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A field evaluation of the impact of temporary cover crops on soil properties and vegetation communities in southern Spain vineyards

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ABSTRACT

Transition from bare soil to temporary cover crop-based soil management has been promoted for at least two decades in vineyards in southern Spain. However, there is limited field evaluation of its impact at commercial vineyard level. Our study evaluates the impact of these two soil managements in sixteen commercial vineyards in Southern Spain. Selected soil physical, chemical and biological properties were measured in a representative inter-row of each vineyard during 2015-2016. Overall, the temporary cover crop vineyard presented a significant improvement in soil organic carbon content and aggregate stability in comparison to the bare soil vineyards, 73 and 29% respectively, as well as presenting more diverse plant communities. Nevertheless, there was a large variability among vineyards that preclude the identification of other impacts and differences among the different kind of temporary cover crops followed by the winegrowers. A refined analysis concentrated in the eleven vineyards on more calcareous soils distinguishing among bare soil, spontaneous cover crop of low biomass production, spontaneous cover crop of high biomass production and barley cover crop of high biomass production was performed. It resulted in a larger improvement in soil properties in the vineyards having a spontaneous cover crop of high biomass production followed by the ones having a cover crop with barley. It also showed how the spontaneous cover crop of low biomass production presented a moderate or negligible improvement in soil properties as compared to the bare soil vineyards. In general terms, the best strategy seemed to be the vineyards with spontaneous cover crops that were able to achieve a high biomass production, above 0.91 t ha^{-1} per year, which also presented a high plant diversity. Our results indicate the need for a proper evaluation of the impact of cover crop-based management based on vineyard assessment of soil properties and their relation with driving variables, as in our case biomass production and composition of the cover crops.

1. Introduction

Soil is a core element for the provision of ecosystems services so, the Common International Classification of Ecosystem Services (CICES, 2011) considers soil formation and composition as well as mass stabilization and control of erosion rates within the Regulation and the Maintenance section. Therefore, the maintenance of biological, chemical, physical conditions of soils including fertility and nutrient storage, or soil structure and erosion control, vegetation cover protection and vegetation on slopes are relevant issues. All these ecosystem services depend on soil properties and their interaction, being mostly influenced by their use and management (Adhikari and Hartemink, 2016). This explains why an appropriate soil use and management are being promoted by several policies at different scales, e.g. the Common Agricultural Policy (CAP) of the European Union.

Sustainable management in woody crops (Montanaro et al., 2017) and specifically in vineyards (Brunori et al., 2016) plays a key role to increase soil C_{org} which could improve the soil natural capital. At the European level, the CAP urges the Member States through national and regional policies to implement Good Agricultural and Environmental Conditions (GAEC). Among others, they promote the implementation of agricultural practices such as the use of cover crops to limit soil erosion and the maintenance or increase of vegetation cover, and therefore increasing soil C_{org} stocks (Borrelli et al., 2016).

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Vineyards are one of the most widespread woody crops in Europe with 3.2 Mha in the EU28. Vines cover a broad range of latitudes and associated edaphoclimatic conditions, from 4° to 51° in the Northern Hemisphere to 6° until 45° in the Southern Hemisphere. Vineyard management includes several practices that can affect soil functioning and the ability of the vineyard to provide key ecosystem services. For instance, intense tillage removes vegetation cover and decreases soil organic matter reducing soil aggregate stability and infiltration rates which decreases ecosystem service provision such as carbon sequestration, erosion protection and regulation of the hydrological cycle (Six et al., 1999; Ruiz-Colmenero et al., 2013; Biddoccu et al., 2016).

In Mediterranean and other semiarid areas, winegrowers are especially reluctant to use permanent cover crops due to concerns over the competition for soil water with the vines (Celette et al., 2008; Ruiz-Colmenero et al., 2013). As a result, most of the winegrowers that implement cover crops tend to use temporary cover crops, defined by Salomé et al. (2016) as those providing ground cover between 4 to 7 months per year. In many countries, farmers do not seed cover crop mixtures but use spontaneous vegetation from the soil seed bank. For instance, in Spain, 93% of the farmers prefer to use spontaneous vegetation cover rather than commercially available cover crop mixtures in tree crops (MAGRAMA, 2013). In addition, the weed community diversity is affected by management practices in vineyards, considering these management practices as environmental filters which can determine weed community composition (Kazakou et al., 2016).

The CAP has been significantly supporting efforts to promote a shift from bare soil to permanent or temporary cover crops for at least the last 20 years (e.g. European Commission, 2003). However, despite significant research in the last decades (e.g. Salomé et al., 2016; Ruiz-Colmenero et al., 2013), it has still been difficult to predict the impact of soil management in specific vineyards. Some studies on soil quality in vineyards (e.g. Salomé et al. 2016; Gómez et al., 2014) show a large unexplained variability among farms with similar soil management which reduces its relevance for extrapolation of the impact of agri-environment schemes under different conditions, i.e. cover crops or reduced tillage. A similar variability has been noted in other tree crops such as olives (e.g. Gómez et al., 2009). Part of this variability can be due to the differences in the duration of the cover crop establishment at the farm as well as its quality of development (e.g. Gómez, 2016; Vicente, 2017), as well as due to a greater species richness in the bordering semi-natural elements of the agricultural areas. This variability of vegetation cover (within the field or its boundaries) plays a key role for the ecosystem service provision of agroecosystems (Altieri, 1999; Jackson et al., 2007; Barbieri and Mahoney, 2009).

This paper presents the results of a study aiming at evaluating the impact of the GAECs in vineyards of an Appellation of Origin in a Southern Spain with these objectives:

1 To evaluate the impact of the soil management commonly used in the study region (bare soil or temporary cover crops) on selected soil and vegetation parameters in the vineyard inter-rows that can provide carbon sequestration, soil fertility, erosion control and plant biodiversity.
2 To explore the sources of variability among vineyards and between management regimes based on the information gathered from field surveys and participatory research with wine growers.

