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SOIL NITRATE AND ORGANIC CARBON IMPROVEMENT BY USE OF LEGUMINOUS PLANTS AS COVER CROPS IN AN ORGANIC OLIVE ORCHARD

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ABSTRACT

The organic olive orchard represents about 0.5 Mio ha in EU and 36% are located in Spain. This production system implies an economic opportunity for rural areas. The use of cover crops between the rows of olive trees is an agricultural practice that farmers are progressively adopting since they reduce soil erosion while improve soil quality. Due to an usual fertilisation strategy in organic farming is the use of leguminous plants, three legumes (*Vicia sativa*, *Vicia ervilia* and *Vicia villosa*) used as cover crops were compared to study their capacity to protect the soil and improve soil fertility during 4 years. Two soil managements were considered after mowing cover crops: plant residues left on surface or incorporated into the soil. Soil nitrate and coverage were monitored monthly and soil organic carbon (SOC) was analysed at the end of every growing season. Despite not being the best species to protect the soil, the coverage at the end of decomposition period increased by 32% in 4 years in the management without incorporation, providing values over 30% of cover. The soil nitrate recorded in May, when the demand for N by the olive tree is greater, increased in the study period by 70% with the residues left on surface and by 50% when the residues were buried. A carbon sequestration rate of 1.08 Mg C ha^{-1} y^{-1} was reached by *V. villosa* without incorporation. Where residues were incorporated, *V. sativa* obtained the highest carbon fixation with 1.21 Mg C ha^{-1} y^{-1}.

Keywords: *Soil protection, soil nitrogen fixation, carbon sequestration, mulching.*

INTRODUCTION

Olive orchards are currently grown in areas with Mediterranean climate covering approximately 10 Mio ha globally (FAOSTAT, 2016), mainly located in Mediterranean basin. Spain is the greatest producer country and has a surface of 2.65 Mio ha cultivated, 1.6 Mio ha located in the region of Andalusia (South Spain) (MAPAMA, 2017). This crop is not very demanding in term of soil fertility

and depth. Historically, olive orchards have occupied hilly areas with shallow soils (Taguas and Gómez, 2015). These soils are very susceptible to be degraded due to erosion, which is favoured by some inappropriate practices like the intensive tillage (Rodríguez-Entrena *et al*., 2014). Cover crops (CC) in the inter-row of olive trees have proven to be an efficient practice to reduce soil and nutrient losses (Francia *et al*., 2006; Ordóñez-Fernández *et al*., 2007).
Organic farming represents an economic opportunity for rural areas, which are generally unproductive, offering a quality product very demanded in Europe (FAO, 2000). The European organic olive orchards represent about 0.5 Mio ha of which 36% are planted in Spain (EUROSTAT, 2016). Concretely, over 75000 ha are located in Andalusia (MAGRAMA, 2016). This production system is being promoted by political plans, since it produces food of high quality respecting the environment. The use of conventional fertilisers of high solubility is limited in organic production, therefore the nutrition of plant can be a significant problem (Rodrigues *et al*., 2006). A usual fertilisation strategy in organic olive orchards is the use of leguminous plants as green manure. Legumes, through symbiosis with *Rhizobium*, can fix atmospheric N, which is incorporated into the soil improving fertility and microbial activity (Stagnari *et al*., 2017). Thus, the use of leguminous plants could reduce soil and nutrients losses (Sastre *et al*., 2017) while the olive trees are nourished by the decomposition of their residues (Rodrigues *et al*., 2013). Few studies compare between different leguminous species assessing the amount of mineral nitrogen in soil. In addition C sequestration through cover cropping has been studied in this work. The potential of CC to mitigate climatic change has been studied by some authors (Repullo-Ruibérriz de Torres *et al*., 2012) but the most of works are focus on comparing different soil managements.
Three different leguminous plants have been tested and compared to spontaneous vegetation to assess the capacity to protect the soil and improve soil nitrogen and carbon. Furthermore, two soil managements: mowing (M) and mowing plus incorporation (M+I) of residues into the soil, have been studied.

MATERIAL AND METHODS

The experiment was conducted for 4 growing seasons (2012-2013 to 2015-2016) in an organic olive orchard sited in the experimental station 'Alameda del Obispo' belonging to IFAPA (Andalusian Institute for Research and Training in Agriculture) near Guadalquivir River in Córdoba (Spain). The olive trees belong to "Picual" variety, 15 years old, and the plantation pattern is 6×5 m. Three leguminous commonly used as CC in Mediterranean areas, were sown: common vetch (*Vicia sativa* L.), bitter vetch (*Vicia ervilia* L.) and hairy vetch (*Vicia villosa* Roth.). They were studied and compared to vegetation that grew spontaneously in the field, *Medicago polymorfa*, *Bromus* sp, *Diplotaxis virgata*, *Hordeum leporinum* and *Anagallis arvensis* were identified as the most abundant species. The legumes were seeded at a rate of 200 kg ha^{-1} of cover every year in November to ensure their establishment.

