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Cover Crop Contributions to Improve the Soil Nitrogen and Carbon Sequestration in Almond Orchards (SW Spain)

Miguel A. Repullo-Ruibérriz de Torres [1], Manuel Moreno-García [1], Rafaela Ordóñez-Fernández [1], Antonio Rodríguez-Lizana [2], Belén Cárceles Rodríguez [3], Iván Francisco García-Tejero [4,*], Víctor Hugo Durán Zuazo [3] and Rosa M. Carbonell-Bojollo [1]

[1] IFAPA Centro "Alameda del Obispo", Av. Menéndez Pidal s/n, Apdo. 3092, 14080 Córdoba, Spain; mangel.repullo@juntadeandalucia.es (M.A.R.-R.d.T.); manuel.moreno.garcia@juntadeandalucia.es (M.M.-G.); rafaelam.ordonez@juntadeandalucia.es (R.O.-F.); rosam.carbonell@juntadeandalucia.es (R.M.C.-B.)
[2] Department of Aerospace Engineering and Fluid Mechanics, Area of Agroforestry Engineering. Ctra. de Utrera, km. 1, University of Seville, 41013 Seville, Spain; arodriguez2@us.es
[3] IFAPA Centro "Camino de Purchil", Camino de Purchil s/n, 18004 Granada, Spain; belen.carceles@juntadeandalucia.es (B.C.R.); victorh.duran@juntadeandalucia.es (V.H.D.Z.)
[4] IFAPA Centro "Las Torres", Carretera Sevilla-Alcalá del Río km 12,2, 41200 Alcalá del Río, Spain
* Correspondence: ivanf.garcia@juntadeandalucia.es

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Abstract: Almond (*Prunus dulcis* Mill. [D.A. Webb]) is the third most widely spread crop in Spain and has traditionally been cultivated in marginal areas and shallow soils under rainfed conditions. However, it recently has been progressively introduced in flat irrigated areas. The implementation of cover crops in the inter-rows of woody crops has been proven as a suitable strategy to reduce the runoff and soil erosion but they also can boost soil quality and health. A field experiment was conducted during two-monitoring seasons to examine the soil nitrogen and carbon sequestration potential of three seeded cover crops [barley (*Hordeum vulgare* L.), hairy vetch (*Vicia villosa* Roth), and a mixture of 65% barley and 35% vetch] and a control of spontaneous flora in irrigated almond orchards (SW Spain). Here, we show that barley provided the highest biomass amount, followed by mixture covers, vetch, and the control treatment. Also, vetch covered the soil faster in the growing stage, but its residues were decomposed easier than barley and mixture treatments during the decomposition period after mowing, providing less soil protection when the risk of water erosion with autumn rainfall is high. On the other hand, vetch improved soil nitrate content by over 35% with respect to barley and mixture treatments at 0–20 cm soil depth throughout the studied period. In addition, a greater carbon input to the soil was determined in the barley plot. That is, the mixture and barley cover crops had higher potential for carbon sequestration, augmenting the soil organic carbon by more than 1.0 Mg ha^{-1} during the study period. Thus, taking into consideration the findings of the present experiment, the establishment of a seeded cover crop would be more advisable than spontaneous flora to mitigate soil erosion, enhancing soil fertility and carbon sequestration in irrigated almond plantations in Mediterranean semi-arid regions.

Keywords: *Hordeum vulgare*; *Vicia villosa*; soil fertility; soil erosion; soil organic carbon; woody crops

1. Introduction

Almond (*Prunus dulcis* Mill. [D.A. Webb]) is the third most widely spread perennial crop in Spain, after olive and vineyard [1]. Traditionally, this crop has been related to marginal rainfed areas due to its drought tolerance and was cultivated in shallow soils where an appropriate soil management is a key factor for soil conservation [2–4]. However, an important increase in the area dedicated to almond cultivation was evident in the last years, particularly in irrigated zones where fertile soils are commonly occupied by other crops [5].

Conventional tillage is the common soil management system used in most almond orchards; however, this practice is becoming less commonly applied because of its great impact on soil quality [6,7]. In the long-term, tillage promotes the compaction of the soil and the formation of a ploughing layer [8] and favors the exhaustion of the soil organic matter, which causes the degradation of the soil [9]. The effects of tillage accumulate progressively over the years and create soils that are considerably more susceptible to crusting and sealing, and provoke the progressive compaction of the soil, which implies a reduction in the infiltration and hydraulic conductivity of the soil and an increase in water erosion risk [10]. In this context, the implementation of sustainable soil conservation measures is vital to improve or maintain its productivity, especially in changing climate conditions [11]. In general, cover crops (CC) are able to supply multiple ecosystem services and their agronomic and environmental benefits are singularly dependent on a specific site. That is, CC play an increasingly important role in improving soil quality, reducing agricultural inputs and enhancing environmental sustainability [12,13]. In rainfed almond orchards, plenty of benefits can come from cover cropping such as water erosion control, soil quality improvements, ecosystem services, encouragement of native pollinators, and honeybee health, among others [14–16]. In addition, there has been renewed interest in the last few years in cover cropping in irrigated orchard systems [17], as a strategy linked to sustainable agricultural intensification and as a response to climate change scenarios and natural resources preservation.