2. Materials and methods

2.1. Area of study

The study region, known as '*Montilla-Moriles*' (37° 38′-29′N, 4° 45′-31′W) comprises 33,607 ha and is located in Cordoba (S. Spain), Fig. 1. Luvisols and Cambisols are the most abundant soil types, and the area has an average annual precipitation of 604 mm that ranges between 306 and 1012 mm, an average annual temperature of 17.2 °C and a reference evapotranspiration of 1270 mm. The area includes terrains within the range of 220 and 682 m a.s.l. and it is characterized by a rugged relief, with slopes ranging mainly from 0 to 50%. In this agricultural region, there are 5052 ha of vines assigned to the Appellation of Origin in which approximately 80% of the cultivated vineyards are of the white grape variety *Pedro Ximénez*. This variety is well-adapted to the climate conditions of the area and is commonly harvested in mid-late August.

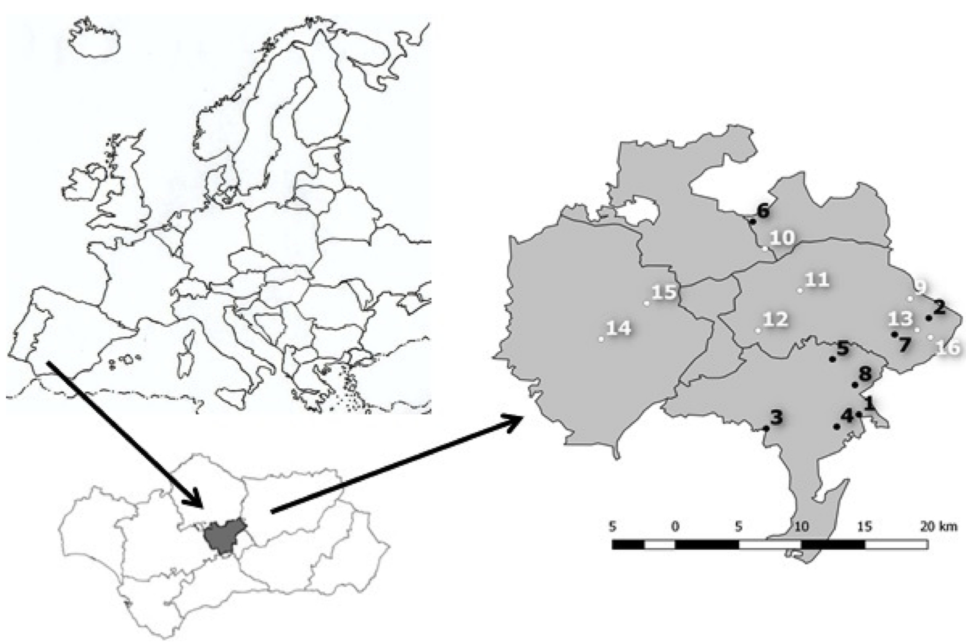

Fig. 1. Location of vineyards within the Appellation of Origin '*Montilla-Moriles*'. Black dots correspond to vineyards with bare soil, white spots identify vineyards which use cover crops.

Table 1
General characteristics of the studied vineyards which use bare soil management (# 1–8) and cover crops in vineyard inter-rows (# 9–16). Age specifies the age of the vineyard, and implementation of the soil management shows the duration of the respective management application at the vineyard. More details of management are in Table S1.

Vineyard ID	Training system	Grapevine spacing	Age (yr)	Type of cover crop[a]	Tillage passes per year[b]	Inter-row vegetation control[c]	Implementation of the soil management (yr)	Soil classification[d]	Soil textural class[e]	$CaCo_3$ (%)
1	Globet	1.85 × 1.85	16	–	2-4	T	16	Calcic Vertisol	Silty clay	1.8
2	Globet	1.85 × 1.85	50	–	2-4	T	50	Calcaric Cambisol	Silty clay	59.7
3	Trellis	1.25 × 2.85	5	–	1-3	T	5	Calcaric Luvisol	Sandy clay loam	2.2
4	Globet	1.75 × 1.75	20	–	2-4	T	20	Calcaric Cambisol	Clay loam	41.8
5	Globet	1.90 × 1.90	14	–	2-4	T / H	14	Calcaric Cambisol	Clay loam	48.6
6	Globet	1.90 × 1.90	30	–	1-3	T	30	Calcaric Cambisol	Sandy loam	16.6
7	Trellis	1.50 × 3.00	10	–	1-3	T	10	Calcaric Luvisol	Clay loam	65.2
8	Trellis	1.25 × 2.85	5	–	1-3	T	5	Calcaric Cambisol	Clay loam	31.2
9	Trellis	1.25 × 2.50	35	Spt	1-3	T / H	3	Calcaric Cambisol	Clay loam	57.9
10	Trellis	1.20 × 2.50	10	Spt	1-3	T / H	6	Calcaric Luvisol	Sandy loam	16.7
11	Trellis	1.20 × 2.90	10	Spt	1-3	T	5	Calcaric Cambisol	Silty clay loam	59.8
12	Trellis	1.20 × 2.90	10	S	2-3	H	9	Calcaric Cambisol	Loam	53.4
13	Trellis	1.20 × 2.90	10	S	2-3	H	9	Calcaric Cambisol	Clay loam	70.3
14	Trellis	1.25 × 2.85	13	Spt	0-1	T	8	Calcaric Cambisol	Clay	27.4
15	Trellis	1.20 × 2.90	10	Mx + Spt	1-3	T / H	7	Calcaric Fluvisol	Silty clay loam	40.6
16	Trellis	1.20 × 2.90	10	S	2-3	H	9	Calcaric Cambisol	Silty clay	50.6

[a] Different typologies of cover crop: Spt: spontaneous vegetation, S: sown (*Hordeum vulgare*) and Mx + Spt: mix of species sown in 2010 (thereafter, vegetation consists of spontaneous species from the soil seed bank and possible remaining species from the mix).
[b] Generally, with a cultivator.
[c] Although the management summarized in the Table is the predominant one, all the vineyards but 14 (organic), apply glyphosate 1–3 times per year in the vine row and sometimes in the inter-rows. T means tillage and H means herbicide.
[d] Soil classification (IUSS, 2014).
[e] USDA textural classification.

2.2. Studied vineyards

The study was carried out in sixteen commercial vineyards using two contrasting soil management strategies. All these vineyards have been implementing the same soil management at least for the last 3 years. Tables 1 and S1 summarizes some of the most relevant characteristics of each vineyard and detailed information about management operations and their periodicity.

