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Long-Term Effects of No-Tillage on Arthropod Biodiversity in Rainfed and Irrigated Annual Crops

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Abstract: Numerous studies show that tillage has a negative impact on the future sustainability of annual crops. Possible negative effects include the loss of arthropod biodiversity on the soil surface. In this context, a comparative study was carried out between tillage and no-tillage plots after four years of differentiated management. Research was carried out on a rotation of rainfed annual crops and on an irrigated maize monoculture. It was found that no-tillage of annual crops was beneficial in increasing the overall diversity and abundance of arthropod species. The dominance of three orders of arthropods on the surface of annual crops was confirmed, corresponding to the increased presence of morphospecies and individual beetles, ants and spiders. In rainfed crops, a significant increase in morphospecies was observed in no-tillage (19.5) compared to conventional tillage (16.2). In irrigated crops, the average abundance of arthropods in no-tillage (96.7) was significantly higher than in conventional tillage (57.8). Arthropod diversity on the soil surface was mainly influenced by the management system used (tillage or no-tillage), followed by soil carbon content and irrigation (irrigation or no irrigation).

Keywords: no-tillage; Conservation Agriculture; arthropods; biodiversity

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1. Introduction

Technological developments in agriculture in recent decades have led to an intensification of land use [1]. One of the main negative effects of agricultural intensification is the reduction of soil biodiversity [2]. Although there is a part of soil biodiversity that lives on the soil surface, called epigeal fauna, there is also soil fauna that lives in deeper layers, such as worms, nematodes and red spiders. Arthropods are the most abundant and diverse components of the epigeal fauna in agricultural environments [3]. This group includes mainly insects and arachnids but also some crustaceans and myriapods.

The loss of biodiversity of the soil fauna community leads to the disappearance of ecosystem services [4]. In general, a rich and diverse epigeal arthropod fauna is a source of ecosystem services provided to the agricultural sector [5]. Among their benefits, the maintenance of ecosystem stability stands out, with a direct impact on the reduction of pest pressure, the decomposition of organic matter, and the provision of nutrients to other living organisms [6].

In order to halt the loss of epigeal fauna biodiversity that is occurring in agricultural areas [7], it is necessary to implement sustainable agronomic practices that promote minimal soil disturbance [8], as outlined in Conservation Agriculture (CA). One of the practices included in CA is no-tillage (NT), which is an agricultural practice based on the suppression of tillage in annual crops. In NT, crop residues from the previous harvest are left on the soil, keeping at least more than 30% of the soil surface covered [9]. The suppression of the impact of machinery on the soil and the distribution of crop residues on the surface lead to an increase in soil organic carbon (SOC) concentrations [10]. In addition to minimising soil disturbance, CA principles also require farmers to diversify crops and maintain a permanent soil cover [11].

The introduction of NT has been observed to result in an increase in SOC, which in turn is linked to an increase in soil organic matter. This leads to greater biodiversity compared to conventional tillage (CT) [12–14]. Studies on SOC concentration and biodiversity show a correlation between SOC concentration and biodiversity abundance [15,16]. In addition to its crucial role in maintaining soil fertility and biodiversity, SOC concentration is an important sink for atmospheric CO_2 [17]. In fact, the promotion of practices to increase SOC levels has become one of the most important climate change mitigation tools [18].

Regarding the effect of NT on the total arthropod community, biodiversity studies are usually based on indices that show the quantitative differences between communities of crops under NT and CT. The most common indices are those proposed by Shannon [19,20] and Simpson [21]. Many studies show a beneficial effect of NT on soil surface arthropod biodiversity, but there are also studies with opposite results. In this sense, Adams et al. [22] concluded that the high abundance of individuals of certain species decreased the Shannon index in NT compared to CT. This may be attributed to the fact that the value of these indices increases as the ratio between the number of species and the number of individuals increases. On the other hand, if the study is based on the influence of NT on populations or species diversity [23,24], the results are much more clearly in favour of NT.

In addition to studies on the effects of NT on arthropod biodiversity, there are numerous studies that conducted research on its effects at a taxonomic level. In general, NT has been shown to have a positive effect on beetle populations. In studies on herbaceous crops, Shearin et al. [25] calculated a 50% reduction in the activity of beetles under tillage conditions compared to NT conditions, while Marasas et al. [26] observed population increases in carabids and staphylinids in untilled soils. On the contrary, the intensification of agricultural practices seems to have a negative impact on *Coleoptera* biodiversity [27]. Regarding coleopteran biodiversity indices, the results of two studies showed a significant increase in the Shannon index with NT compared to CT [28,29]. NT seems to have a very positive effect on soil beetles [20,23,30–35], although the number of individuals was lower under NT in two rotations studied in the USA [21,36].

For ants, the main group of *Hymenoptera* living on the soil surface, the effect of NT does not seem to be so clear. Although there are studies showing an increase in their populations under NT [23,37,38], others show better results in tilled soils [39]. Campos et al. [39] attribute the higher number of individuals trapped in tillage systems to the greater effort required by ants to find food in bare soil without ground cover. Therefore, the ants have to move more and longer distances, which increases the probability of being captured.

Arachnids are the soil surface predators that benefit most from NT measures [14,37]. According to Rodríguez et al. [14] and Blanchart et al. [37], the increase in their biodiversity may be due to the absence of mechanical ploughing and the abundance of crop residues on the soil. The increase in their populations is more than evident in other studies [20,23], which show that there are six times more spider populations under NT than under CT. Other studies show results with population increases ranging from 50 to 150% [21,31–33].

To our knowledge, no studies have yet compared the effect of NT and CT under irrigation and rainfed conditions on arthropod biodiversity, especially in Southern Spain. Rodríguez et al. [14] performed their trials comparing NT and CT in a Mediterranean climate in Northern Spain, but they compared irrigation systems and did not study rainfed conditions. Likewise, Pérez-Fuertes et al. [40] studied the effect of irrigation and rainfed condition on arthropods communities in fields from Northern Spain without comparing soil management systems. Furthermore, this research considers the factor of crop rotation. Crop diversification and rotation promote biodiversity and populations of pests' natural enemies for arthropods [41], but the comparison of NT systems and irrigation has not been performed in the study area.