The implementation of CC is considered to be the best way to increase organic carbon (C) stocks in agricultural soils [18], since more C and nitrogen (N) are added to the soil pools by its decay residues [19,20]. In this context, CC have proven to be efficient tool for C sequestration in Mediterranean fruit crops cultivated in slopes such as olive [21,22], almond [23], and vineyard slopes [24,25].

In relation to type of cover crops, the legume species tend to be commonly used, since their seeds are easily available and they are not hosts of pests and diseases. That is, legumes have clear benefits due to their ability to fix atmospheric N, thus decreasing the need for external fertilizers and improving the productivity of subsequent crops [26–28]. In contrast, gramineous plants tend to be mainly used as CC due to their good soil protection [29]. In the case of barley, its life cycle is not very long and it provides high soil coverage with excessive biomass that can compete with almond trees. Moreover, grasses are easily controlled by mechanical or chemical mowing [30,31]. As an intermediate option, the grass-legume combinations are less common; their management and effects under irrigated systems have not been very extensively studied. In this context, Pedraza et al. [32] reported that the combination of narbon bean (*Vicia narbonensis* L.) and black oat (*Avena strigosa* L.) are a viable and profitable option in rainfed cropping systems.

In addition, it is crucial to consider the importance of an appropriate soil management, especially under the current (and future) scenarios of climate change [33]. In this context, several works have been published in relation to the use of different land cover types for woody crops, and the advantages of these kinds of practices in slopes provided by avoiding the soil erosion and improving the soil water retention [34], as well as improving the physico-chemical properties of soils and its biodiversity [8,35–37].

In almond orchards, Ramos et al. [14,38] studied oat-vetch mixture with a forage approach. Ruffo and Bolero [39] outlined the decomposition process of grass-legume combination, concluding that the decomposition dynamics of hairy vetch residue are a potential source of N, while the decomposition dynamics of rye are more useful in soil conservation.

Taking the previous findings and the importance of proper cover management for irrigated woody crops into consideration, the objective of this study was to compare the effect of different seeded cover crops [barley (*Hordeum vulgare* L.), hairy vetch (*Vicia villosa* Roth), and a mixture of 65% barley and 35% vetch] and a control of spontaneous flora on soil N and C sequestration potential in irrigated almond orchards in a semiarid Mediterranean environment.

2. Materials and Methods

2.1. Location and Experimental Design

The field experiment was conducted during two growing seasons (2016/2017–2017/2018) in an irrigated almond orchard located in IFAPA (Andalusian Institute for Research and Training in Agriculture, Fishing and Food) 'Alameda del Obispo' Experimental Station in Cordoba (SW Spain) (37°51′48″ N; 4°47′29″ W).

Meteorological data during the study period were collected from a weather station sited near the experimental orchard. The soil of the experimental plot was classified as *Entisol* group *Xerofluvent* subgroup *Typic* [40], and some of its main properties are shown in Table 1.

Table 1. Main soil physico-chemical properties of the experimental plot.

Depth	pH	pH	SOC	NO_3^-	P	K
(cm)	(H_2O)	($CaCl_2$)	(%)		(mg kg^{-1})	
0–5	8.63	7.80	0.92	47.78	11.55	309.10
5–10	8.64	7.82	0.88	37.54	8.83	246.35
10–20	8.66	7.84	0.71	26.09	6.22	174.47
20–40	8.63	7.86	0.65	22.89	5.22	119.63
40–60	8.70	7.88	0.50	20.44	5.87	88.93
Depth	**CO_3^{-2}**	**CEC**	**Sand**	**Silt**	**Clay**	**Textural class**
(cm)	**(%)**	**(meq 100 g^{-1})**		**(%)**		
0–5	18.02	14.13	41.57	40.32	18.12	Loam
5–10	17.07	14.43	43.18	38.86	17.96	Loam
10–20	17.04	15.33	43.65	36.94	19.42	Loam
20–40	17.42	14.43	43.02	37.14	19.84	Loam
40–60	18.10	14.60	44.60	37.08	18.33	Loam

SOC, soil organic carbon; NO_3^-, nitrate; P, Olsen's extractable phosphorus; K, available potassium; CO_3^{-2}, carbonates; CEC, cation exchange capacity.

The planting grid of 7 × 6 m involved drip irrigated almond trees cv. "Guara" 10 years old (Figure 1). The three types of seeded CC were as follows: (1) barley grass (*Hordeum vulgare* L.); (2) hairy vetch legume (*Vicia villosa* Roth); and (3) a mixture of both (65% barley + 35% vetch), and were compared with natural flora that grew spontaneously in the plot, which was considered as the control treatment. The experimental design was a randomized complete block with three replications per CC and the single plot consisted of two inter-rows with the distance between 3 trees in a row (12 m) and 3.5 m CC strip width.

Figure 1. Experimental plot during almond flowering (February 2017).

To ensure the establishment of studied cover plants, 200 kg ha^{-1} of seeds was planted (Table 2), reaching on average a plant density of 451, 439, and 435 plants m^{-2} of vetch, barley, and mixture, respectively. Before sowing, the soil was tilled with a disk harrow pass to homogenize the plot. The weeds were controlled with pre-emergence herbicide before the experiment started.

Table 2. Theorical and final plant density.

Plant Cover		Seed Weight	SD	Theoretical PD	Emergence	Real PD
		(g per 1000 Seeds)	(kg ha^{-1})	(Seeds m^{-2})	(%)	(Plants m^{-2})
Vetch		42.1	200	475.06	95	451.31
Barley		38.70	200	516.80	85	439.28
Mixture	Vetch (35%)	42.1	70	166.27	90	149.64
	Barley (65%)	38.7	130	335.92	85	285.53

PD, plant density; SD, seed density.