Vineyards 1 to 8 keep a bare soil along the inter-rows, using moderate tillage which consists in several tillage passes (1–4) mainly with a cultivator at 15 cm deep, from the beginning of autumn. Occasionally, this is combined with herbicide applications throughout the year. Vineyards 9 to 16 were the ones with a cover crop management. In the cover crop vineyards herbaceous vegetation is generally a temporary cover crop removed in early March (either mechanical or chemically) when water competition between vines and weeds increases.

Different typologies of cover crops can be distinguished. Vineyards # 9, 10 and 11 use spontaneous vegetation as a cover crop. Vineyards # 12, 13 and 16, sown barley (*Hordeum vulgare*) every year during fall and occasionally, barley residues are incorporated into soil profile as straw when they are not used as forage. Vineyard # 14 is an organic vineyard with permanent cover crops where herbaceous vegetation is controlled by regular cutting in early spring. Vineyard # 15 sowed a commercial mixture including cereals, legumes and cruciferous seven years ago, and since then the cover crop is a combination of the local vegetation and some possible remains of the original mix.

In this area, the traditional training system is the horizontal globet, being still possible to find almost half of the vineyards under this system. However, in the last years it is changing to the trellis system, mostly motivated by subsidies and management cost savings.

2.3. Soil properties

It was not possible to locate all the vineyards with the desired requirements in a single textural soil class, although the sampling design took care of distributing the two set of vineyards (bare soil and cover crops) into a similar range of textural classes (Table 1). Soil measurements were performed at several points randomly arranged at the top 10 cm in the middle of a representative inter-row of each vineyard, avoiding vineyard's borders (located at more than 25 m) and areas with changing slope gradients. For a general view of the sampled inter-row areas in the respective vineyards in December 2015, see Figure S1.

Table 2 shows a summary description of the measured properties, protocols of analysis, date of sampling and number of replications. We analyzed soil physical (dry bulk density B_d, macroaggregate stability M_{as} (> 250 µm), saturated hydraulic conductivity $Ln(K_{sat})$, percolation stability PS), chemical (organic carbon C_{org}, $pH(H_2O)$) and biological variables (tea bag index TBI, which is defined by the litter stabilization factor S and the decomposition rate factor k; and the soil respiration rate in laboratory CO_2).

2.4. Characterization of vegetation

We evaluated several vegetation variables in the middle of the same selected inter-row where the soil samples were taken. The sampling consisted of four 1 m^2 subplots spaced 6 m apart measured at four dates: 10th December 2015, 15th February 2016, 8th March 2016 and 31st March 2016. At each sampling date the number of different species per vineyard were identified using the nomenclature of Castroviejo (1986-2012). Average vegetation ground cover (%) at the four subplots, was estimated using a grid of 10 × 10 cm within the same subplots (Londo, 1976). After this, the aboveground vegetation was cut, and oven dried at 65 °C for seven days to calculate the dry biomass ($t \cdot ha^{-1}$). To enable the comparison of vegetation between managements regardless the date of sampling (Table 2) we selected the maximum amount of dry plant biomass VG_{mb} and the maximum ground cover GC_m per vineyard.

To evaluate the possible similarities regarding the species the Sørensen index (*IS*) was calculated as follows:

$$IS = \left(2 \cdot \frac{c}{a + b}\right) \cdot 100 \tag{1}$$

where a is the total number of plant species of one community, b is the

Table 2
Description of the measured variables along the vineyard inter-rows, sampling dates and measurement method. n is number of subsamples per vineyard.

Soil property	n	Sampling date	Protocol
Dry bulk density ($g \cdot cm^{-3}$), B_d	16	8th-15th February 2016	Core method, 24 h at 105 °C
Macroaggregate stability ($g \cdot kg^{-1}$), M_{as}	4	10th December 2015	Barthès and Roose, 2002
Saturated hydraulic conductivity ($mm \cdot h^{-1}$), $Ln(K_{sat})$	16	8th-15th February 2016	ÖNORM L 1065 (2006-12-01)
Percolation stability ($ml \cdot 600s^{-1}$), PS	4	8th-15th February 2016	Auerswald, 1995
Organic carbon (%), C_{org}	4	10th December 2015	Nelson and Sommers, 1982; Jackson, 1958
pH (H_2O)	8	8th-15th February 2016	pH meter; deonised water
Litter stabilisation factor, S	11	From 3rd-4th February to 30th-31st March 2016	Keuskamp et al., 2013
Decomposition rate, k	11		
Soil respiration rate($mg \cdot kg^{-1} \cdot d^{-1}$), CO_2	4	10th December 2015	Vähäoja et al., 2005

Vegetation variables	n	Sampling date	Protocol
Species composition	4	10th December 2015	Londo, 1976 (1 m^2 plots)
Max. plant biomass ($t \cdot ha^{-1}$), VG_{mb}	4	15th February 2016	Dried above ground biomass at 65 °C for 7 days
Max. ground cover (%), GC_m	4	8th March 2016 31st March 2016	Londo, 1976 (1 m^2 plots, grid 10 cm x 10 cm)
Sørensen index (%), IS	–	–	Magurran, 2004

Table 3
Average and standard deviation of the soil and vegetation variables followed by the coefficient of variation (%) in brackets; $p < 0.05$ (in bold) implies significant differences between treatments determined by a Kruskal-Wallis test. Last column shows thresholds of these properties to be considered as degraded soils.