The overall objective of this study is to demonstrate the positive influence of NT on the biodiversity of epigeal fauna in a Mediterranean climate. Specifically, this study examines the effect of NT versus CT in crops under rainfed and irrigated conditions during four seasons in two farms in Southern Spain. In addition, this study considers the effect of the following factors: soil management (NT–CT), irrigation–no irrigation, and the amount of SOC in relation to the abundance of the different orders captured. In this case, the aim was to determine how these factors influence the diversity of morphospecies within each order of arthropods on the soil surface. As a result of these tests, it was also possible to determine the SOC storage capacity that NT can achieve compared to CT in dryland and irrigated areas.

2. Materials and Methods

This study of arthropod biodiversity was carried out in 2 farms located near the city of Cordoba (Spain) (Figure 1). Specifically, it was conducted in Rabanales, at coordinates 37°55′53″ N, 4°43′04″ W, and Alameda del Obispo, at 37°51′47″ N, 4°47′28″ W. One of the farms (the University of Cordoba Rabanales farm) is an annual crop farm with a dryland rotation (Cereal-Sunflower-Leguminous-Cereal), while the other (IFAPA's Alameda del Obispo farm) is a farm cultivated with irrigated corn. On each of the two farms, two study plots were implemented, one of them with NT and the other one under CT.

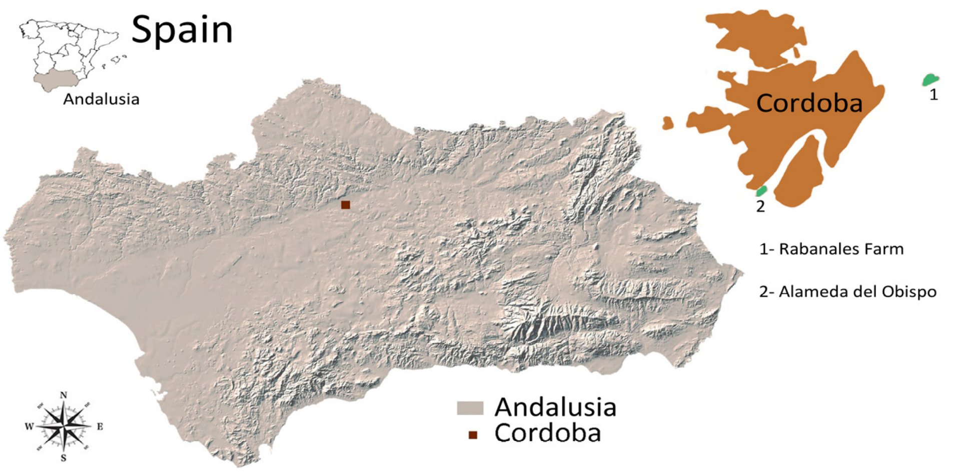

Figure 1. Locations of the studied farms.

In both farms, the study started with an original surface managed under CT. The differential management between NT and CT was maintained for 4 years. Specifically, it was maintained from 2010–2011 to 2013–2014 in Rabanales and from 2015–2016 to 2018–2019 in Alameda del Obispo. A meteorological station is situated in Alameda del Obispo (37°51′26″ N, 4°48′10″ W). It is equipped with sensors to measure air temperature (HMP45A probe, Vaisala) and rainfall (tipping-bucket rain gauge, ARG 100). For each meteorological variable, half-hourly and daily averages are recorded. Figures 2 and 3 describe the evolution of precipitation and air temperature during the years of crop development. The prevailing climate in Cordoba is typically Mediterranean, characterised by very hot summers and a lack of rain.

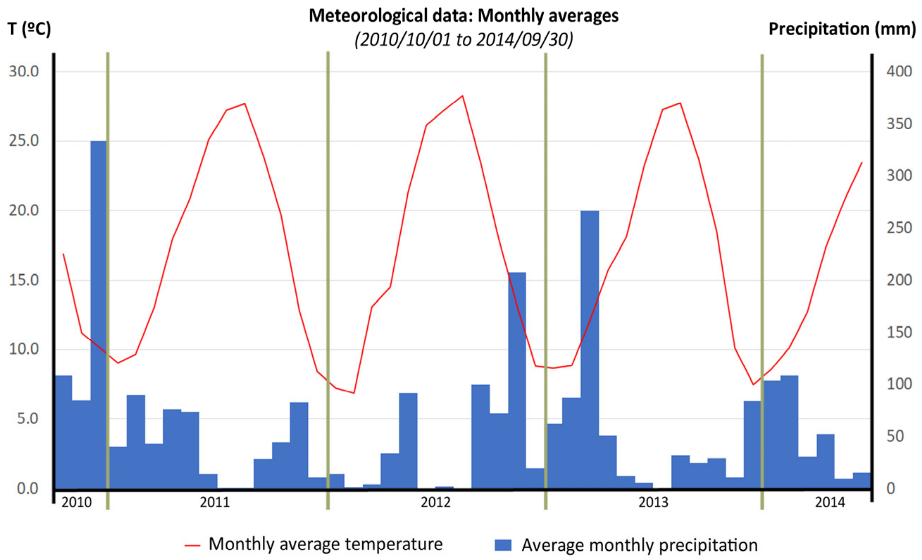

Figure 2. Monthly precipitation and average monthly temperature in Cordoba during the 2010–2011 to 2013–2014 agricultural seasons.