At the end of April—beginning of May, the CC were removed with a flail mower in order to avoid competition by the water uptake with the main crop. The weeds in the almond trees row strip (3.5 m wide) were controlled by systemic herbicide (glyphosate 36%).

2.2. Field and Laboratory Measurements

The measurements of the percentage biomass and residue cover that protect the soil was estimated with a metal frame of 0.25 m^2 randomly placed, which served to mark out the sampling point for soil samples. In each replication, four biomass samples were taken, and once we had mowed the decomposition of residues, these samples were monitored. Additionally, the cover percentage was measured following the subjective valuation per sector method developed by Agrela et al. [41] using a frame of 1 m^2, divided into hundred grids. The method consists of evaluating the different cover percentages estimated in each of the grids on a scale of 0–5, thus obtaining a value matrix and a final cover percentage. Every growing season, the coverage was estimated in the same four points selected per block.

The collected biomass samples were washed with distilled water to prevent contamination in the subsequent analysis. Then, they were placed in an oven at 65 °C until they reached a constant weight to estimate the dry matter. The N and C contents were measured in a LECO elemental analyzer (TRUSPEC, CNS; St. Joseph, MI, USA).

Soil samples were taken at 0–5, 5–10, and 10–20 cm with an Edelman auger and then air-dried and sieved through a 2-mm mesh sieve for their subsequent analysis. Soil cylinder cores with known volumes were taken in order to measure the bulk density. Soil nitrate determination was carried out by extraction with KCl and subsequent measurement with colored complex in a UV–vis spectrophotometer was conducted according to a method described by Griess–Illosvay [42]. The C sequestration capacity of plant cover treatments caused by the soil organic carbon (SOC) content was analyzed by the Walkley-Black method [43]. The volumetric technique was used, in which a 2-mm sieved dry soil sample (0.5 g) is oxidized by a potassium dichromate (10 mL) and sulfuric acid (20 mL) solution. The generated heat in the acid dilution was used while 200 mL of distilled water was added to chill the solution. Then orthophosphoric acid (15 mL) and diphenylamine (0.5%) were added as indicators. A blank with the reagents indicated above without a soil sample was also prepared. The organic carbon was determined by titrating the volume of dichromate that is not reduced in a ferrous sulfate solution (1M), which turned to bright green after violet blue.

2.3. Statistical Analysis

Analysis of variance (ANOVA) was performed in order to ascertain whether differences in biomass production, soil cover, soil nitrate, and C sequestration existed among the different plant-cover treatments for each sampling date. Subsequent comparison of means was carried out by the Fishers Least Significant Difference (LSD) test ($p \leq 0.05$). Previously, the homogeneity of variance, the random distribution of residuals, and the normal distribution of errors were tested. Angular data transformations were conducted for the data expressed as percentages (soil cover).

3. Results and Discussion

The rainfall and temperature parameters during the study period are shown in Figure 2. The precipitation amount recorded in each growing season was similar to the average of the last years (≈600 mm), with 550 mm throughout the first hydrological year (2016/2017) and 600 mm during the second (2017/2018).

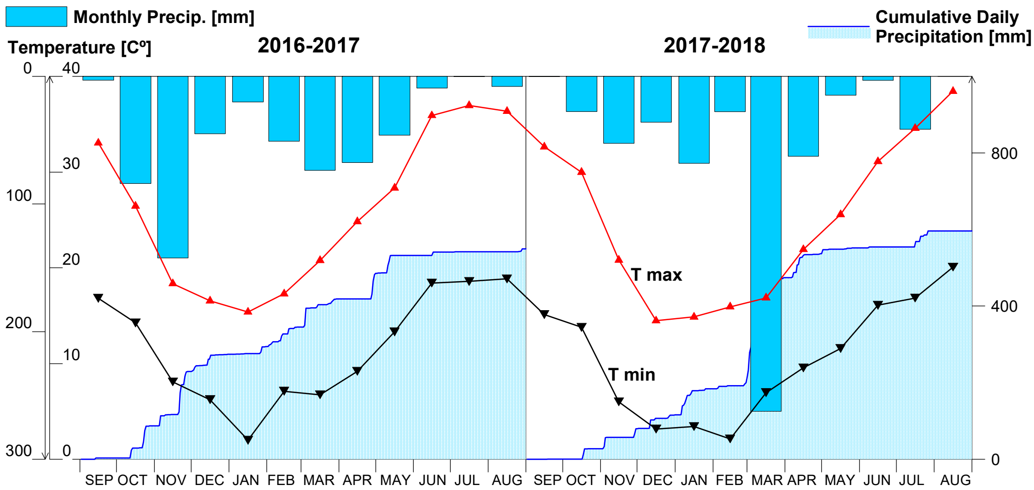

Figure 2. Monthly average of maximum and minimum temperature, monthly precipitation, and annual cumulative precipitation during the two-monitoring seasons.

Although the total annual precipitation amount was the same as for a standard year in the study area, but different patterns were observed, a 270 mm in autumn and 131 mm in winter during the first season, and conversely 107 and 350 mm in autumn and winter during the second season, respectively. Therefore, the higher precipitation in autumn 2016 and the lower oscillation between maximum and minimum temperatures could encourage the growth of plant covers in their first stage of its development.

