found for both systems come from lower input costs for organic farming that partly compensate for lower wine production while selling prices do not differ between systems. In our case study, the lower production costs for organic farming likely comes from lower input costs and cheaper pesticides (e.g., copper) (Scialabba and Hattam, 2002) while equipment and labor costs were equivalent between systems (See fig. S7 in supplementary materials). The similar sales prices between both farming systems might appear surprising. However, in our study, winegrowers have contrasted business models in both systems that are highly determined by the reputation of the denomination of origin they claim for their products (generic versus communal ones) (Gergaud et al., 2017). Moreover, organic farming is known to exhibit better margin, but only when price premiums are applied (Crowder and Reganold, 2014). Therefore, in our study, production costs level is crucial and appears to be a management lever for winegrowers when the market is dominated by downstream firms on price setting (Pailler and Corade, 2004). Finally, as yield in strongly determined in our region by the balance between pathogen infestation levels and pesticide use intensity (Blaise et al., 1996), an economic analysis of this balance and its effects on the profitability for farms under different farming systems could be an interesting research perspective.

Our global analysis of synergies and trade-offs between agro-ecosystem goods reveals a strong trade-off between regulating services and commodity production, and synergies between regulating and supporting services (Wittwer et al., 2021; Dai et al., 2017). These trade-offs are partly related to types of farming systems. However, independently of the certification scheme, production contexts that enhance pest control services inevitably lead to lower agricultural production level, highlighting here again the necessity to go beyond the organic/non-organic dichotomy to understand the drivers of this trade-offs (Ostandie et al., 2021a, 2021b). Intensive farming practices that benefit wine production are also detrimental to natural enemy communities and to pest control services (Muneret et al., 2019a, 2019b). In addition, we also found a strong trade-off between wine production and biodiversity conservation but only for conventional systems, suggesting that key farming practices used in conventional systems favour the emergence of such trade-off. Interestingly, no other trade-offs between wine production and other agroecosystem services were found for organic systems suggesting that enhancing wine production in these systems does not come at the expense of other environmental or economic performance.

Contrary to our expectations, the landscape context, alone or in interactions, did not affected any agroecosystem goods or ecosystem services. We especially expected that landscape context would have impacted biodiversity conservation as demonstrated in several other studies (Tscharntke et al., 2012; Kolb et al., 2020). Our analysis of primary indicators (see supplementary materials Fig. S8) revealed that only the abundance of soil arthropods was negatively affected by the proportion of semi-natural habitats, which have already been reported in other studies (Vanbergen et al., 2007; Lehmitz et al., 2012; Pfingstmann et al., 2019; Ostandie et al., 2021a, 2021b). Our study therefore highlights that agroecosystem goods and services in vineyards mainly respond to local drivers related to farming practices rather than to landscape composition. Of course, other aspects than farming practices or landscape related to production contexts such as microclimate, soil type or land-use history might have an effect on vineyard multifunctionality. However, our results strongly suggest that farming practices at the field scale are strongly impacting agroecosystem multifunctionality.

5. Conclusion

In the present study we analysed how organic and conventional farming in interaction with the landscape context affect agroecosystem goods and ecosystems services based on the quantification of 14 primary indicators related to ecological, agronomic and economic performances of vineyard agroecosystems. Our study reveals that organic farming at the field scale does not benefit to multifunctionality compared to conventional farming. Organic farming benefits pest control, has lower production costs but supports lower crop yields. However, despite lower yields, organic systems are competitive in our region as they exhibit lower production costs and similar margins for winegrowers. Our analysis demonstrates that the trade-off between productivity and pest control exists in both farming systems but that organic farming avoids the trade-off between wine production and biodiversity conservation observed in conventional systems. We now think that we need to go beyond the organic versus conventional debate (Ostandie et al., 2021a, 2021b) and identify how combined management options across scales may promote synergies between agronomic, ecological and economic performances in order to optimize vineyard multifunctionality.

Authors contributions

N.O., B.G., D.T., P.T., A.U. and A.R. conceived the ideas and designed methodology; N.O. and P.T. collected the data; N.O. and A.R. analysed the data; N.O. and A.R. led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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Data availability

The authors are unable or have chosen not to specify which data has been used.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.agsy.2022.103489.

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