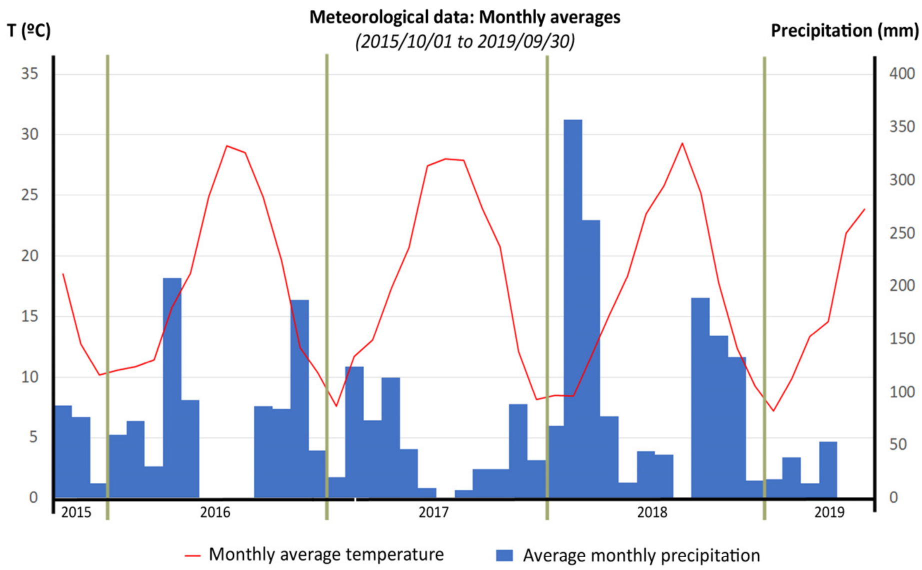

Figure 3. Monthly precipitation and average monthly temperature in Cordoba during the 2015–2016 to 2018–2019 agricultural seasons.

Table 1 shows the main soil characteristics of the farms where the study was carried out. The soil samples were analysed at the Soil Laboratory of the Alameda del Obispo Centre in Cordoba. This research centre belongs to the Institute for Agricultural Research and Training (IFAPA) of the Regional Ministry of Agriculture. In the Rabanales farm, the soil has a neutral pH with some basicity and a medium content of organic matter (OM). The clay fraction is slightly predominant in its textural composition. In the Alameda del Obispo farm, the soil has a basic pH, with low OM content and a textural composition in which the sand fraction predominates.

Table 1. Main characteristics of the soil in the Rabanales and Alameda del Obispo farms.

RABANALES											
Depth	**pH H_2O**	**pH $CaCl_2$**	**P**	**K**	**OC**	**OM**	**CO_3^{2-}**	**CEC**	**SAND**	**SILT**	**CLAY**
cm	-		mg/kg			%		meq/100 gr		%	
0–20	7.72	7.16	13.22	262.68	1.66	2.85	11.04	24.04	30.68	32.13	37.19
20–40	7.79	7.17	10.88	188.96	1.34	2.26	12.61	27.13	30.95	30.84	38.21
40–60	7.96	7.28	8.07	164.04	1.06	1.79	15.18	27.18	28.34	30.85	40.81
ALAMEDA DEL OBISPO											
Depth	**pH H_2O**	**pH $CaCl_2$**	**P**	**K**	**OC**	**OM**	**CO_3^{2-}**	**CEC**	**SAND**	**SILT**	**CLAY**
cm	-		mg/kg			%		meq/100 gr		%	
0–20	8.60	7.74	7.90	186.62	0.42	0.71	19.18	11.73	49.23	34.89	15.88
20–40	8.68	7.84	4.55	97.28	0.29	0.49	21.07	11.37	49.39	34.65	15.96
40–60	8.72	7.83	4.11	103.20	0.25	0.42	20.13	10.79	51.56	34.23	14.22

P: available Phosphorus; K: exchangeable Potassium; OC: organic carbon; OM: organic matter; and CEC: cation exchange capacity.

Four years after the start of the study, 2 sampling seasons of epigeous arthropods were carried out. They were carried out in May and June 2014 on the Rabanales farm and in May and June 2019 on Alameda del Obispo farm. In each of these farms, two plots were created, one under NT and the other under CT (Figure 4). In each plot, 6 sampling units were established, equidistantly distributed throughout the plot. Each sampling unit consisted of 4 pitfall traps (plastic cups with preservative liquid placed at ground level) placed in a straight line and separated by 1 metre (a, b, c and d). As preservative liquid, 40 mL of ethylene glycol diluted in 10% water was poured into each of the traps [42]. After 72 h, the traps were removed. The individuals captured in the 4 pitfall traps corresponding to the same sampling unit were collected in the same jar for subsequent global analysis in the laboratory.

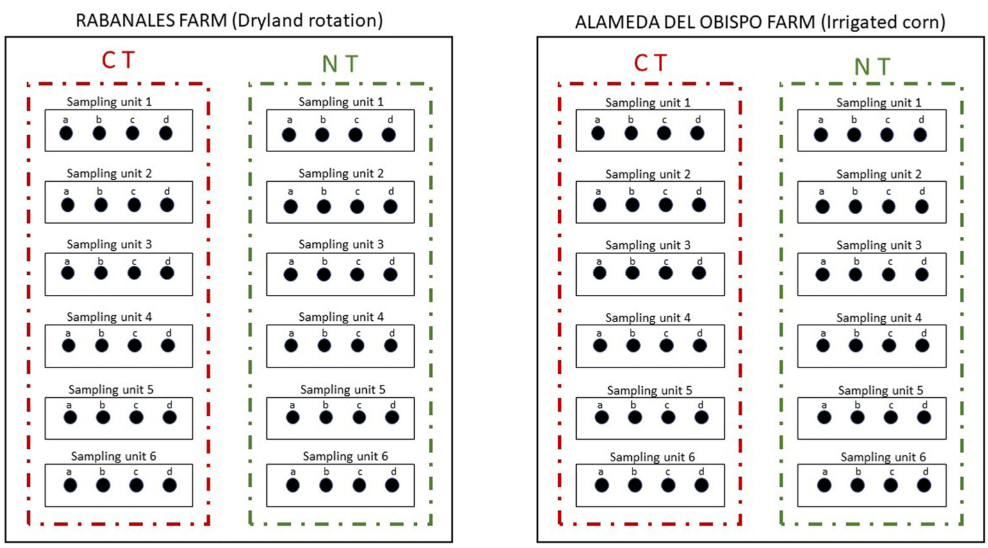

Figure 4. Sampling model followed to capture arthropod specimens.

On arrival at the laboratory, the samples were filtered through a 2 mm mesh sieve. The arthropods retained on the sieve were visually inspected and separated by morphospecies. In other words, individuals with a similar appearance were catalogued within the same morphospecies. Once the number of morphospecies and the number of individuals were quantified for each sample unit, a calculation of biodiversity was made using the Shannon Biodiversity Index (Equation (1)).