The total volume of irrigation for the first and second seasons was 764 and 772 mm, and the almond yield was 2725 and 2639 kg ha^{-1}, respectively, without significant differences between the soil management strategies (Table 3). Thus, during the first season (2016/2017), the average yields in the plots with vetch, barley, mixture, and the control were 2868, 2630, 2808, and 2594 kg ha^{-1}, respectively, whereas during the following season, these final yields were 2761, 2606, 2666, and 2523 kg ha^{-1}. Although these values did not offer differences between the considered soil management strategies, the most remarkable result was the slight improvements observed with the covers of vetch and mixture, in comparison to the control treatment.

Table 3. Almond production per cover crop and season.

Season	*Vicia villosa*	*Hordeum vulgare*	Mixture	Control	Average
			(kg ha^{-1} of Kernel)		
2016/17	2868	2630	2808	2594	2725.1
2017/18	2761	2606	2666	2523	2639.4

3.1. Biomass and Soil Covering Potential by Plant Covers

The vetch plants had an earlier development than barley, but the latter produced a higher biomass before mowing, particularly during the first season. The mixture treatment (65% barley + 35% vetch) provided intermediary results in the first season (Figure 3). However, the biomass of mixture cover in the second season reached statistically similar values to those fixed by barley. In the second season, all seeded plant covers grew to a lesser extent, as fertilizers were not spread on the soil and almond trees were nourished by fertigation.

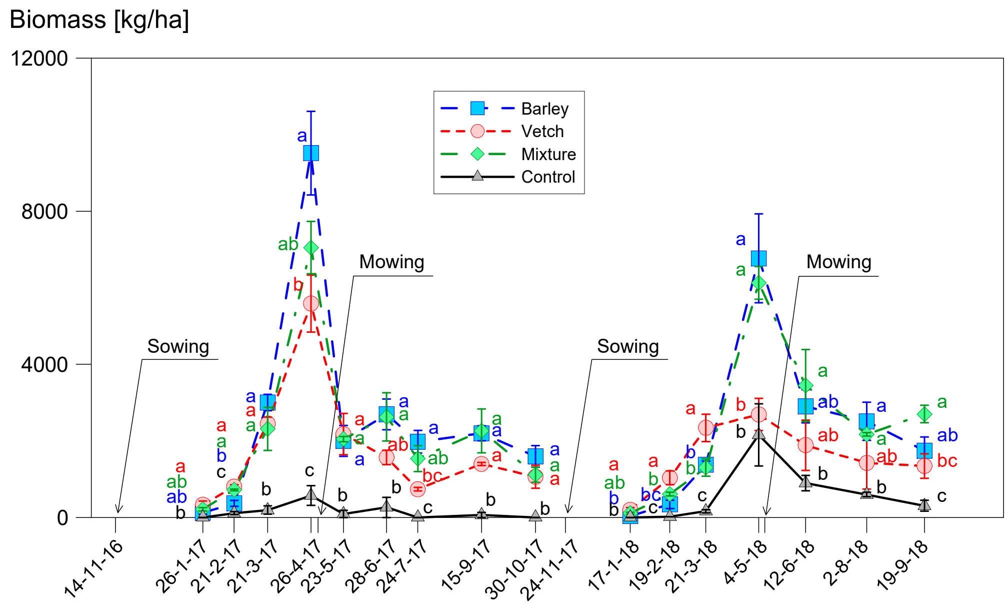

Figure 3. Biomass production of plant covers for each treatment during the two-monitoring seasons. Vertical bars represent standard error. Different letters in each sampling date are statically different based on the LSD test ($p \leq 0.05$). X units follows the format DD-MM-YY.

Our findings are in line with Finney et al. [44], who monitored the behavior of 18 types of CC during two years, stating that non-legume CC can increase biomass in a greater extent than legume CC. Comparable, Ramos et al. [38] determined the biomass of oat, common vetch, and a mixture of oat-vetch as CC in almond orchards, reporting that the mixture with a very low proportion of vetch had similar yield than those found with single oat cover. Additionally, Assefa and Ledin [45] and Tuna and Orak [46] yielded higher biomass from mixture (oat-vetch) cover than apart by plant species.

In relation to control plot with cover of spontaneous plants the biomass production was quite low during the monitoring period especially during the first season. This fact presumably was due to the absence of seed bank leaving the soil with scarce coverage and protection. Throughout the first season only some moss grew and in the second season species such as *Diplotaxis* spp. and *Spegularia rubra* emerged. These results agreed with those pointed out by Ramos et al. [38], who found very low weed incidence for all treatments and years. In the same way, Aznar-Sánchez et al. [47] claimed that spontaneous plant covers usually produce less biomass than sown plant covers. In our study the control cover treatment provided the lowest biomass values in the developing stage as well as in the decomposition period (after mowing). In this context, according to Travlos et al. [48] the soil temperature and soil water potential can exert a great influence on emergence and composition of the weed flora in cultivated areas.

3.2. Potential Soil Covered by Cover Crops

A fast increase of the percentage of soil covered was denoted for all cover crop treatments during the developing stage in contrast to the decomposition period, when degradation of plant residues was more gradual as well as less uniform. Being the legume-based cover with less high and more creeping covered the soil faster during first stages compared with remaining cover treatments (Figure 4). However, after mowing vetch showed the lowest biomass amount and soil covered than the seeded covers, protecting the soil in a lesser degree at the end of the decomposition period, and just before the sowing period of the following season. Although there was no statistical differences with barley and mixture treatments at this stage during the second season as shown in Figure 4. In this context, the soil covered is extremely important for protection against rainfall impact and the reduction of runoff and soil erosion [49,50].

