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The modernization of traditional vineyards into intensive trellis systems reduces the species richness and abundance of reptiles

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Abstract

Aim of study: Traditional vineyards have, in the last few decades, been transformed into trellis systems, but little research has been carried out into the consequences as regards biodiversity. We compared the abundance and species richness of reptiles in conventional-traditional vineyards and trellis vineyards.

Area of study: The study was conducted in a wine appellation area of origin denominated as Montilla-Moriles, Southern Spain.

Materials and methods: Reptile's species richness and abundance were estimated by walking transects in 24 different vineyards (12 trellis and 12 traditional vineyards) in four consecutive years.

Main results: The results showed an extremely low abundance in both management systems, since no reptiles were recorded in 43.1% of the transects. However, there was a greater abundance and diversity of reptiles in the traditional vineyards than in the trellis vineyards, with 7 *vs*. 3 species being found in traditional and trellis vineyards, respectively.

Research highlights: The lack of refuge in trellis vineyards owing to the vertical growth of plants, whose branches grow higher from the ground, is probably the main cause of the lower abundance and species richness found in trellis systems, since both types of vineyard had bare ground owing to ploughing and the application of herbicides. Since the transformation of traditional vineyards into those with trellis systems is often subsidized, this modernization should be accompanied by certain agri-environmental measures (*e.g.,* cover crops, artificial refuges or natural hedges) in order to compensate for the associated negative effects.

Additional key words: agricultural intensification; landscape homogenization; land use changes; lizards; squamate; *Vitis vinifera.*

Abbreviations used: AIC (Akaike information criterion); CAP (common agricultural policy)

Authors' contributions: Conception and design of the experiment: JGC, AJC, FST. Data collection: JGC, AJC, MCB, MTS. GIS tasks: JGC, MCB, MTS. Statistical analysis: JGC, AJC. Drafting the manuscript: JGC. Revision and editing the manuscript: all the authors.

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Introduction

The Common Agriculture Policy (CAP) has traditionally been identified as one of the main causes of agricultural intensification in Europe (Donald *et al.*, 2002), and this intensification has strongly reduced the biodiversity in European agroecosystems (Donald *et al.*, 2001; 2002; Voříšek *et al.*, 2010). The 2014 EU CAP has, therefore, progressively integrated different instruments with which to support the environment with the aim of enhancing the biodiversity in agricultural landscapes (Pe'er *et al.*, 2019). These instruments include Ecological Focus Areas and Agri-Environmental Schemes, such as reducing inputs of fertilisers and/or pesticides; crop rotation; enhancing habitats for wildlife and introducing buffer strips (Science for Environment Policy, 2017), and the CAP is consequently now viewed as being "greener". However, some authors have been quite critical of these measures because they are not sufficient to maintain the biodiversity and ecosystem functions in agroecosystems (Pe'er *et al.*, 2014; 2017; 2019; Cole *et al.*, 2020). One of the reasons for these criticisms is, for example, the consideration that woody crops are 'green by definition' and the consequent belief that the mandatory 'greening' measures are not necessary in order to obtain direct payments (Assandri *et al.*, 2017a).

Nevertheless, intensification also occurs in the case of woody crops that have no mandatory agri-environmental compensatory measures. In the case of vineyards (*Vitis vinifera*), the traditional vineyards formed of plants that are not arranged around wires but are left free-standing (also known as *gobelet*) are currently being replaced with a new trellising system (denominated as *spalliera*), which is a row-based system in which the plants grow vertically supported by wires and poles (Assandri *et al.*, 2017b; Montero-García *et al.*, 2017; Fig. S1 [suppl]). Indeed, the European Commission promotes the restructuring and conversion of traditional vineyards with economic support (EC, 2016). For instance, in 2020, the region of Andalusia (Southern Spain) received 3 million euros for the restructuring and conversion of vineyards from the European Agricultural Guarantee Fund (BOJA, 2020). This economic support has boosted vineyard modernization, and the areas occupied by trellised vineyards in Spain have increased by 76.7% since 2010, and by 2019, 45.1% of the areas devoted to vineyards had been cultivated using this system (MAPA, 2020). Likewise, in the Peyne watershed in Southern France, 51% of the *gobelet* surface was lost between 1962 and 2012, whereas trellised vines gained 35% of the total surface in the same period (Vinatier & Arnaiz, 2018).