Equation (1). Shannon Biodiversity Index.

$$H = \sum[(pi) \times \ln(pi)] \quad (1)$$

where *pi* = the proportion of the number of individuals of each species over the total number of individuals captured in the sampling unit.

The different morphospecies of each order captured in each sampling unit were quantified to determine how NT affects the biodiversity of a particular order. In the same way, we calculated the number of specimens in each order to understand the effect of this agronomic practice on the abundance of each order.

In order to observe the statistical significance of the results, an analysis of variance was carried out using Statistix 9 software (Analytical Software). Subsequently, the least significant differences (LSD) test was conducted at $p \leq 0.05$ to verify the existence of significant differences between the biodiversity results obtained under NT and CT. Specifically, we used the results obtained in May and June on each farm and worked with their average data.

To assess the level of soil organic carbon (SOC) present at the study sites, samples were taken at three different soil depths (0–5, 5–10 and 10–20 cm) in each sampling unit of each treatment and farm. In the soil laboratory of Alameda del Obispo, the SOC content of these samples was analysed through the method of oxidation in acid medium with dichromate described by Walkley-Black [43]. In the case of the arthropods, the results were compared to identify the degree of SOC increase under NT with respect to CT.

In order to study the influence of the factors of management, irrigation, and SOC content, it is necessary to consider the possible correlations between variables. For this purpose, a correlation matrix was created using Pearson's correlation coefficient [44]. Taking into account the correlation results between the variables, a principal components study was carried out, which helped to analyse how each factor affected the richness of the morphospecies of the different orders that occurred during the sampling seasons. For the correlation analysis, the sampling data from the Rabanales and Alameda del Obispo farms were studied together.

3. Results

The yield in both experimental farms for each season was recorded. The results differed based on the soil management systems used on rainfed crop rotation and an irrigated monoculture. On average, the yield in the rainfed farm with the crop rotation cereal-sunflower-legume-cereal was 21% higher under NT (1.98 t/ha) than CT (1.57 t/ha). However, in the irrigated corn, the CT system was on average 12% higher than the NT system (11.37 t/ha CT vs. 10.01 t/ha NT). Nevertheless, given the variability of data, no statistically significant differences were identified between management systems on either farm.

The average number of arthropod morphospecies per sampling unit was significantly higher in the NT soil compared to the CT soil on the rainfed farm (Rabanales) (Figure 5). Specifically, the average number of morphospecies in the NT was 19.5 compared to 16.2 in the CT. On the other hand, when looking at the total number of individuals in the rainfed farm, there were more individuals in the CT soil than in the NT soil. An average of 10 more individuals per sample unit appeared in the tillage, 72.0 individuals compared to 62.2. With regard to the study of the Shannon Biodiversity Index, the results obtained are similar to those observed for morphospecies, with better results obtained in the NT than in the CT soil, although in this case without significant differences. Specifically, the value of the Shannon Biodiversity Index in the rainfed areas was 2.16 in the NT compared to 2.01 in the CT.

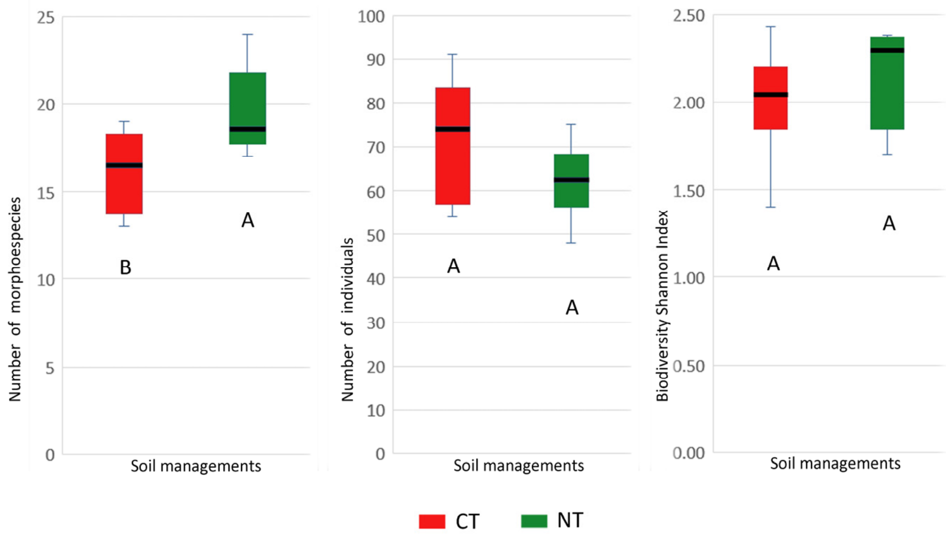

Figure 5. Average number of morphospecies, average abundance of individuals, and average number of the Shannon Biodiversity Index, per sampling unit on the Rabanales farm (rainfed rotation). The letters show significant differences between different crop management systems on each farm. LSD test at $p \leq 0.05$.

For the Alameda del Obispo farm with irrigated maize, in contrast to what was found in Rabanales, lower data on species diversity were observed. In terms of the comparison of the biodiversity found under the different management systems, the values of morphospecies recorded were 12.7 in the NT and 10.7 in the CT (Figure 6), although the statistical analysis did not show significant differences. On the contrary, significant differences were found in the abundance of arthropods, where 50% more individuals were found in the NT (96.7) compared to the CT (57.8) soil. The Shannon Biodiversity Index for irrigated crops was 1.56 in the NT and only 1.47 in the CT. Similar to the findings on the morphospecies, the results also showed higher biodiversity values on the rainfed farm than on the irrigated farm. The average number of arthropod captures was similar in the rainfed and irrigated areas, around 70–80 individuals per sample unit, but with a higher abundance under CT in the rainfed farm and under NT in the irrigated farm.