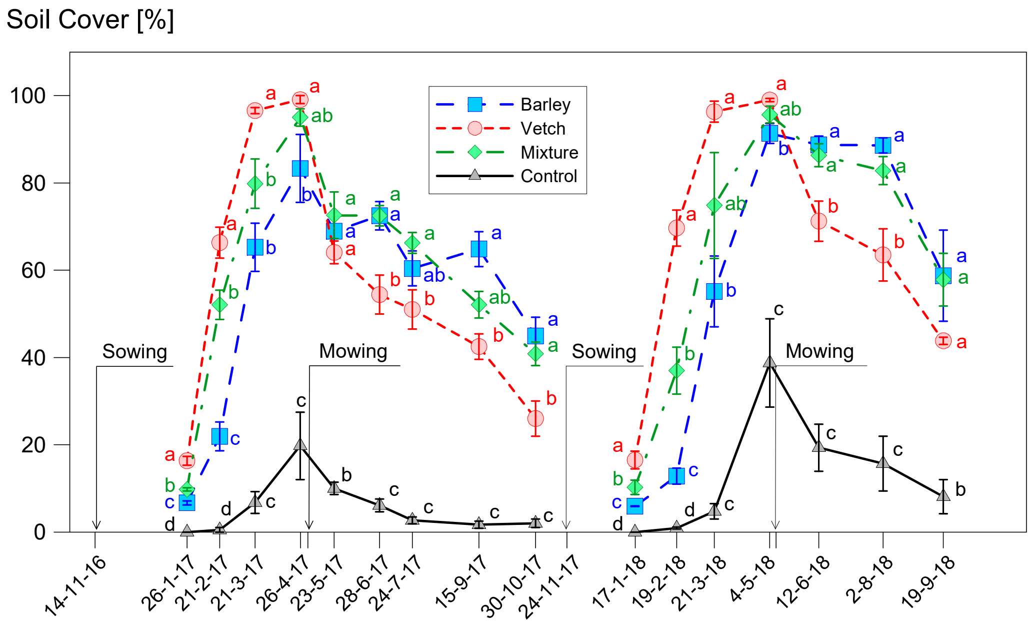

Figure 4. Degree of soil covered by cover crop treatments during the study period. Vertical bars represent standard error. Different letters in each measuring date are statically different based on the Least Significant Difference (LSD) test ($p \leq 0.05$). X units follows the format DD-MM-YY.

At the end of the decomposition period in the first season, the legume and control treatments ended up with a cover degree lower than 30%, which was the standard value established in conservation agriculture as a threshold value to maintain the soil protection [51]. That is, the end of decomposition period is a critical stage where protection provided by CC might be scarce and there is a high erosion risk due to autumn rainfalls, as was pointed out by Rodríguez–Lizana et al. [52]. Consequently, the use of plant species that maintain an appropriate degree of protection until the sowing of the next growing season is recommended. This is the case for the barley and mixture that maintained soil cover higher than 40% and 50% in the first and second seasons, respectively (Figure 4).

A study by Ramírez–García et al. [29] comparing the degree of soil protection provided by different CC indicated that leguminous plants need more development time than grasses or cruciferous to reach a soil covered percentage of 30%. In this context, Sastre et al. [53] studying different CC in olive orchard obtained greater annual soil loss rates with legume-based cover than with grasses.

The faster that CC residues are decomposed by soil microorganisms, the greater the likelihood that surface coverage will drop below the 30% threshold needed for erosion control. That is, the quality of plant residues is usually associated with two factors: the time it lasts to protect the soil and maintain its physical properties, and the supply of C and mineral elements from its decomposition into the soil. These two aspects are influenced by both climate and the residue's composition, as was stated by Thorburn et al. [54].

3.3. Cover Crops and Soil Fertility

The mineralization of residues from different CC started after mowing. The soil nitrate content was increased at the topsoil layer (0–5 cm) during the decomposition period, reaching a peak in July of the first season (Figure 5). The legume-based treatment provided the best results, increasing the soil nitrate by more than the remaining cover treatments. The mixture treatment obtained intermediate values at the peak of the first season while barley and control plots provided similar increases. However, non-significant differences were found in some sampling dates due to the high variability, as shown by the relative size of the error bars in Figure 5.