The use of the *spalliera* system facilitates mechanisation and the application of agrochemical products, thus reducing harvesting costs and increasing productivity (Torquati *et al.*, 2015; Montero-García *et al.*, 2017; MAPA, 2017). Nevertheless, the modernization of vineyards entails an important structural change. In traditional vineyards, the branches growth around the trunk, covering the ground and creating an "umbrella" that provides shade and refuge to the wildlife, while in trellis vineyards, the vines grow vertically, thus offering less refuge. This transformation, therefore, reduces habitat heterogeneity and the availability of shelter, which could reduce the biodiversity in this crop. However, very few studies have been conducted to evaluate the consequences of this transformation for wildlife and all those that do exist are based on birds (*e.g.* Paiola *et al.*, 2020; Casas *et al.*, 2020; Cabodevilla *et al.*, 2021), with the exception of one paper that also focused on rabbits and hares (Cabodevilla *et al.*, 2021). In Italy, some experiments have shown that the *spalliera* system harbours fewer birds' nests and territories than the traditional *pergola* systems (Assandri *et al.*, 2017a,b; 2018), while in Switzerland, the probability of the occurrence of Woodlarks (*Lullula arborea*) was found to be greater in the traditional *gobelet* vineyards than in the *spalliera* systems (Arlettaz *et al.*, 2012). In Spain, Casas *et al.* (2020) found that great bustards avoided trellis vineyards, and Cabodevilla *et al.* (2021) showed that some birds species were more likely to occur in trellis vineyards, while other bird species and the European rabbit (*Oryctolagus cuniculus*) were found more frequently in traditional vineyards. However, no research has been conducted in order to evaluate the loss of biodiversity by comparing the traditional vineyards with no wires and *spalliera* vineyards when using reptiles as a biodiversity indicator. Reptile species richness and abundance can be considered good bioindicators of local habitat changes in agricultural areas owing to low dispersal capacity and the small home range (Kazes *et al.*, 2020; Chiatante *et al.*, 2021). Moreover, the effect of agricultural intensification in vineyards and other woody crops on reptiles has been poorly explored (Biaggini & Corti, 2015, 2021; Carpio *et al.*, 2016; Kazes *et al.*, 2020). In the light of these considerations, the aim of this work is, therefore, to compare reptile abundance and species richness in traditional vineyards (*gobelet*) and in trellis vineyards (*spalliera*) in order to test whether the modernization of vineyards is affecting reptile diversity. We hypothesized that both reptile abundance and species richness would be lower in trellis vineyards than in the traditional ones mainly as a consequence of the lack of refuge.

Material and methods

Study area and experimental design

The study area was located in a wine appellation area of origin denominated as Montilla-Moriles, which is located in Cordoba province (37°31'21"N- 4°37'34"W), southern Spain, where wine production is of great importance, and vineyards cover an area of approximately 5,000 ha. This area is principally devoted to intensive agriculture, where natural vegetation is very scarce and covers less than 1% of the area (Aparicio, 2008). The main crops are vines, olive groves and dry cereals. The study area is characterised by a Mediterranean climate, with a marked hot and dry season and mild winters, and a mean annual temperature of 17.9ºC and a mean annual rainfall of approximately 518 mm (data obtained from Climate-data.org).

Twenty-four different plots were surveyed in four consecutive years (2018-2021). The plots were surveyed for only one year (4 plots in 2018, 4 plots in 2019, 8 plots in 2020 and 8 plots in 2021), signifying that there were no repeated measures of the same plot in consecutive years. The plots were distributed in two areas separated by approximately 10 km, and in each area, the plots were at least 500-m apart from each other. The 24 plots were divided into two types (Fig. S1 [suppl]): those in conventional-traditional vineyards (n=12) and those in trellis vineyards (n=12), and both types were monitored in each of the years in which the study was conducted. The traditional vines in Southern Spain (which are known as *gobelets*) have a shorter and thicker trunk, and the branches grow more horizontally (no higher than 1-m), covering the ground around them. Trellis vineyards (also known as *espalier, espaldera* or *spalliera*) are a row-based system in which the plants are supported by wires and poles (Assandri *et al.*, 2017b; Montero-García *et al.*, 2017). Trellis vineyards have taller and thinner vines, which grow vertically (generally <2-m) and cover larger areas (Casas *et al.*, 2020). These features facilitate mechanisation, including the mechanical harvesting and the application of agrochemical products (Torquati *et al.*, 2015; Montero-García *et al.*, 2017), thus implying greater profitability. Both types of vineyards were rainfed, and herbicides were applied to prevent the growth of herbaceous vegetation, thus keeping the ground bare.