Soil properties	Bare soil	Cover crop	p	Range of degraded soils
Dry bulk density ($g \cdot cm^{-3}$), B_d	1.17 ± 0.17 (14.7)	1.24 ± 0.18 (14.3)	0.01	> 1.58 (USDA, 1999)
Macroaggregate stability ($g \cdot kg^{-1}$), M_{as}	146.57 ± 56.31 (38.4)	253.20 ± 131.36 (51.9)	0.00	< 300 (Barthes and Roose, 2002)
Saturated hydraulic conductivity ($mm \cdot h^{-1}$), $Ln(K_{sat})$	1.14 ± 0.72 (62.8)	0.98 ± 0.78 (79.8)	0.05	< 1.19 (USDA, 1999)
Percolation stability ($ml \cdot 600s^{-1}$), PS	6.65 ± 5.92 (88.9)	6.21 ± 5.56 (89.5)	0.94	< 150 (Mbagwu and Auerswald, 1999)
Organic carbon (%), C_{org}	0.80 ± 0.13 (15.8)	1.03 ± 0.25 (24.4)	0.00	< 0.841 (Pastor et al., 1996)
pH (H_2O)	7.60 ± 0.09 (1.2)	7.55 ± 0.07 (1.0)	0.00	< 5.6 or > 8.4 (Benítez et al., 2002; García et al., 2004)
Litter stabilisation factor, S	0.56 ± 0.07 (11.7)	0.58 ± 0.06 (10.9)	0.24	~ 0.55 (Keuskamp et al., 2013)
Decomposition rate, k	0.01 ± 0.01 (50.4)	0.01 ± 0.01 (56.1)	0.07	~ 0.01(Keuskamp et al., 2013)
Soil respiration rate ($mg \cdot kg^{-1} \cdot d^{-1}$), CO_2	42.60 ± 5.46 (12.8)	43.21 ± 5.30 (12.3)	0.99	< 57 (Woods End Research and Woods End Research, 1997)

Vegetation variables	Bare soil	Cover crop	P
Species identified	32	44	–
Average number of species	9 ± 3	12 ± 5	0.22
Max. plant biomass ($t \cdot ha^{-1}$), VG_{mb}	0.42 ± 0.50 (119.9)	1.66 ± 1.23 (74.2)	0.00
Max. ground cover (%), GC_m	24.1 ± 22.2 (92.1)	61.5 ± 25.4 (41.3)	0.00
Sørensen index (%), IS[a]	63.2		< 70%

[a] Lower values than 70% indicate that the compared plant communities are different.

total number of species of a different community and c is the number of common species in both communities (Magurran, 2004). Community treatments were bare soil and cover crop vineyards in the inter-row. The Sørensen index (IS) varies between 0 (no common species) and 100% (all species are common) being 70% the threshold commonly used to indicate that the compared communities are different.

2.5. Data analyses

A Kruskall-Wallis pairwise test ($p < 0.05$) and a Spearman correlation analysis (with significance when $p < 0.05$) was carried out to explore the possible differences in a given property between the two managements (bare soil and cover crop), including the whole set of vineyards, firstly. Maintaining the initial grouping into bare soil and cover crop vineyards, the refined classification included soil carbonate content and the maximum aboveground biomass of the inter-row vegetation (related to cover crop typology).

These two additional criteria within each class were considered to account for the effect of soil carbonate content on soil properties following the approach of Salomé et al. (2016). For this reason, the studied vineyards were classified in two groups: high (> 20%) or low soil carbonates content (Andrades Rodríguez and Martínez, 2001). The biomass threshold was included to take into account the effect of cover crop development on soil properties already mentioned (e.g. Vicente, 2017). The threshold to classify vineyards with a high or low aboveground biomass was calculated as the average of the maximum biomass in the bare soil vineyards plus the standard deviation, resulting in 0.91 $t \cdot ha^{-1}$.

In order to discard the effect of carbonates, we decided to perform the analysis using high carbonate content vineyards. Considering this criterion, only categories with two or more vineyards were included in this analysis (to compare the differences in aboveground biomass production due to different types of cover crops). Therefore, vineyards # 1, 3, 6 and 10 were omitted from this second analysis. Within high carbonates soils, # 8 was not included either, as it was the only vineyard with high aboveground biomass production. Therefore, to explore the different types of cover crops, eleven of the vineyards were sorted in four categories, all with > 20% carbonates: bare soil with low biomass

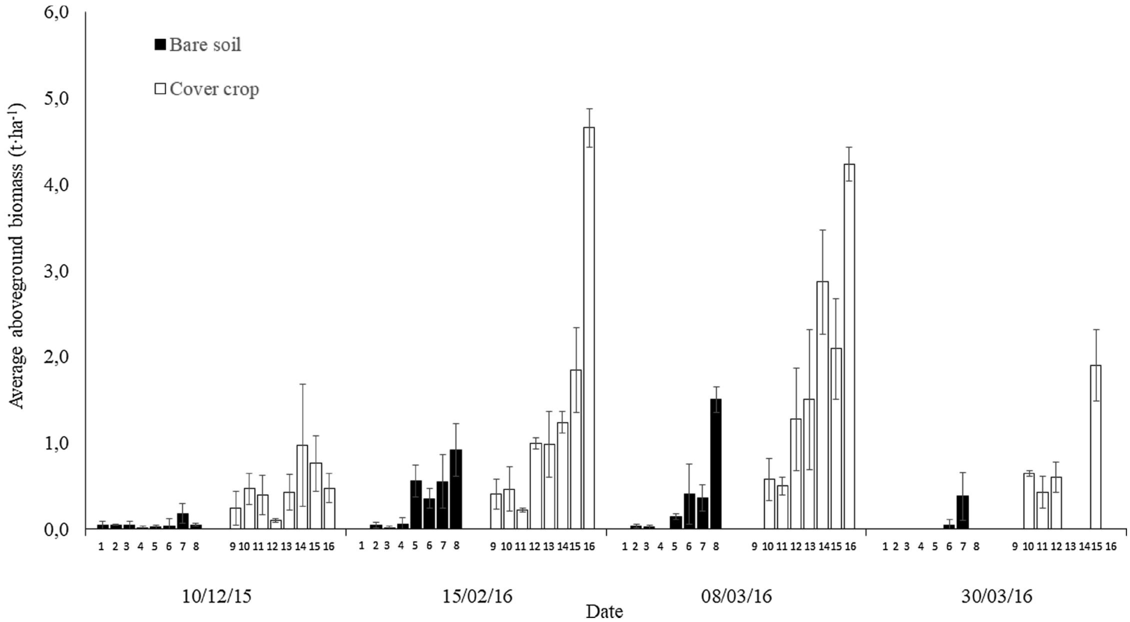

Fig. 2. Temporal development of the average dry weight of the aboveground biomass along the inter-rows for bare soil and cover crop vineyards (white and black bars, respectively). Each bar represents one vineyard (from # 1–16) per sampling date.