The experimental design was split-split plot with five replicates. Each block included two inter-rows with the aim of comparing to soil management after the mechanical mowing of the CC. In one of the inter-rows plant residues were buried by a discs harrow pass (M+I), in the other inter-row the residues were left on the surface to decompose as mulch (M). The mowing was performed by a hammer cutter at the end of April every year.

The biomass of the CC and their residue after mowing was measured in a metal frame of 0.25 m^2 randomly placed in each subplot, which served to mark out the sampling points for soil samples. After mowing, the monitoring was just carried out in the M area. The soil cover of residues was also measured following the subjective valuation per sector method (Agrela *et al*., 2003), using a frame of 1 m^2, divided into one hundred grids. One permanent point per block and soil management was selected to assess the evolution of coverage.

The soil was sampled in one point per block and soil management at depth of 0-5, 5-10 and 10-20 cm with an Edelman auger every month. The soil samples were taken in the points selected for biomass when it was taken. In addition, core cylinders of known volume were used to measure the bulk density. The soil samples were air-dried and sieved through a 2 mm mesh sieve for their subsequent analysis. Soil nitrate was analysed monthly according to the method described by Griess-Illosvay (Bremner and Keeney, 1965) and soil organic carbon (SOC) was analysed at the end of every growing season by Walkley-Black chromic acid wet oxidation method (Sparks *et al*. 1996).

RESULTS AND DISCUSSION

The evolution of the biomass of CC was monitored every season (Fig. 1). In the developing stage the growth of plants was similar in M and M+I managements. After mowing, the decomposition period only was able to be studied in M system, since the residues were buried in the other management. The decomposition pattern was similar for all leguminous species. However, the spontaneous vegetation had smaller amount of biomass except in the last season. Due to the soil had been managed without weeds before the beginning of the experiment, the seed bank was scarce in this treatment. In the last season, the subplots of spontaneous vegetation obtained a large amount of biomass, which was greater than *V. sativa* and *V. ervilia*. Another leguminous plant, *Medicago polymorfa*, was the most abundant species of the spontaneous flora. It was the treatment with the highest amount of residue at the end of the decomposition period in the last season (Fig. 1). This is a critical point since the risk of erosion increases with the intensive rainfall events in autumn. From an environmental point of view, the selection of a cover crop that maintains the soil protected at that period until the growth of CC in the new season is critical (Rodríguez-Lizana *et al*., 2018). The maintenance of cover is the most effective way to protect the soil against erosion. The table 1 shows the percentage of cover in the M system from mowing to the end of decomposition period.