Reptile sampling

The species richness and abundance of reptiles were estimated in each plot by walking transects from April to June, when reptiles are more active owing to the mating season (Godinho *et al.*, 2011; Carpio *et al.*, 2017). The walking transects were conducted in accordance with the daily activity patterns of the reptiles on sunny windless days, while cold rainy days were avoided. The minimum temperature at the beginning of the transects was 17ºC, and the maximum was 30ºC. In the same year, each plot was surveyed twice every two weeks by walking transects for 30 minutes (Hutchens & DePerno, 2009), and in the same week, the transects were repeated on two consecutive days. Reptiles were counted if they were observed in a 10 m-wide belt, 5 m on each side of the survey line (Carpio *et al.*, 2015; 2017). In the traditional vineyards, reptiles were sought under and above the trunks. Finally, the total number of individuals and the number of species recorded per transect were used as response variables (see statistical analysis). The Shannon diversity index was not calculated owing to the low number of species registered per transect and the significant proportion of transects in which no reptiles were recorded (see results).

Habitat features obtained using GIS

In order to consider the differences in habitat features among the sampling plots, which could affect reptile abundance and diversity, buffer areas of a 100 m radius were created around the perimeter of each plot. We selected 100 m around the plots because the home range of lizards (the most frequently registered group) is usually very low (Salvador *et al.*, 1995; Diego-Rasilla & Pérez-Mellado, 2003). The land use in these buffer areas was classified in five classes (traditional vineyards, trellis vineyards, olive groves, natural vegetation and other land uses with lower importance) using aerial photographs obtained from the Spanish National Geographic Institute. This procedure was performed using QGIS software. After this classification, the Shannon landscape diversity index and the edge density (m/ha), which can be considered as good measures of habitat heterogeneity, were calculated using Fragstat software (McGarigal *et al.*, 2012).

Statistical analysis

Generalized linear mixed models were created, in which the response variable was the total number of individuals (abundance) recorded per transect, using a Poisson distribution with the log-link function. The type of vineyard (traditional *vs*. trellis), the percentage of trellis vineyards, the Shannon landscape diversity index, the edge density and the year were included as independent variables, and the interactions 'type of vineyard*edge density' and 'type of vineyard*landscape diversity' were also included, which made it possible to test whether the type of the vineyard had a different effect depending on the landscape features. The plot (n=24) and the area (n=2) were included as random factors. We performed the full arrangement of models (all possible combinations) and model selection using the Akaike information criterion (AIC; Burnham *et al.*, 2011), which shows that the models with the lowest AIC are the best. As a rule, a $\Delta AICi < 2$ suggests substantial evidence for the model (and, therefore, for the variables included) (Burnham *et al.*, 2011). For each candidate model, we calculated the Akaike model weight (ωm), which reflects the probability that a model is the best approximating model given the set of candidate models considered. Finally, for each predictor in the candidate model set, we also calculated the relative predictor importance (ωp) and the averaged parameter estimate (β) based on the sum of the Akaike weights across all models in the candidate model set that included the predictor (Symonds & Moussalli, 2011). We additionally plotted species rank–abundance diagrams for each type of vineyard using the number of species observed to check differences in species composition between both type of vineyards. The statistical analyses were performed using InfoStat and the PRIMER v6 computer programme (Clarke & Gorley, 2006). All deviations are shown as a standard deviation (SD).

Results

Our data from the four years pooled showed that no reptiles were recorded in 26.6% and 62.8% of the transects performed in traditional and trellis vineyards, respectively, with an overall average value of 1.85 (± 2.47) individuals per transect. In those transects in which some individuals were detected, only one species was observed in 60.0% and 95.2% of the transects performed in traditional and trellis vineyards, respectively. Of the 347 individuals recorded, 278 and 69 were recorded in traditional and trellis vineyards, respectively. Table 1 shows that the traditional vineyards had a higher number of individuals and species (mean, median and maximum) than the trellis vineyards.