(# 2, 4, 5, 7), cover crop with spontaneous low biomass (# 9, 11), cover crop with spontaneous high biomass (# 14, 15) and cover crop with sown high biomass (# 12, 13, 16).

The Kruskall-Wallis pairwise test ($p < 0.05$) was repeated then to assess the measured variables among categories.

These tests were performed with the software tool Infostat 2017 (National University of Cordoba, Argentina).

3. Results

3.1. Exploratory analysis of differences in soil properties between bare soil and cover crop vineyards

Table 3 shows mean values and variability of soil and vegetation variables for bare soil and cover crop vineyards. Significant differences in soil physical properties were detected: dry bulk density, (B_d), macroaggregate stability (M_{as}) and log-transformed saturated hydraulic conductivity ($Ln(K_{sat})$). Regarding chemical properties, these differences were noticed in organic carbon (C_{org}) and pH (H_2O). No differences were observed in the TBI factors or soil respiration.

Despite the large coefficients of variation (especially among the bare soil vineyards), significant differences between treatments in vegetation variables were detected, Table 3. Fig. 2 shows the average development of dry weight of aboveground biomass at each vineyard at the different sampling dates. It can be observed that some bare soil and cover crop vineyards show an overlap regarding this development.

A total catalogue of 52 plant taxa was identified in the inter-rows of the 16 vineyards. In Table 4 a summary of the taxa distribution of each vineyard is presented. The number of different species identified at the inter-rows of the bare soil and cover crop vineyards was 32 and 44, respectively. The Sørensen index (*IS)* between the inter-rows of the bare soil and cover crop vineyards was 63.2% (Table 3) which indicates significant differences between the communities of the two groups of vineyards. Despite these differences in vegetation communities, some species identified such as *Brassica nigra* was present in almost all the vineyards (with the exception of # 16). Analyzing each management separately, *Lamium amplexicaule* was found in seven of the bare soil vineyards while *Sonchus asper* appeared in six of the eight cover crop vineyards, Table 4.

3.2. Assessment of soil properties and inter-row vegetation on vineyards on high carbonate content soils and vegetation development

Fig. 3 shows the distribution of the sixteen vineyards according to soil management (bare soil or cover crop), carbonate content (high or low) and maximum aboveground biomass of the vegetation measured along the inter-rows (high or low), considering the cover crop typology. Four categories with more than two vineyards, were identified in high carbonate soils: bare soil with low biomass (# 2, 4, 5, 7), cover crop with spontaneous low biomass (# 9, 11), cover crop with spontaneous high biomass (# 14, 15) and cover crop with sown high biomass (# 12, 13, 16).

Fig. 4 depicts the average and standard deviation of the soil measured properties for the four categories above mentioned, including the significance of differences, which were observed for all the variables measured but $pH(H_2O)$ and litter stabilization factor (*S*). Table 5 summarizes the analysis of vegetation variables. The number of species is lower in the bare soil and in the sown cover crop vineyards, the latter dominated by the sown specie *(Hordeum vulgare*). The number of species were higher in the spontaneous vegetation treatments, in particular in those with high biomass which roughly doubled the number of species of the bare soil and the sown cover crop. Both maximum inter-row aboveground biomass (VG_{mb}) and ground cover (GC_m) show clear and significant differences among the groups of vineyards (Kruskal-Wallis, $p < 0.05$). The Sørensen index (*IS*) indicates that the plant communities are not similar among the four categories but that more common species are found in low biomass bare soil and spontaneous low biomass cover crop vineyards (e.g. *Brassica nigra*, *Lamium amplexicaule*, *Malva* sp., *Galium tricornutum*, *Sherardia arvensis* and *Urtica urens*, present in at least,four of the six vineyards of both classes), Table 4.

4. Discussion

4.1. Overview of differences in soil and vegetation variables between bare soil or cover crop vineyards

Soil properties at the sixteen vineyards grouped in the two soil managements as classified in the study area were measured and compared.

The overall comparison of the average soil properties reflects the

Table 4
Species identified along the vineyard inter-row during the sampling period (December 2015-March 2016) in bare soil (1–8) and cover crop farms (9–16). Crosses means the presence of the species in the vineyard. Some species could only be identified at the genus or family level. Last column shows the percentage of species per vineyard related to the total number of taxa (N = 52).

Vineyard ID/Taxa	*Amaranthus albus*	*Anagallis arvensis*	*Arum italicum*	*Brassica nigra*	*Brassicaceae*	*Bromus matritensis*	*Buglossoides arvensis*	*Calendula arvensis*	*Campanula erinus*	*Cardamine hirsuta*	*Centranthus calcitrapae*	*Chrysanthe-mum coronarium*	*Conyza bonariensis*
1				X									
2				X									
3		X	X	X					X				
4				X									
5		X		X					X				X
6		X		X		X		X					
7				X									
8		X		X					X				
9	X	X		X					X		X		
10	X			X				X					
11		X		X	X		X	X	X				
12				X			X	X					
13				X								X	
14		X		X	X			X		X			X
15		X		X	X	X		X					
16													

Vineyard ID/Taxa	*Convolvulus arvensis*	*Daucus carota*	*Diplotaxis virgata*	*Ecballium elaterium*	*Erodium malacoides*	*Euphorbia prostrata*	*Euphorbia sulcata*	*Fumaria capreolata*	*Fumaria parviflora*	*Galium murale*	*Galium tricornutum*	*Geranium rotundifolia*	*Geranium* sp.
1			X										
2	X	X											
3			X			X					X		
4													
5	X				X						X	X	X
6													
7											X		
8		X								X	X		
9							X				X		X
10			X										
11										X	X		
12											X		
13					X								
14	X	X		X			X	X	X		X		
15													
16													

(*continued on next page*)

Table 4 (*continued*)