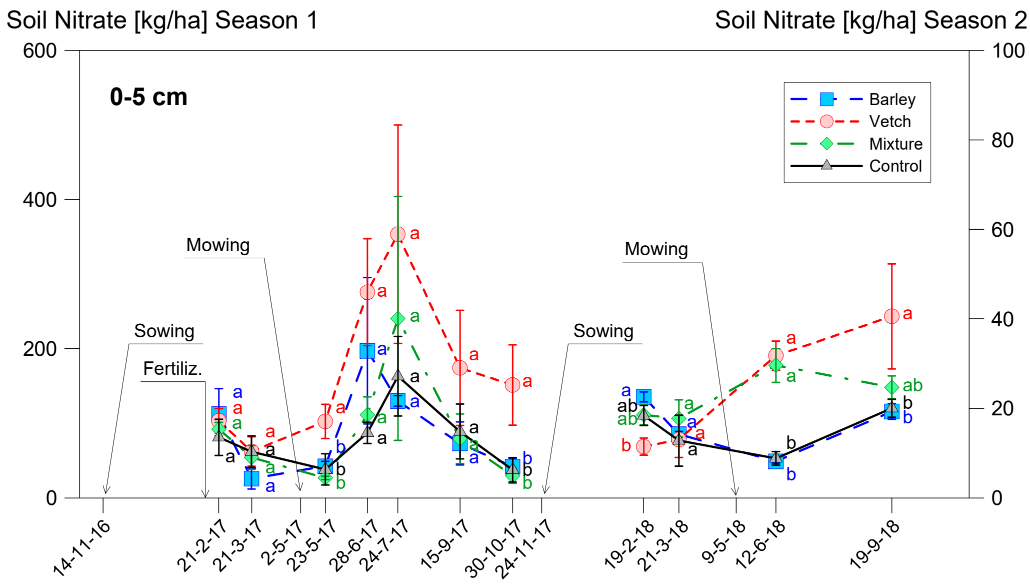

Figure 5. Soil nitrate content at 0–5 cm soil depth during the two-monitoring seasons. Vertical bars represent standard error. Different letters in each measuring date are statically different based on the LSD test ($p \leq 0.05$). X units follows the format DD-MM-YY.

In the next second season, only vetch and mixture levels augmented the soil nitrate contents after mowing, although barley and control plots enhanced them later. At the end of the decomposition period, the vetch plot showed the highest value for both seasons and the mixture plot recorded intermediate outcomes between the vetch and the others in the second year at 0–5 cm soil depth (Figure 5). Due to the fact that mineral fertilizers were not spread on the soil and fertigation in almond tree row was the only incorporation system in the second season, soil nitrate in the inter-rows was lower than in the first season. For this reason, the data of each season have been represented at different soil depths in order to clearly compare the impact of CC treatments. Figure 6 displays the soil nitrate content at 0–20 cm soil depth registering a similar trend as 0–5 cm soil depth, but more statistical differences were found in June of the second season, with rates for mixture treatment between vetch and barley. Conversely, more statistically homogeneous nitrate levels were fixed at the end of the second season.

In accordance with Wang et al. [55] in addition to erosion protections of CC, they can improve soil fertility through nutrient release during the decomposition of their residues, thereby fostering soil quality and health. Moreover, Gómez–Muñoz et al. [56] by comparing the ruderal flora and legume cover in olive orchards highlighted the importance of plant cover for retaining nutrients when tree demand was low but releasing them in early spring when tree demand is high, particularly when residues were incorporated into the soil.

Overall, the soil nitrate dynamic was similar in the four plant cover treatments, since nitrate was extracted by plants from soil and stored in their tissues, preventing lixiviation and after mowing, the N was released during the decomposition period. In this context, Abdalla et al. [57] performed a systematic analysis to investigate the impact of different forms of CC (legume, non-legume, and legume and non-legume mixtures) on NO_3 leaching from soils, demonstrating a significant cost reduction by the implementing of this strategy. In addition, Rodríguez–Lizana et al. [20] using different CC in olive orchard claimed that throughout the decomposition cycles, the C, N, and P release accounted from 40 to 58% of the C, N, and P amounts in the residues after mowing.

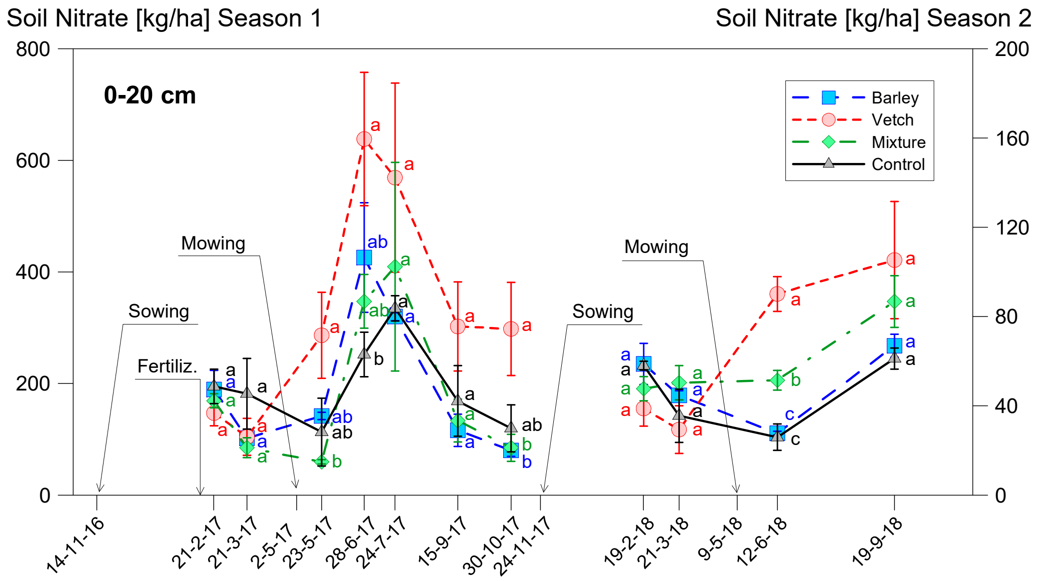

Figure 6. Soil nitrate content at 0–20 cm soil depth during the two-monitoring seasons. Vertical bars represent standard error. Different letters in each measuring date are statically different based on the LSD test ($p \leq 0.05$). X units follows the format DD-MM-YY.