Seven different species were recorded in the transects, with *Podarcis vaucheri,* and *Psammodromus algirus* being the most abundant species (Table 2). Seven different species were found in the traditional vineyards, and only three species in the trellis vineyards (Table 2). Rank–abundance diagrams showed that the dominant species in both traditional and trellis vineyards was *Podarcis vaucheri*, followed by *Psammodromus algirus* in both crops, while the third most dominant species was different, as it was *Timon lepidus* in traditional vineyards and *Psammodromus hispanicus* complex in trellis vineyards (Fig. 1).

According to the model average procedure, the year and the type of vineyard were the most important predictors of the number of individuals, since these variables had the greater coefficients (β) and ωp values (Table 3). Moreover, both variables were included in all the candidate models, which indicates that this variable is an important predictor of reptile abundance. The variable 'landscape diversity' and the interaction 'landscape diversity*type of vineyard' were included in three candidate models, which suggest that they were of some importance as regards explaining the number of individuals. The remaining variables had lower ωp and/or coefficients, and were consequently less important predictors. The number of individuals was greater in the traditional vineyards (mean = 2.96 ± 2.86 SD) than in the trellis vineyards (0.73 ± 1.27) (Fig. 2). Finally, differences among years were also found, with higher values in 2021 (2.77 ± 2.61) and 2018 (1.83 ± 2.84) than in 2019 (0.41 ± 0.76) and 2020 (0.38 ± 0.49).

Discussion

Traditional vineyards are part of the cultural and historical landscape in the Southern Iberian Peninsula, and are characterised by highly heterogeneous land cover and low-input farming practices that allow a rich biodiversity to exist within them (Paiola *et al.*, 2020). However, agricultural intensification has dramatically transformed traditional vineyards in all wine regions worldwide, and several works have shown a lower abundance and diversity of different taxonomic groups in intensive vineyards (Viers *et al.*, 2013). Indeed, our results suggest that neither type of vineyard is a suitable habitat for reptiles, since no individuals were registered in a significant proportion of the transects, with an overall median value of 1 individual per transect, thus evidencing the scarcity of reptiles in both management systems. Moreover, according to Guerrero-Casado *et al.* (2021) and Salvador *et al.* (2021),

Table 1. Descriptive statistics concerning the number of individuals and the number of reptile species recorded per transect, depending on the vineyard type, in both types of vineyard.

	Number of individuals				Number of species			
	Mean	**SD**	**Median**	**Max**	**Mean**	**SD**	**Median**	**Max**
Traditional	2.96	2.86	2	10	1.13	0.93	1	4
Trellis	0.73	1.27	0	7	0.38	0.49	0	2

SD = standard deviation. Max = maximum number of individuals or species recorded per transect.

Table 2. Total number of individuals (and their relative frequency in both types of vineyard) of the seven species recorded during fieldwork.

Species	Traditional		Trellis	
	Nº of individuals	**Relative frequency (%)**	**Nº of individuals**	**Relative frequency (%)**
Podarcis vaucheri (Boulenger, 1905)	176	63.31	62	89.86
Psammodromus algirus (Linnaeus, 1758)	47	16.91	1	1.45
Psammodromus hispanicus complex	4	1.44	1	1.45
Timon lepidus (Daudin, 1802)	14	5.04	0	0
Zamenis scalaris (Schinz, 1822)	1	0.36	0	0
Tarentola mauritanica (Linnaeus, 1758)	1	0.36	0	0
Hemorrhois hippocrepis (Linnaeus, 1758)	1	0.36	0	0
Unidentified	34	12.23	5	7.25
Total	278		69	