Vineyard ID/Taxa	*Herniaria cinerea*	*Hordeum leporinum*	*Hordeum vulgare*	*Lamarckia aurea*	*Lamium amplexicaule*	*Linaria amethystea*	*Malva* sp.	*Medicago minima*	*Medicago sativa*	*Medicago* sp.	*Phalaris paradoxa*	*Picris comosa* subsp. *comosa*	*Plantago albicans*	*Poa annua*
1					X									
2					X		X							
3		X					X							
4					X									
5					X		X							
6					X	X								X
7					X		X	X		X				
8	X				X			X		X		X		
9					X		X	X		X				
10					X		X							
11					X		X					X		
12	X		X				X		X			X		
13			X					X						
14					X		X	X			X	X		
15		X		X				X	X	X		X	X	
16			X											

Vineyard ID/Taxa	*Sagina apetala*	*Sanguisorba minor* subsp. *magnolii*	*Sherardia arvensis*	*Silene vulgaris*	*Silybum marianum*	*Sinapis alba*	*Sonchus asper*	*Sonchus oleraceus*	*Stellaria media*	*Urtica urens*	*Vicia hybrida*	*Vicia sativa*	Species/ Total taxa (%)
1							X			X			10
2			X							X			13
3			X				X			X			23
4										X			6
5			X										23
6							X		X				17
7								X		X			15
8		X			X				X	X			29
9			X				X			X		X	31
10	X						X		X	X			19
11	X		X				X					X	29
12	X						X			X			23
13													10
14			X				X		X			X	42
15				X		X	X				X		31
16													2

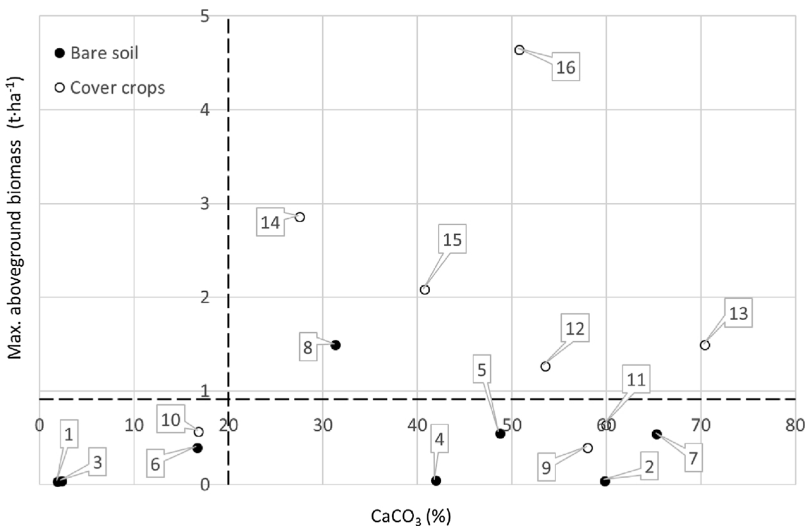

Fig. 3. Classification of the vineyards based on the soil carbonates content in the X axis* and maximum above ground biomass of the inter-row vegetation in the Y axis**. Labels indicate the vineyard number. Bare soil vineyards, black circles; cover crop vineyards, white circles. In high carbonate soils, four categories with two or more vineyards were identified: bare soil with low biomass (# 2, 4, 5, 7), cover crop with spontaneous low biomass (# 9, 11), cover crop with spontaneous high biomass (# 14, 15) and cover crop with sown high biomass (# 12, 13, 16).
* High carbonates content > 20%.
** High aboveground biomass > 0.91 t·ha^{-1}.

heterogeneity within the two groups of vineyards regarding soil characteristics and agricultural operations. Nevertheless, despite this large variability significant differences were found in some of the physical properties measured such as bulk density (B_d), macroaggregate stability (M_{as}) and saturated hydraulic conductivity ($Ln(K_{sat})$). Concerning the characterized chemical properties, the differences were observed in organic carbon (C_{org}) and $pH(H_2O)$). Generally, worse values of dry bulk density B_d (higher) and saturated hydraulic conductivity $Ln(K_{sat})$ (lower) in cover crop vineyards could be explained by the natural consolidation of soil with cover crops and the lower disturbance of soil by tillage passes at the sampling date. On the other hand, macroaggregate stability (M_{as}) and organic carbon content (C_{org}) are higher in the cover crop vineyards which suggest the positive effect of the cover crops on these soil properties. There was not a clear trend between manure application and macroaggregate stability (M_{as}) or organic carbon content (C_{org}) (see Figure S2 a) and b), respectively). Nevertheless, a significant correlation was found between mean macroaggregate stability (M_{as}) and organic carbon (C_{org}) for the sixteen vineyards (Spearman's R = 0.62, $p = 0.00$; Table S2). These results are in line with other authors who noted the improvement of these two variables in cover crop vineyards after four years of treatment under semiarid conditions, e.g. Peregrina et al. (2010); Ruiz-Colmenero et al. (2013).

It is worthy to note that in our study area significant improvement in key indicators of soil quality in the temporary cover crop systems, macroaggregate stability (M_{as}) and organic carbon (C_{org}) which increased by approximately 73 and 29% respectively, were found despite the relatively large variability in soil and management details among the vineyards. This suggest an overall strong effect of the transition from bare soil to temporary cover crops in the study area promoted by several environmental schemes related to the CAP in the last 20 years.

While cover crop vineyards tend to have a higher VG_{mb} during the entire sampling campaign, the standard deviations are larger as well due to the differences in aboveground biomass production of the