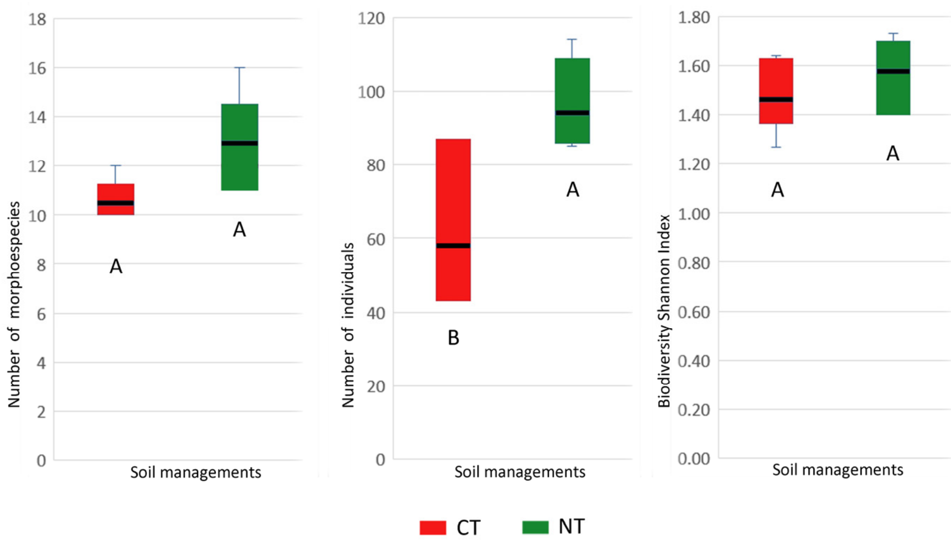

Figure 6. Average number of morphospecies, average abundance of individuals, and average number of the Shannon Biodiversity Index, per sampling unit on the Alameda del Obispo farm (irrigated corn). The letters show significant differences between different management systems for each farm. LSD test at $p \leq 0.05$.

Looking at the different orders in detail, *Coleoptera* (beetles) were found to be the order with the greatest diversity of morphospecies in the soil on the dryland and irrigated farms. Beyond *Coleoptera*, the richness of the morphospecies of *Hymenoptera* (ants) and *Araneae* (spiders) is also important. The comparison between the different soil management systems within the different orders of the rainfed crop rotation made it possible to identify differences between agricultural practices (NT vs. CT).

In the rainfed plots (Rabanales) (Figure 7), a greater number of *Coleoptera* morphospecies were observed in the NT soil (6.8 on average) than in CT soil (6.0 on average), although without significant differences. *Hymenoptera* capture data show even smaller differences between the management systems, with 3.8 ant morphospecies in the NT soil and 3.7 in the CT soil. Finally, spider captures, although without significant results, showed a greater number of morphospecies in the NT soil (4.7) compared to the CT soil (3.7).

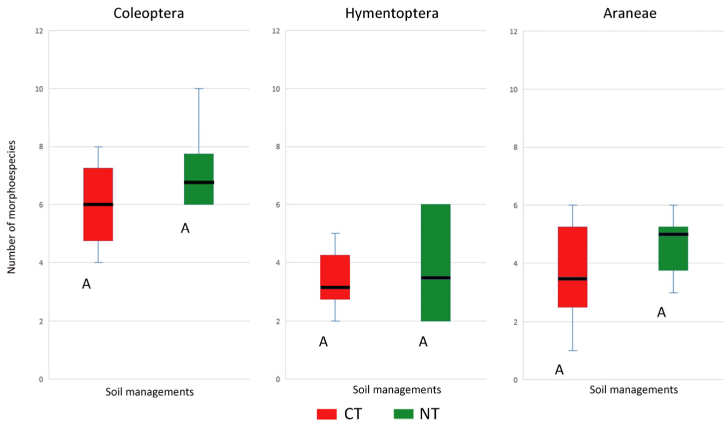

Figure 7. The average number of morphospecies per sampling unit in each management system (CT and NT) of *Coleoptera* (beetles), *Hymenoptera* (ants), and *Araneae* (spiders) on the Rabanales farm (dryland). The letters show significant differences between different management systems for each order. LSD test at $p \leq 0.05$.

The study of the abundance of individuals of the orders *Coleoptera*, *Hymenoptera*, and *Araneae* on the Rabanales farm (Figure 8) did not show any significant results regarding the effects of NT on their populations. Even in the case of ants, the number of individuals was reduced when the land was left unploughed. The opposite was true for spiders, where the population increased by more than 25% on average. Therefore, the positive effect of NT on the overall diversity of arthropods does not apply to all orders.

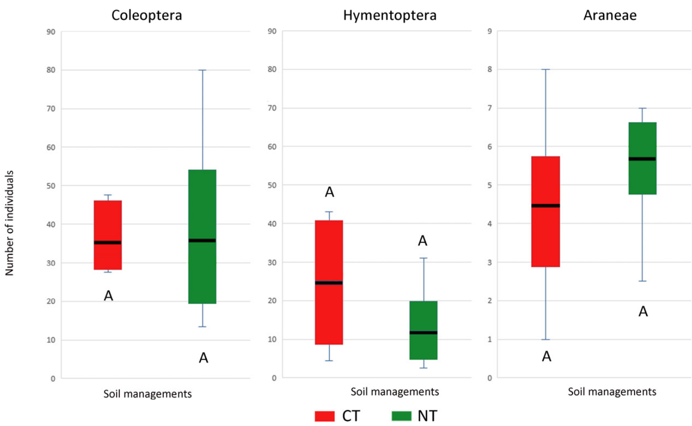

Figure 8. Average number of individuals of *Coleoptera* (beetles), *Hymenoptera* (ants), and *Araneae* (spiders) per sampling unit under each management system (CT and NT) on the Rabanales farm (rainfed). The letters show significant differences between different management systems for each order. LSD test at $p \leq 0.05$.

In the irrigated farm (Alameda del Obispo) (Figure 9), the average number of beetle morphospecies was higher in the NT soil (4.0) than in the CT soil (3.7), but without significant differences. For Hymenoptera, the average number of ant morphospecies in the NT soil was 3.5 compared to 2.3 in the CT soil, with significant differences. Finally, for spiders, the situation was reversed, with more morphospecies observed in the CT soil (3.2) than in the NT soil (2.8).