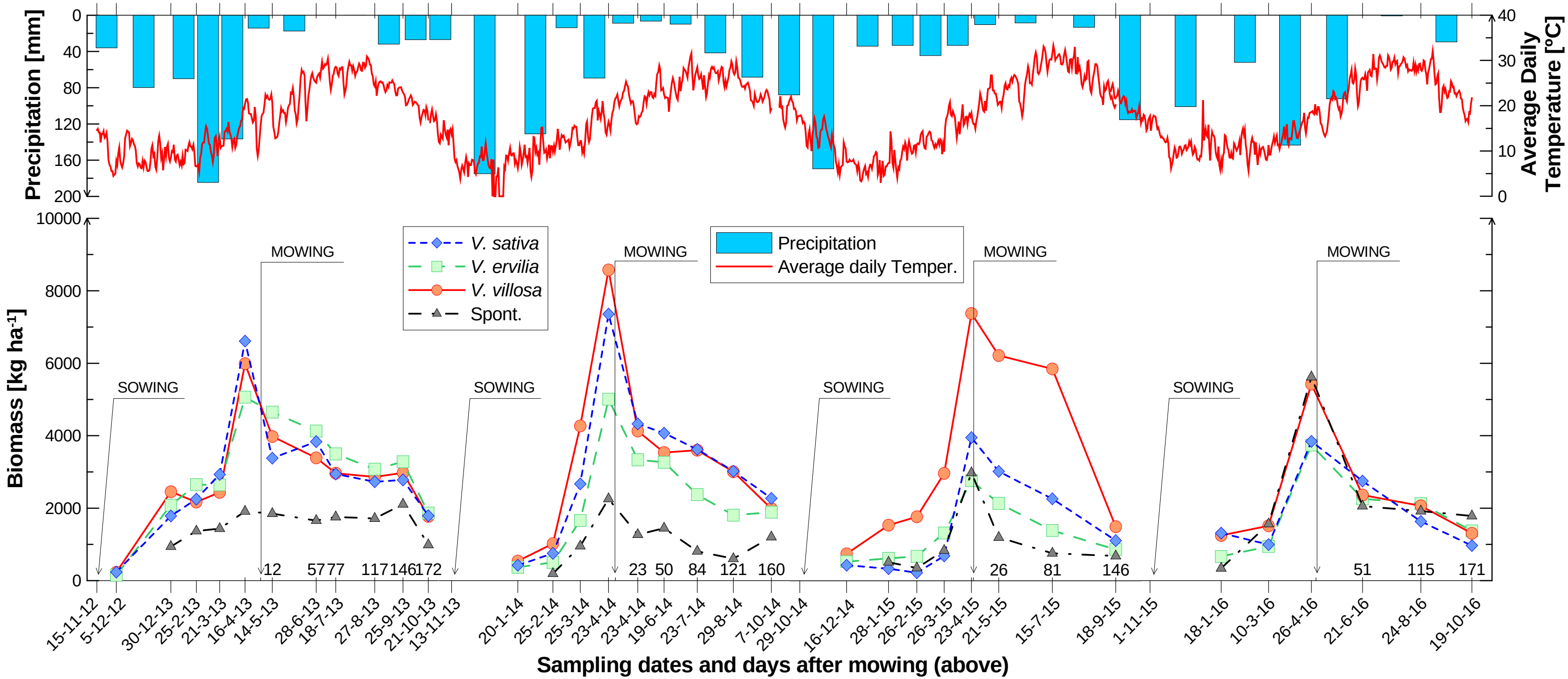

Fig. 1. Evolution of CC biomass and residue after mowing of CC during 4-season study period. The average of both soil managements (M and M+I) is represented before mowing, after mowing, M system is represented. Average daily temperature and precipitation between sampling dates is also shown.

Table 1. Cover of the studied CC after mowing (M management). Different letters indicate significant differences according to LSD test ($P \leq 0.05$). DAM: Days After Mowing.

Season	Date	DAM	*V. sativa*	*V. ervilia*	*V. villosa*	Spont.
1	14/05/2013	12	89.6 a	87.0 a	86.2 a	59.6 b
	28/06/2013	57	86.8 a	83.4 a	82.8 a	51.4 b
	18/07/2013	77	82.2 a	75.6 a	78.8 a	48.2 b
	27/08/2013	117	75.6 a	70.8 a	75.0 a	44.0 b
	25/09/2013	146	49.4 a	46.6 a	47.6 a	36.4 a
	21/10/2013	172	36.8 a	35.2 a	30.4 a	25.0 a
2	23/05/2014	23	91.6 a	88.4 a	92.2 a	38.2 b
	19/06/2014	50	84.8 a	70.6 a	85.2 a	27.4 b
	23/07/2014	84	83.6 a	61.4 bc	73.6 ab	30.8 c
	29/08/2014	121	76.4 a	52.4 b	69.2 ab	25.4 c
	07/10/2014	160	59.4 a	36.0 bc	58.0 ab	28.0 c
3	21/05/2015	26	88.8 ab	85.2 b	98.4 a	57.6 c
	15/07/2015	81	59.4 b	51.2 b	84.4 a	37.2 c
	18/09/2015	146	49.4 a	33.8 b	62.8 a	22.0 b
4	21/06/2016	51	62.4 ab	64.0 ab	69.6 a	48.2 b
	24/08/2016	115	61.8 a	65.0 a	61.4 a	57.4 a
	19/10/2016	171	39.0 b	57.0 a	44.2 b	42.2 b

V. villosa was the species with the highest amount of biomass in the second and third seasons. In the last season, *V. ervilia* was not established properly and this treatment was composed partially by spontaneous vegetation, which had a slower decomposition than legumes due to the low C:N ratio (Quemada, 2004). Other species commonly used as CC such as grasses or crucifers are more suitable for erosion control since they have lower decomposition rate than legumes (Repullo-Ruibérriz de Torres *et al*., 2012). However, the cover at the end of decomposition period provided values over 30%, threshold internationally considered in conservation agriculture (González-Sánchez *et al.*, 2015). In average, all treatments increased the cover at the end of decomposition period in the last season with regard to the first one (Table 1). Legumes are mainly recommended for improving soil fertility either in M or M+I systems. When the residues are buried, the decomposition is faster due to soil moisture and the metabolic activity of soil microorganisms (Gómez-Muñoz *et al.*, 2014). In this experiment, soil nitrate was usually greater in M+I than in M management during the study period. Table 2. indicates the soil nitrate concentration at May of every year, since spring is considered the period when the demand for N by tree is greater.