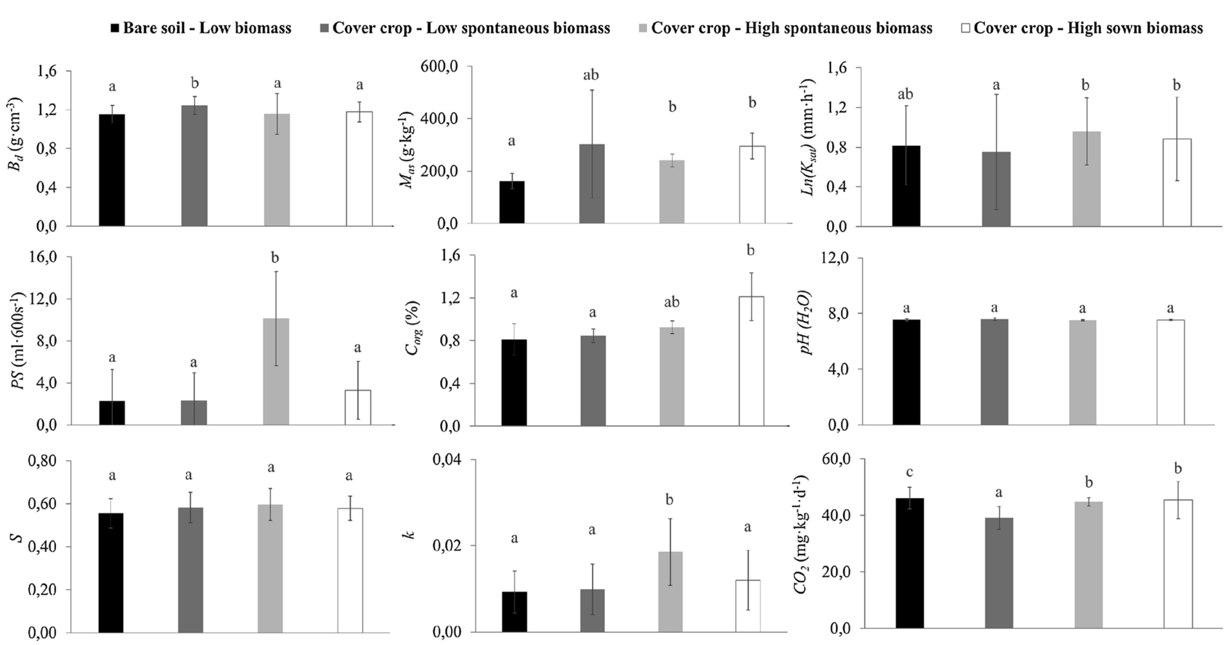

Fig. 4. Average and standard deviation for the soil properties measured in each category: bare soil with low biomass, cover crop with spontaneous low biomass, cover crop with spontaneous high biomass and cover crop with sown high biomass. Different letters mean significant differences among categories (Kuskall-Wallis test, $p < 0.05$). Dry bulk density (B_d), macroaggregates stability (M_{as}), saturated hydraulic conductivity ($Ln(K_{sat})$), percolation stability (PS), organic carbon (C_{org}), $pH (H_2O)$, litter stabilization factor (S), decomposition rate factor (k) and soil respiration rate (CO_2).

Table 5
Number of species, mean values and standard deviation of the maximum inter-row aboveground biomass (VG_{mb}) and ground cover (GC_m). Different letter indicates significant differences (Kruskal-Wallis test, $p < 0.05$) among different classes. Sørensen index (*IS*) for the four categories compared. Values < 70% implies differences in vegetation communities.

Vegetation variables	Bare soil – Low biomass	Cover crop – Spontaneous low biomass	Cover crop – Spontaneous high biomass	Cover crop – Sown high biomass
Species identified	17	22	31	15
Average number of species	9 ± 3 a	16 ± 1 ab	19 ± 4 b	6 ± 6 a
Max. plant biomass ($t \cdot ha^{-1}$), VG_{mb}	0.33 ± 0.31 a	0.52 ± 0.19 a	2.54 ± 0.68 b	2.28 ± 1.31 b
Max. ground cover (%), GC_m	22.98 ± 23.7 a	39.2 ± 28.0 ab	86.3 ± 8.7 c	68.3 ± 12.7 bc
	IS (%)[a]			
Bare soil - Low biomass	–	56.4	45.8	37.5
Cover crop – Spontaneous low biomass	–	–	41.5	32.2
Cover crop - Spontaneous high biomass	–	–	–	47.8
Cover crop - Sown high biomass	–	–	–	–

[a] Lower values than 70% indicate that the compared plant communities are different.

different types of cover crops in each vineyard, either spontaneous or sown. In fact, there are some vineyards that despite of being under different soil management present similar maximum aboveground biomass production. These vineyards are in an intermediate position between bare soil managed vineyards with a negligible growth of vegetation and cover crop vineyards with a dense cover crop. This can be explained by the differences in the intensity of agricultural managements among vineyards, different plant species used as cover crops and the particular circumstances of each vineyard such as the date in which the vegetation was removed, vegetation height or infestation of rabbits in the zone. However, even the low aboveground biomass cover crop vineyards presented a relevant average biomass production ($> 0.5\, t \cdot ha^{-1}$) compared to similar areas in dry Mediterranean conditions (Vicente, 2017), despite the relatively dry study year in the region (423 mm).

As expected, the *IS* showed differences between both plant communities (63.2%) which could be related to more competitive weed species which are adapted to frequent disturbance events and may therefore pose a larger problem for inter-row vegetation management. In terms of number of species (52 taxa) there is a relatively high diversity as it corresponds to similar Mediterranean systems with a general high rate of diversity, even in the most intensely managed systems (Foraster, 2007; Hernández-Plaza et al., 2011). The plant species community is composed of weeds, ruderal, nitrophilous and short or very short cycle therophytes. The higher number of species at the cover crop vineyards (44 versus 32 in bare soil) could be explained by the dynamics of the studied agroecosystem since spontaneous vegetation is removed later in the season which allows the arrival of a greater number of propagules (especially seeds) of species from the borders of the vineyard.

4.2. Soil management effect on soil and vegetation degradation within homogeneous vineyards

Due to the large heterogeneity in cover crop types among the different vineyards and the confounding effect of the large variability in soil calcium carbonate content, it was necessary to incorporate them to elaborate a more appropriate appraisal of the impact of temporary cover crops in the study area.

Salomé et al. (2016) noted a large variability in soil indicators measured in a large set of vineyards based on soil and cover crop typologies. They measured significant differences regarding soil organic carbon and microbial carbon biomass between permanent cover crop and bare soil vineyards in the three groups of soils (no stony calcareous, no stony no calcareous and stony no calcareous). Nevertheless, these significant differences were detected when they performed the same analysis comparing bare soil and temporary cover crop vineyards without accounting for differences in calcareous nature of the soils.