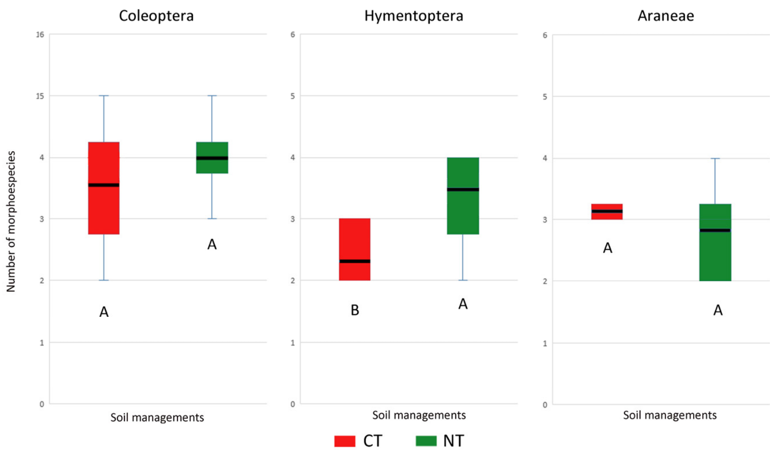

Figure 9. Mean number of morphospecies per sampling unit according to the management system (CT and NT) in *Coleoptera* (beetles), *Hymenoptera* (ants), and *Araneae* (spiders) on the Alameda del Obispo farm (irrigated). The letters show significant differences between different management systems for each order. LSD test at $p \leq 0.05$.

The individual study of the average population of the three orders best represented on the Alameda del Obispo farm (Figure 10) shows that, in the case of beetles and ants, the four-year NT management system has significantly improved their populations. The data are statistically significant for both orders. For beetles, populations ranged from an average of 10 individuals in the CT soil to 16 in the NT soil. For ants, the increase was 43.7 in the CT soil and 71.6 in NT soil. On the other hand, the case of spiders breaks this trend, and the number of individuals in the untilled plot was reduced, with statistically significant data in relation to the CT plot. This showed a decrease from an average of 5.9 individuals in the CT soil to 3.3 in the NT soil.

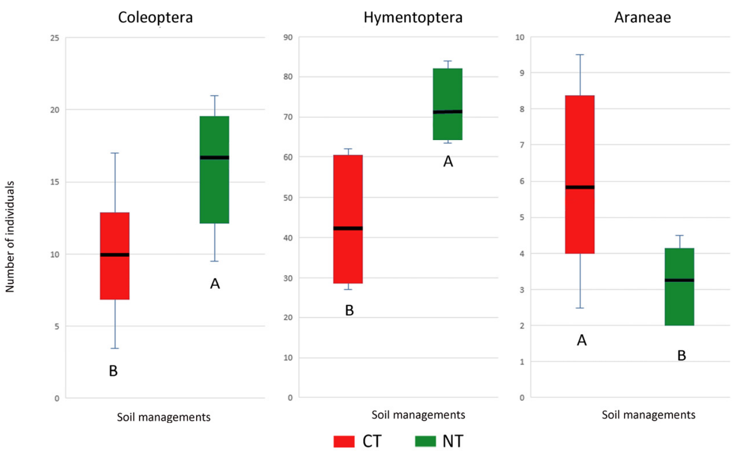

Figure 10. Mean number of *Coleoptera* (beetles), *Hymenoptera* (ants), and *Araneae* (spiders) per sampling unit for each management system (CT and NT) on the Alameda del Obispo farm (irrigated). The letters show significant differences between different management systems for each order. LSD test at $p \leq 0.05$.

Therefore, a general trend towards greater biodiversity was observed four years after the implementation of NT management techniques compared to CT techniques. There were significant differences between the morphospecies observed, particularly in the case of ants on the irrigated farm. Only spiders showed better results under CT than NT. Regarding SOC, the results obtained on each farm after a four-year study are shown in Figure 11. On rainfed plots, the carbon improvement produced by NT is very evident. A significant increase is shown when the total sampled profile (0–20 cm) is compared with the CT soil, in which the SOC concentration is 1.51%, while in the NT soil, it rises to 2.14%. Therefore, there was more than 40% of SOC after four years of NT on the Rabanales farm. If we consider that we started from an initial content of 1.66%, NT was able to sequester carbon, where the CT system resulted in SOC losses. This SOC increase in NT is fundamentally based on the most superficial layer of the soil profile (0–5 cm), where there was 70% more SOC after four years.