In particular, for the legume-based cover, the release was greater after mowing, since on average vetch plants were 14% higher in terms of N biomass than barley (Figure 6). This fact supports the higher nitrate content that was determined in vetch plots at both studied soil depths (0–5 and 0–20 cm). That is, on average the vetch provided over 35% more soil nitrate than barley and mixture covers. Some studies analyzed the role of CC in terms of soil fertility, highlighting the importance of the legume to be sown, since the different species differ in their capacity to fix N and its content in biomass at level of stems and root [58,59], and consequently in the ability to contribute N to the main crop.

Our findings coincide with those found by Pastor et al. [60], who monitored the behavior of spontaneous and legume covers in an organic olive orchard and vineyard during a 10-year study period. These authors determined a progressive increase in soil C and N with legume-based cover crops, recommending their establishment in autumn and winter. In this context, Ordóñez–Fernández et al. [28] studied the impact of common vetch (*Vicia sativa* L.), bitter vetch (*Vicia ervilia* L.), chickling vetch (*Lathyrus sativus* L.), and hairy vetch (*Vicia villosa* Roth) covers on soil nitrate and compared with a control of spontaneous vegetation cover in organic olive orchards. According to this study, all sown legume-based covers enhanced the soil N levels with respect to spontaneous vegetation; *Vicia ervilia* particularly that promoted the highest increase of the soil nitrate content. Gómez–Muñoz et al. [56] determined the spring to be the period with the maximum olive tree demand for plant nutrients. Their findings were similar to those found in our experiment, although they obtained the highest rate of soil N availability in that period, while in our case higher concentrations were denoted in summer (first season) and at the end of the cover in the crops decomposition stage (second season).

3.4. Soil Organic Carbon

Figure 7 shows the soil organic carbon content by effect of studied plant covers in the present experiment. In general, the organic matter was increased by C released from the residue decomposition. Concretely, barley treatment with a higher biomass amount increased the maximum development (before mowing) than other plant cover treatments, providing greater C input into the soil.

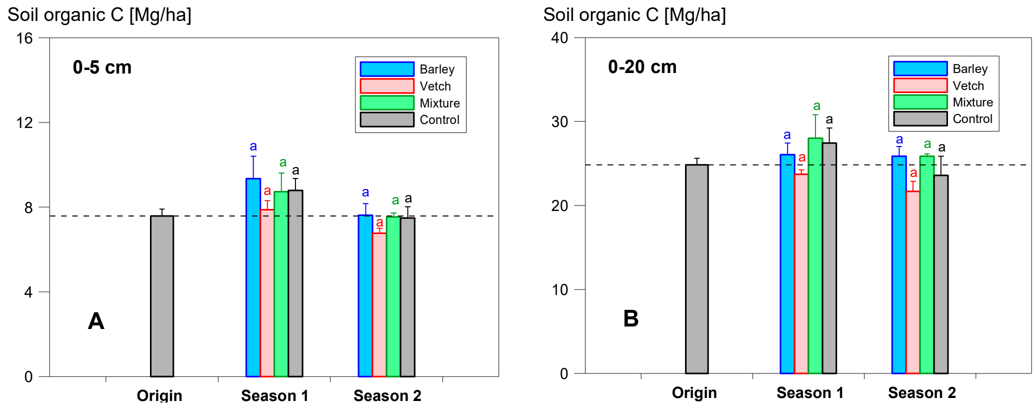

Figure 7. Soil organic carbon at the beginning and the end of the experiment during the study period at 0–5 cm (**A**) and 0–20 cm soil depth (**B**). Vertical bars represent standard error. Different letters in each season are statically different based on the LSD test ($p \leq 0.05$). X units follows the format DD-MM-YY.

An increasing trend for SOC at topsoil horizon (0–5 cm) in the first season was determined and a decreasing in the second season, which continued lessening until similar values than those registered at the beginning of the experiment (Figure 7A). However, considering the entire 0–20 cm soil depth, the SOC in both barley and mixture plots reached more than 1.0 Mg ha^{-1} during the two-year monitoring seasons, in spite of not being found significant differences between plant cover treatments (Figure 7B). According to these results, annual rates of 0.5 Mg SOC ha^{-1} yr^{-1} could be assumed, representing a higher C sequestration annual rate than that proposed by "4 per Mille" initiative [61]. In this agreement, this arrangement was adopted at the COP21 with the aim of increasing the soil organic matter by 0.4% per year in order to mitigate the global emissions of greenhouses gases caused by human activities. Regarding the control plots, the biomass provided by the spontaneous vegetation was statistically similar to the remaining treatments. The absence of differences between treatments could be explained by different reasons. Thus, the lack of statistical differences shows that at least for a two-year monitoring period, it is difficult to reach relevant differences in terms of SOC (as has been observed in the present work). Hence, long-term experiences would be needed in order to verify any trends in organic C.

On the other hand, the soil tillage through disk harrow performed in order to bury the cover crop residues before the sowing of the next growing season implied to augment CO_2 emissions and SOC oxidation.