In addition, published values of aboveground net primary production of herbaceous vegetation in vineyards varies considerably based on the typology of the cover crop. For instance, Kazakou et al. (2016) measured 3.9 and 5.2 $t \cdot ha^{-1}$ in a French vineyard located in Southern France with a spontaneous and a sown cover respectively; Steenwerth and Belina (2008) studied two types of sown cover crops in Central California measuring 2.9 and 3.4 $t \cdot ha^{-1}$. Scandellari et al. (2016) reported values of 0.5 and 6.5 $t \cdot ha^{-1}$ in two Italian vineyards with spontaneous vegetation cover, due to less propitious conditions for the ground cover growth in Northern Italy as compared to Southern Italy.

Considering these two driving variables (high carbonates and cover crop development/type: bare soil-low biomass, high and low spontaneous biomass; high sown biomass) a clear trend emerges. For most of the variables measured, the cover crop categories showed better soil properties with significant differences compared to bare soil vineyards. The maximum improvement, as compared to the bare soil vineyards, in soil physical, chemical and biological properties is found in the spontaneous high biomass vineyards followed by the temporary cover with barley. The vineyards using a spontaneous cover crop with low biomass productivity presented a discrete improvement in the evaluated soil properties as compared to the vineyards implementing a bare soil management.

The moderate intensity of tillage and herbicide as applied by winegrowers in the study region leads into bare soil vineyards with some significant aboveground inter-row biomass growth, 0.33 t·ha^{-1}. This is not far from the lower threshold mentioned by Scandellari et al. (2016) for and spontaneous cover crop in S. Italy. Furthermore, in the spontaneous cover crop vineyards many species which come from the surrounding habitats of the vineyard, cannot finish their life cycle, which limits their survival in the vineyards and therefore generates low biomass values. Each season, these species start again to colonize the soil, with no possibility to establish a viable population like in permanently disturbed soils. The *IS* detected differences in the community composition among the four categories. In general terms, the spontaneous high biomass production cover crop presented also a significantly more diverse plant community. Vineyards using a temporary barley cover crop have a relatively low number of species (ranging from 1 to 12). As expected, the most impoverishing treatment from the point of view of plant biodiversity is the one which generates a cover by sowing barley, given that it is a monospecific crop that eliminates by competition a large part of the present taxa. In this type of vineyards, a higher species diversity may well be caused by outer variables such as, a poorer development of the barley or the presence of non-cultivated reservoirs nearby the vineyards.

4.3. Comparison of soil degradation variables in the studied vineyards to other agroecosystems

While cover crop vineyards shows better soil quality indicators, it is interesting to compare not only relative differences between managements, but also their absolute values in relation to reference thresholds used as indicators of soil quality in other woody crops (Table 2).

Gómez et al. (2009), based on a review of available published values, proposed a range of values for the different soil properties and used them to evaluate soil degradation status in a large set of olive orchards in the same region. When comparing the reference values with the mean ones measured for each category (Fig. 4), average dry bulk density (B_d) and pH (H_2O) were in the acceptable range for non-degraded soils in all vineyards. On the other hand, the average saturated hydraulic conductivity ($Ln(K_{sat})$) and soil respiration rate (CO_2), were below these reference values. The average organic carbon (C_{org}) shows that bare soil vineyards are closely under the threshold while cover crop types overpass it. For macroaggregate stability (M_{as}), the average values of cover crop vineyards are over or close to the threshold compiled by the same authors. It is worthy to mention the large variability in the spontaneous low biomass, which could be explained by differences of vineyards textural classes or the number of year implementing the same management.

The large variability is also present in percolation stability (*PS*) and could be attributable to the same reasons mentioned above. Comparing these values with the percolation stability classes in relation to land use (Mbagwu and Auerswald, 1999), they range within the slow class corresponding to continuously cropped, conventionally-tilled or unmulched plots with low organic matter content. It seems that the cover crop effect on this variable is still moderate as these authors stated that land use history has a stronger influence than the location in the soil profile, finding the highest values in > 30-year-old grass pasture.

The Tea Bag Index (*TBI*) measures the decomposition of green and rooibos tea bags providing information about a fast-initial phase and a slower second phase (ESDAC, 2018). The decay of green tea is an indicator of how much of the labile fraction of the material is stabilized (S). On the other hand, rooibos which decomposes much slower, is a proxy for the initial decomposition rate (*k*). Keuskamp et al. (2013) explained that *k* is linked with short-term dynamics of new input while *S* represents the long-term carbon storage. In our study, the absolute values of the litter stabilization factor (*S*) in all the four categories were in the upper range of those reported by the authors, being close to those indicated in their study for desert environments with loamy soils. For the decomposition rate (*k*), values for bare soil and low biomass cover crop (0.009 and 0.010) were in the lower range of those reported by the same authors being similar to those described for some desert environments while high biomass either with spontaneous or sown vegetation (0.019 and 0.012) are closer to some grassland and forest habitats.

5. Conclusions

The implementation of an inter-row temporary cover crop is a common agricultural practice in woody crops in order to protect soil against erosion, promote biodiversity and increase soil organic carbon while minimizing the risk for competition for soil water in arid and semiarid conditions, compared to a permanent cover crop. The studied vineyards show a representative range of soils and soil managements treatments at vineyard level that are commonly carried out at the Appellation of Origin "*Montilla-Moriles*". The impacts of temporary cover crops on soil properties and vegetation variables resulted in a significant, albeit moderate, improvement in soil organic carbon and aggregate stability as compared to bare soil vineyards with a moderate tillage intensity. This seems to confirm a positive impact of this strategy on key variables regulating the provision of ecosystem services by the soil in the study area at the mid and long-term.

The introduction of soil carbonate content and cover crop characteristics (aboveground biomass and typology) allowed a better quantification of the impact of temporary cover crops on several soil variables as compared to bare soil vineyards. Our results raise concerns on the evaluation of the impact of soil management on the provision of ecosystems services based on a scaling up of the results which usually comes from simplified farm survey-based studies comparing only the effects of bare soil and cover crop management or from declarations related to the CAP. The combination of these results with management details at farm level and their analysis regarding the driving variables (as in our case biomass production and carbonate content) can provide a clearer understanding of the changes promoted by different agri-environmental schemes, such as the use of cover crops in woody crops.

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Appendix A. Supplementary data

Supplementary material related to this article can be found, in the online version, at doi:https://doi.org/10.1016/j.agee.2018.11.010.

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