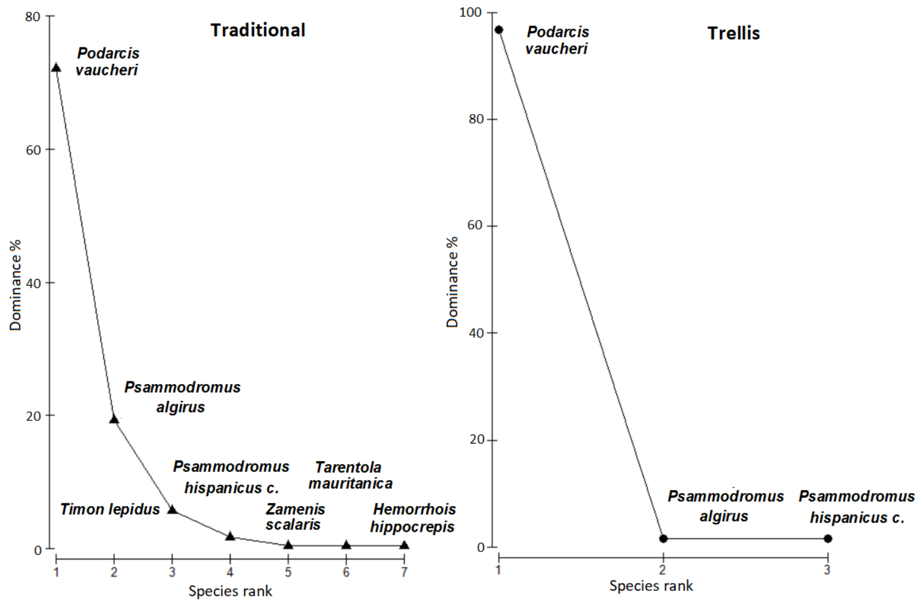

Figure 1. Rank–abundance diagrams of reptile species for each type of vineyard.

ten different species of reptiles can be found in the study area (excluding *Natrix maura* and *Mauremys leprosa*, which are more associated with aquatic habits), but only seven different species were found in the vineyards surveyed, and only one individual was registered for three species, thus suggesting that the current management of vineyards is not suitable for most local reptile species.

Our results further showed than reptile abundance was different depending on the management system, with a higher abundance being recorded in the traditional vineyards than in the trellising crops. The trellising system entails landscape simplification and homogenization, which is mainly achieved by increasing the field size and employing a higher level of mechanisation (Assandri *et al.*, 2017b; Cabodevilla *et al.*, 2021). Moreover, the crop structure is different in traditional and trellising vineyards. In *spalliera* vineyards, the vertical growth of plants with taller and thinner trunks whose branches grow higher from the ground and in which the distance between rows is higher (Cabodevilla *et al.*, 2021), which dramatically reduces the amount of shelter available for reptiles. In the traditional *gobelet* vineyards, however, the shorter thicker trunks (hollows and cavities are particularly more abundant in the older trunks) with branches covering the ground and with a shorter distance between rows offer more refuge and shade. Furthermore, since herbicide and

Table 3. Model selection according to the AIC criteria and model averaging results for candidate models explaining the number of individuals. The coefficients for each variable in each model are shown. Coefficients for the level of fixed factors were calculated using reference values for 2018 and "traditional" in the variable year and vineyard type, respectively.

Predictor	Model							β	SD	ωp
	1	2	3	4	5	6	7			
Vineyard type	-0.720	-0.334	-0.209	-0.159	-0.266	-0.238	-0.140	-0.295	0.198	1
Year 2019	-0.275	-0.260	-0.131	-0.103	-0.108	-0.106	-0.097	-0.154	0.078	
Year 2020	-0.234	-0.214	-0.120	-0.109	-0.100	-0.090	-0.107	-0.139	0.059	1
Year 2021	0.234	0.203	0.113	0.091	0.083	0.083	0.075	0.126	0.065	
Landscape diversity	-0.343	0	0	0	-0.132	-0.143	0	-0.103	0.136	0.435
Type*lands.divers.	-0.334	0	0	0	-0.353	-0.329	0	-0.145	0.349	0.435
Trellis vineyard (%)	0	0	0.0001	0	0	0.0002	0	0.0001	0.0005	0.093
Edge density	0	0	0	0.0001	0.0002	0	0	0.0002	0.0001	0.213
AIC	520.2	520.31	521.47	521.72	522	522.12	522.15			
ΔAIC	0	0.11	1.27	1.52	1.80	1.92	1.95			
ωm	0.243	0.230	0.129	0.114	0.099	0.093	0.092			

β = averaged parameter estimate; SD = standard deviation; ωp = relative predictor importance; ωm = Akaike model weight.