Fruit orchards such as olive, almond, and vineyards can increase SOC by the implementation of CC [62]. Analogously, Olson et al. [63] confirmed the positive effect of CC on soil properties and SOC rates compared to for soils without them. The results of meta-analysis made by Poeplau and Don [18] determined that the CC in rotation up to 54 years were linearly correlated with soil depth at 22 cm and annual SOC change at the rate of 0.32 Mg ha^{-1} yr^{-1}. In this context, Ramos et al. [14] in almond orchards (SE Spain) throughout a five-year monitoring period registered an increase of 2.16 Mg C ha^{-1} yr^{-1} in the soil seeded with oat respect to the tillage system without cover crop, and 1.80 Mg C ha^{-1} yr^{-1} for oat-vetch mixture at 0–20 cm soil depth.

Additionally, Almagro et al. [64] assessed the effects of different soil management practices on dynamic organic carbon in organic rainfed almond orchards for 4 years, stating an increase of 0.52 Mg C ha^{-1} yr^{-1} with spontaneous CC with respect to reduced tillage. Vicente–Vicente et al. [62] evaluated the effects of recommended soil management practices, revealing an enhancement of 2.04 Mg C ha^{-1} yr^{-1} caused by the implementation of CC for conventional systems in almond orchards, with this value being higher than those reported for olive and vineyard.

Figure 8 displays the C/N ratio of CC in the last sampling date before the mowing and the dynamics of this process during the decomposition period during the first season. A key role of the C/N ratio has to be taken into consideration in this process that determines how easily residue can decompose. According to our findings, a linear increase of the C/N ratio for all CC treatments since the first residue sampling was determined after mowing. Barley cover values ranged from 24 to 32 and for mixture cover treatment from 18 to 33, contrasting with vetch cover that recorded always lower values from 11.5 to 19 throughout the decomposition period. In relation to control treatment, the generated residues were very low due to the lower biomass production and in some cases, there were not enough samples to be analyzed. Occasionally the plant species that grew in the control plots were spontaneous legumes that made the C/N ratio even lower than those registered in the remaining treatments. The lack of residue data from control plots affected the ANOVA, as it could not provide significant differences between the control and the different cover crops studied in this experience. Likewise, even assuming a wide data variability and taking into consideration the average values obtained in each sampling date, we could corroborate relevant increases of C/N when Barley, Vetch, or a mixture of them both, which were introduced as cover crops.

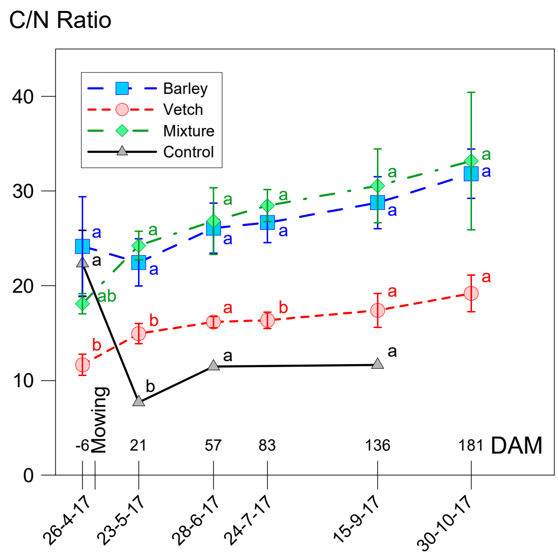

Figure 8. The C/N ratio dynamics throughout the decomposition process during the first season. Vertical bars represent standard error. Different letters in each measuring date are statically different based on the LSD test ($p \leq 0.05$). No biomass samples from control plots in July and the last sampling date. DAM, days after mowing. X units follows the format DD-MM-YY.

The lower C/N ratio of residues from vetch covers in relation to grass covers has been claimed to occur by Repullo–Ruibérriz de Torres et al. [21]. Thus, the grass residues that are poor in N with a high C/N ratio decompose and release plant nutrients slowly. By contrast, legume residues which are rich in N have a low C/N ratio, decompose quickly, and supply plant nutrients during the early stages of the crop [65]. In addition, Aulakh et al. [66] reported the great influence of soil moisture during the first stages of residue decomposition process, specifically on with those residues with a low C/N ratio, as is the case for legume-based covers.

4. Conclusions

The effects of different cover crops (barley, vetch, mixture, and spontaneous flora) on soil fertility were assessed in this experiment. Overall, the implanted cover crops (barley, vetch, and mixture) had a high potential to protect the soil and increase soil organic carbon, making them a good strategy to be implemented in irrigated almond orchards. In this context, the first remarkable step would be the absence of significant differences in terms of yield, which would justify the introduction of these strategies to enhance the soil fertility without affecting the final yield (because of higher crop water requirements).

Relating to biomass production, barley and mixture would offer the best results, especially when comparing to the control. Moreover, the percentage of soil cover was especially improved under the three studied covers, avoiding of the development of the soil erosion process.

Relating to the soil fertility in terms of soil nitrate, the best results were observed for the case of vetch. Thus, although this treatment did not contribute the greatest amount of carbon to the soil, its ability to fix nitrogen could lead to an overall savings in fertilizer N for almond production.

Moreover, the cover crops based on grasses (barley and mixture) provided higher biomass than legumes, encouraging an increase in SOC. However, the mixture cover treatment was able to augment the SOC to be similar than the rates found for barley, as well as to enable it to provide soil protection. Likewise, additional long-term experiments should be taken into account in order to corroborate these positive trends for barley and mixture cover crops.

Finally, the scarce studies in relation to the benefits of cover crops in irrigated almond orchards highlight the convenience of including this topic in research and developing experiments under different edaphoclimatic conditions.

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