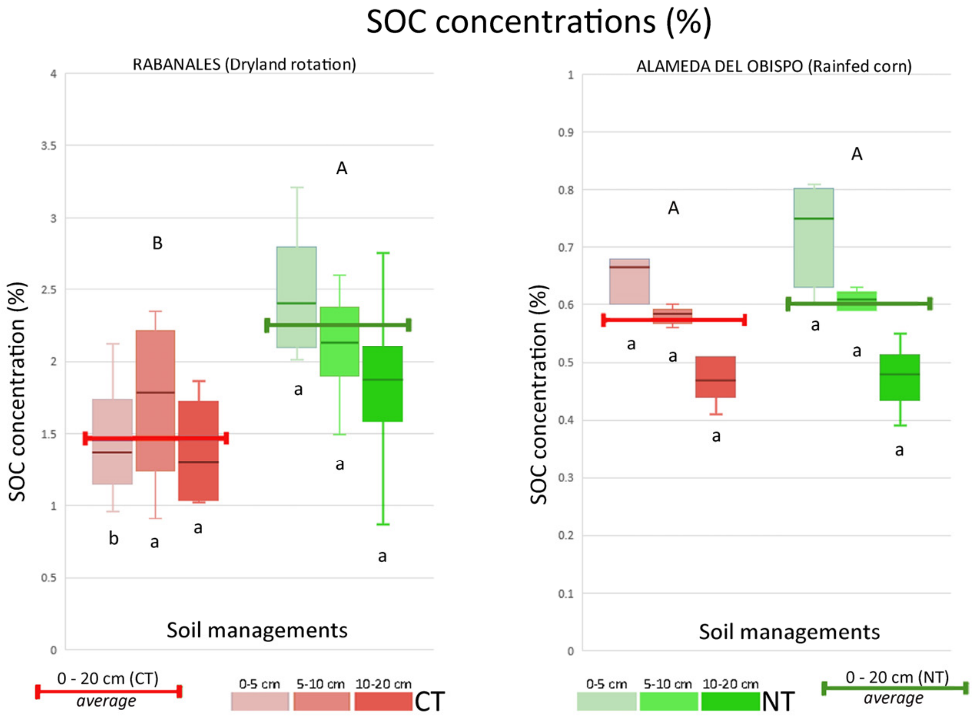

Figure 11. Carbon concentrations in the soil on the Rabanales and Alameda del Obispo farms. The letters show significant differences in carbon percentages between the different management systems. LSD test at $p \leq 0.05$. The capital letters refer to the differences in the whole profile (0–20 cm) and the lower-case letters to the differences on each depth (0–5, 5–10 and 10–20 cm).

On the irrigated farm, there was an increase in SOC under NT, but it was less pronounced than in the rainfed case. After a four-year study, at 0–20 cm there was 0.57% SOC under CT compared to 0.60% SOC under NT. In both cases, and compared to the initial concentration of 0.42%, there was a carbon increase. Similar to the findings in the rainfed farm, the greatest increase in SOC under NT compared to CT occurred at the shallowest level (0–5 cm). Specifically, it was 0.65% under CT and 0.73% under NT.

The correlation matrix (Table 2) shows that the soil management system and irrigation are highly correlated with the observed morphospecies diversity, with a similarity close to 64% in the case of the management system used in the study plot and around 44% with or without the application of irrigation on the plots. Regarding carbon at different depths, the correlation with the number of morphospecies is low.

Table 2. Pearson correlation index between variables.

	OC (0–5)	OC (10–20)	OC (5–10)	Individuals	Management System	Morphospecies
OC (10–20)	**0.8136**					
(*p*-value)	0.0000					
OC (5–10)	**0.8568**	**0.8322**				
(*p*-value)	0.0000	0.0000				
Nº individuals	**0.4511**	**0.3383**	**0.4024**			
(*p*-value)	0.5591	0.7726	0.6900			
Management	**0.3655**	**0.1885**	**0.1430**	**0.5319**		
(*p*-value)	0.0000	0.0003	0.0066	0.5473		
Morphospecies	**0.1011**	**0.0983**	**0.0824**	**0.6485**	**0.6370**	
(*p*-value)	0.0218	0.0150	0.0204	0.0000	0.2284	
Irrigation-No irrigation	**0.8016**	**0.8363**	**0.8952**	**0.4348**	**0.0028**	**0.4389**
(*p*-value)	0.0000	0.0000	0.0000	0.5113	0.9579	0.0243

Using the data in Table 2, the analysis of principal components was carried out, and the results are shown in Table 3.

Table 3. Principal component analysis (table above) and vectors relative to the variables studied (table below).

	Eigenvalues	Percent of Variance	Cumulative Percent of Variance
1 component	3.56677	59.4	59.4
2 component	1.05777	17.6	77.1
3 component	0.97562	16.3	93.3
4 component	0.18696	3.1	96.5
5 component	0.12229	2.0	98.5
6 component	0.09059	1.5	100.0

Factor	Vector 1	Vector 2	Vector 3	Vector 4	Vector 5	Vector 6
OC (0–5)	−0.4963	−0.1287	−0.0910	−0.3383	0.7694	0.1495
OC (10–20)	−0.4905	0.0302	0.0432	0.8534	0.0959	−0.1383
OC (5–10)	−0.5036	0.0825	0.0714	−0.3720	−0.3305	−0.6978
Shannon biodiversity index	0.0180	−0.5395	0.8415	−0.0131	0.0132	0.0100
Soil management system	−0.1351	−0.7989	−0.5054	0.0206	−0.2862	0.0759
Irrigation	−0.4908	0.2154	0.1455	−0.1353	−0.4555	0.6825

In order to explain 100% of the variance, it is necessary to use six main components, but statistically it is considered sufficient to take into account those with which 80% can be explained. In our case, using only the first three components, 93% of the variance is already reached. The first principal component corresponds to the chosen soil management system (NT–CT), the second component is made up of the soil organic carbon content at all depths, and the third one refers to irrigated or rainfed (non-irrigated) crops. The graphical representation of these components is shown in Figure 12.

Figure 12 shows the formation of two sets of values depending on the variables studied in relation to the number of the morphospecies of each arthropod order. PC 1 is derived from the equation obtained by incorporating the values of vector 1, as presented in Table 3. PC 2 is derived from the equation corresponding to vector 2. PC 3 is derived from the equation corresponding to vector 3. It can be observed that the two groups are characterised by CT or NT. This result confirms the progress made in the correlation matrix, which showed a high correlation between the soil management system and the abundance of morphospecies. It can also be seen that within each group, NT (group 1) and CT (group 2), two subgroups of orders appear depending on the irrigation–non-irrigation variable.

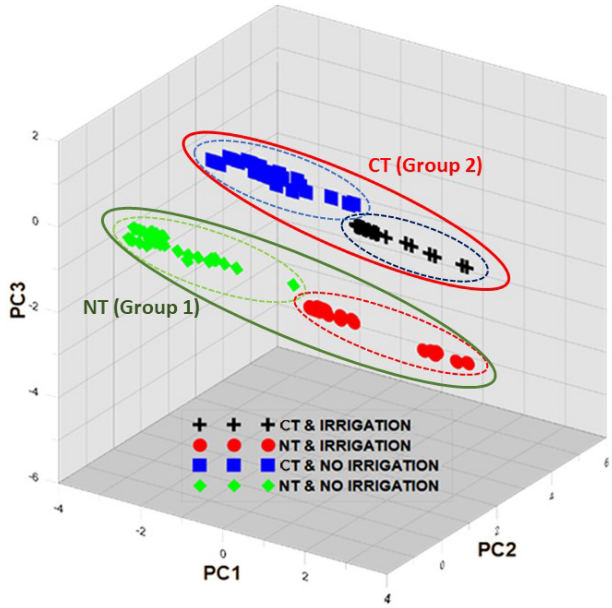

Figure 12. Graphic representation of the main components that affect the diversity of the morphospecies of the arthropod orders captured on the Rabanales and Alameda del Obispo farms. (CT = conventional tillage; NT = no-tillage).