Table 2. Soil nitrate (kg ha^{-1}) at the several depths studied in the month of May every season.

		Mowing				Mowing + Incorporation			
Season	Depth (cm)	*V. sativa*	*V. ervilia*	*V. villosa*	Spont.	*V. sativa*	*V. ervilia*	*V. villosa*	Spont.
1	0-5	17.67	18.43	27.46	2.90	8.94	8.57	11.64	6.04
	5-10	8.29	7.63	12.15	2.94	7.20	9.47	9.45	7.48
	10-20	5.90	10.16	15.06	3.52	12.55	18.77	13.94	8.74
	0-20	31.87	36.22	54.66	9.36	28.69	36.80	35.03	22.26
2	0-5	21.42	67.32	82.03	11.60	72.07	24.54	114.45	12.99
	5-10	18.37	17.93	66.49	11.04	76.17	25.88	170.01	14.04
	10-20	26.29	29.41	36.23	17.63	122.26	51.77	222.88	22.72
	0-20	66.07	114.67	184.75	40.27	270.50	102.20	507.34	49.75
3	0-5	2.82	3.01	24.48	2.41	1.97	4.54	14.06	2.96
	5-10	2.71	3.42	16.87	2.61	2.45	4.63	15.98	2.71
	10-20	4.35	3.70	22.98	4.31	3.74	6.25	25.17	3.70
	0-20	9.89	10.12	64.33	9.33	8.17	15.42	55.21	9.37
4	0-5	65.20	27.59	92.21	53.95	21.73	19.80	37.06	23.70
	5-10	28.29	13.76	23.06	27.57	16.60	15.48	27.04	9.78
	10-20	39.64	14.55	43.27	24.36	19.31	26.36	33.78	17.17
	0-20	133.13	55.90	158.54	105.87	57.64	61.64	97.88	50.66

In the first season, similar nitrate values were obtained between management systems except for spontaneous vegetation that was higher in M+I. In the second season, the CC had a good development and more biomass was obtained. This led to obtain better increment of soil nitrate, mainly in M+I. *V. villosa* reached over 500 kg nitrate per ha in the first 20 cm in that season. In the third season, lower concentrations were obtained due to a worse growing of CC in the developing stage, although *V. villosa* provided a great amount of soil nitrate in both managements. M was the best management systems in term of soil N in the last season. It was due probably to the precipitation recorded between May, which was scarce in the other seasons. The soil unprotected in M+I facilitated the lixiviation of nitrates in comparison to M system. In all cases *V. villosa* was the species that produced the greatest amount of biomass and provided the highest soil nitrate concentration. Regarding SOC, all seeded CC increased the SOC in the first 20 cm (Table 3). However, the tillage performed at sowing every year produced C emissions, the low biomass reached by spontaneous vegetation in both management, was not enough to improve the SOC in this treatment along the study period. The highest carbon sequestration rate was reached by *V. villosa* without incorporation. Nevertheless, where residues were incorporated, *V. sativa* obtained the highest carbon fixation with 1.21 Mg C ha^{-1} y^{-1}.

Table 3. SOC fixation in 4-season study and annual fixation for that period.

	Mowing		Mowing + Incorporation	
Species	SOC fixation (4 seasons)	Annual SOC fixation	SOC fixation (4 seasons)	Annual SOC fixation
	kg ha^{-1}	*Mg ha^{-1} yr^{-1}*	*kg ha^{-1}*	*Mg ha^{-1} yr^{-1}*
V. sativa	2264.1	0.57	4857.1	1.21
V. ervilia	790.3	0.20	1408.9	0.35
V. villosa	4327.6	1.08	2035.0	0.51
Spont.	-772.0	-0.19	-1937.4	-0.48

CONCLUSIONS

Legumes CC are useful to improve soil fertility through increments in nitrate and SOC. The M+I management system accelerated the supply of soil nitrate by residue, but M soil management maintained the soil covered and protected from erosion for a longer period. The use of CC allows obtaining agronomic and environmental benefits which is an opportunity for organic farming.

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