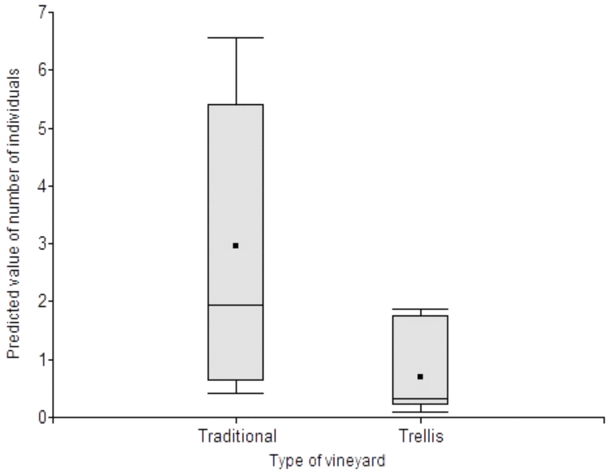

Figure 2. Box plot showing the predicted value of the number of individual reptiles in the two types of vineyards.

sulphide treatments are similar in both types of vineyards (Cabodevilla *et al.*, 2021), and both types of vineyard have bare ground, we deem that the lack of refuge is the main factor explaining the lower abundance and species richness in trellis vineyards.

The number of species recorded was also higher in the traditional than in the trellis vineyards. *Podarcis vaucheri* was practically the only species recorded in the trellis vineyards (Fig. 2), whose dominance can be explained by the arboreal behaviour of the lizards of this genus (Kaliontzopoulou *et al.*, 2009; Ayres & Domínguez-Costas, 2021) in comparison with other lizard species more usually seen at ground level, which probably cannot find sufficient refuge at ground level owing to the lack of elements such as rocks or natural vegetation. In the case of the *Timon lepidus,* although some individuals were recorded in traditional vineyards, no individuals were recorded in trellis vineyards, probably because this species cannot find suitable shelter owing to its larger size. Moreover, some individuals of *Tarentola mauritanica, Timon lepidus, Zamenis scalaris* and *Hemorrhois hippocrepis* were observed in the surroundings of trellis vineyards during the fieldwork (personal observations), but these species were not recorded within the trellis vineyards. Similar results were found in Israel (Kazes *et al.*, 2020), where significantly lower reptile abundance and species richness were recorded in intensive vineyards when compared to adjacent natural patches. There is, therefore, a slightly differential response to land-use changes depending on the reptile species, with some species being more vulnerable than others (Biaggini & Corti, 2015).

The extremely low reptile abundance and diversity recorded particularly in trellis vineyards suggest that some agri-environmental measures should be taken in order to boost the presence of reptiles in this modern crop system. For instance, several works have shown the benefits of cover crops in vineyard inter-rows as regards reducing soil erosion (Biddoccu *et al.*, 2020) and enhancing the biodiversity of several taxonomic groups (see the review of Paiola *et al.*, 2020, and Geldenhuys *et al.*, 2021). Further works should, therefore, be carried out to test whether herbaceous cover crops could increase reptile abundance, or whether they are unable to act as a substitute for homogenization, the lack of refuge and the loss of micro-niches within the trellis vineyards. Likewise, increasing the landscape diversity around the crops (*e.g.* natural vegetation patches, hedge and boundaries) could be effective as regards boosting lizard abundance in vineyards, since the more habitat heterogeneity, the more ecosystems functions and processes, and the more biodiversity in agricultural landscapes (Fahrig *et al.*, 2015).

In summary, the results shown herein evidence the lower abundance and species richness found in trellised vineyards when compared with traditional *gobelet* vineyards, suggesting that the transformation of traditional vineyards into intensive trellised systems is harmful for the diversity of reptiles. The economic incentives intended for the transformation of traditional vineyards into trellis systems should, therefore, be accompanied by some type of agri-environmental compensatory measure, such as the implementation or the maintenance of natural vegetation, hedges and boundaries, or the establishment of cover crops around the grapevines, which could mitigate the negative consequences of this transformation.

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