4. Discussion

The results show a general increase in biodiversity parameters on both farms (rainfed and irrigated) when implementing NT management practices. Therefore, the effects observed after four years of CA are in line with those observed in previous studies [12–14]. On the Rabanales farm, the increase in morphospecies was relevant, with statistically significant differences observed between NT and CT. On the irrigated farm (Alameda del Obispo), a statistically significant increase was observed in the general population under NT compared to CT. This is in line with other studies developed on different continents [23,24]. These studies were carried out in areas close to the Tropic of Capricorn, with humidity and temperature conditions similar to those observed in the irrigated farm in Alameda del Obispo.

The results obtained with the Shannon Biodiversity Index on both farms and for each soil management system are within the range expected for cultivated land (between 1.5 and 3.5) [45]. Although no outstanding results were obtained, higher average values were shown for the NT management system in both the dryland and irrigated areas, consistent with other studies [19,20].

Regarding the *Coleoptera* order, the obtained data are in line with those obtained in a large number of studies [20,23,25–27,30–35] that show how beetle populations increase when NT techniques are applied. This increase was particularly relevant for the irrigated plot, where the number of beetles almost doubled. With regard to the number of morphospecies, NT showed another important benefit, with a slight increase in diversity compared to that observed in CT dryland and a much more evident increase in irrigated land.

In the case of Hymenoptera, the results were positive when NT was applied to irrigated land, as noted by Fernandez et al. [38], who studied a rotation that included maize and where NT practices had beneficial effects on ant diversity and abundance. In fact, in Alameda del Obispo, the increase of both morphospecies diversity and abundance of individuals in the NT soil was significant and clear. Under rainfed conditions, although ant diversity was slightly higher in the NT soil than in the CT soil, populations were significantly lower in unploughed plots. This result agrees with Blanchart et al. [37] and Campos et al. [39], who indicate a higher probability of ant trapping in cultivated soils. These authors suggest that the reason for this is that ants have to make a greater effort to find food in ploughed soil, which has fewer resources, than in unploughed soil. In any case, the differences are not significant to the detriment of NT.

Finally, in the case of *Araneae*, the advantages of NT demonstrated by Rodriguez et al. [14] and Blanchart et al. [37] were only confirmed on the rainfed farm (Rabanales). On this farm, both the diversity and abundance of spiders increased, although without significant values. However, these findings are in line with the results obtained by other authors [20,21,23,31–33]. On the irrigated farm (Alameda del Obispo), a decrease in both species and individuals of spiders was observed in the NT soil with respect to the CT soil. This is the only circumstance in which there was a lower result in morphospecies in the NT soil compared to the CT soil. Even in the case of these populations, there was no significant decrease.

The increase of SOC produced in the rainfed land when applying NT compared to CT is in line with that observed in various scientific studies [9,10,17,18]. In fact, it is confirmed that NT can be a tool to increase SOC in drylands, while CT causes carbon losses. On the irrigated farm, an increase in SOC was observed under both NT and CT. In this respect, the results reported by Follet et al. [46] in an irrigated wheat-corn rotation were similar to those obtained on the Alameda del Obispo farm. Soil organic carbon enhanced under both CT and NT, with greater intensity in the unploughed plots.

The soil under NT maintains a better structure, which has several advantages, such as a greater capacity to retain water, which is especially important in the case of rainfed systems. This also reduces the effect of temperature changes in the soil. Both aspects favour the presence of living organisms in the soil profile, which favours the biodiversity that appears on the soil surface [16]. There is also less habitat destruction and a greater amount of food available [47]. It is therefore clear that less intensive soil management practices are the main factor affecting soil arthropod populations. The second-most important variable was that related to organic carbon content at three different depths, which is consistent with the findings of Carter et al. [15] and Sapkota et al. [16]. This is because soil organisms need organic matter to feed and develop their biological functions. Therefore, a greater amount of carbon and organic matter has a positive effect on the rest of the agrosystem [15]. Finally, it has been confirmed that the irrigation or non-irrigation of plots can also influence arthropod biodiversity. According to Pérez-Fuertes et al. [40], soils under rainfed systems usually have fewer arthropods. Therefore, the results obtained showed a similar mean abundance of individuals in irrigated and dryland plots, with a higher number of morphospecies in dryland plots in crop rotation. Regarding the total number of arthropods captured, it was observed that beetles had a higher average number of individuals in dryland than in irrigated farms, while ants showed a higher abundance in irrigated land than in dryland. In Pérez-Fuertes et al. [40], the results for ants were reversed, with greater abundance in dryland than in irrigated land.

5. Conclusions

The present study confirms the positive impact of Conservation Agriculture on soil biodiversity in agricultural areas. In our case, no-tillage of annual crops had a beneficial effect on the overall increase in arthropod morphospecies and on biodiversity indicators. This effect was similar for rainfed and irrigated crops. The benefit of NT on the increase of morphospecies in rainfed crops and on populations in irrigated crops was significant.

The predominance of three arthropod orders on the surface of annual crops was confirmed, corresponding to the greater presence of morphospecies and individuals of beetles, ants, and spiders. When comparing soil management systems, a general trend of increasing diversity and abundance of beetles and ants was observed in NT compared to CT. For spiders, however, this trend was only observed in rainfed conditions and crop rotation. The most obvious benefits of NT were observed for *Hymenoptera* on irrigated land, with significant increases in both individual abundance and morphospecies diversity.

It was confirmed that arthropod biodiversity on the soil surface was mainly influenced by the management system (NT or CT), followed by the SOC content and the presence or absence of irrigation in the plots. Furthermore, the positive impact of NT as an eligible agricultural practice for climate change mitigation has been demonstrated through its potential to improve soil organic carbon. This effect was more pronounced in a rainfed crop rotation than in an irrigated monoculture.

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