Agriculture, Ecosystems and Environment 141 (2011) 193–201

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Effects of organic farming on plant and arthropod communities: A case study in Mediterranean dryland cereal

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ARTICLE INFO

Article history:
Received 4 May 2010
Received in revised form 22 February 2011
Accepted 23 February 2011
Available online 21 March 2011

Keywords:
Diversity
Richness
Abundance
Weed and arthropod
Agri-environment scheme
Farmland

ABSTRACT

Organic farming is considered an important way to preserve biodiversity in agricultural landscapes. However, more work is still necessary to enable a full appraisal of the potential benefits of this way of farming, since studies differ in the evaluation of its effectiveness. Studies are particularly scarce in the Mediterranean region, where different climatic and ecological conditions prevent simple extrapolations from work carried out at northern latitudes. In the present study, an analysis of weed and arthropod communities was conducted in 28 pairs of organic and conventional fields in a dry cereal farmland in central Spain. Plants were identified to the species level, and arthropods to the family level. Pitfalls and sweep nets were used to sample respectively, ground-dwelling and plant-visiting arthropods. Abundance (total numbers of individuals), richness (total numbers of plant species or arthropod families), diversity (Shannon–Wiener index) and biomass (milligrams per pitfall/sweep-net) were calculated for each field and compared between organic and conventional fields using Generalized Linear Mixed Models (GLMMs). To explore the effect of predictor variables on weed richness and arthropod biomass, GLMMs were used. Organic fields showed higher abundance of weeds and arthropods (3.01 and 1.43 times, respectively), higher weed richness and diversity (2.76 and 2.33 times, respectively), and a 24% reduction in cereal plants. Arthropod diversity was lower in organic fields due to the presence of three dominant groups: Collembola, Chloropidae (Diptera), and Aphididae (Hemiptera). Weed richness increased as cereal cover decreased in organic fields. Total arthropod biomass was slightly higher in organic fields, and was affected by weed abundance and diversity. The differences between organic and conventional fields found in this study were higher than those reported for northern latitudes. This could be explained by the richer weed flora in the Mediterranean region, and a higher weed seed availability favored by the two-year rotation system typical of Iberian dry cereal farmland. We conclude that organic farming may contribute to preserve biodiversity in dryland cereal agroecosystems in the Mediterranean region.

1. Introduction

A wealth of evidence points to agricultural intensification as the main cause of biodiversity loss in farmland ecosystems (Donald et al., 2006; Foley et al., 2005; Millennium Ecosystem Assessment, 2005; Wilson et al., 2009, 2010). This negative impact of modern agriculture on many plant and animal taxa will probably raise in the future, due to increasing demands in agricultural production. This is at present an issue of major concern worldwide (Clough et al., 2007a; Fuller et al., 2005; Hole et al., 2005), and there is a growing consensus that further increases in agricultural production must avoid further adverse environmental impacts (Firbank, 2009; Royal Society, 2009). One of the ways to reverse this negative trend would be to use organic farming methods (Geiger et al., 2010). Agri-environment schemes including organic farming and other environmentally friendly practices are today considered the most important instruments to counteract the negative effects of modern agriculture (EEA, 2004). However, published studies differ in their evaluation of the effectiveness of these measures, which makes it difficult to assess their benefits (Bengtsson et al., 2005; Frampton and Dorne, 2007; Kleijn et al., 2006).

In a comprehensive review of comparative studies of organic and conventional farming systems, Hole et al. (2005) found inconsistencies between and within studies which suggested that the benefits to biodiversity of organic farming may vary according to factors such as location, climate, crop-type and species. They concluded that further studies are still needed in order to understand the impacts of organic farming, before a full appraisal of its potential role in biodiversity conservation in agroecosystems can be made. For example, many recent studies have attempted to evaluate the

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0167-8809/$ – see front matter
doi:10.1016/j.agee.2011.02.030

effectiveness of organic farming using birds, plants or invertebrates as study subjects (Beecher et al., 2002; Bengtsson et al., 2005; Diekötter et al., 2010; Chamberlain et al., 2010; Clough et al., 2005, 2007a; Fuller et al., 2005; Gabriel et al., 2006, 2010; Gibson et al., 2007; Piha et al., 2007; Roschewitz et al., 2005; Schmidt et al., 2005; Weibull et al., 2003). However, most of these studies have been carried out at mid- or high latitudes of the northern hemisphere, and very few in the Mediterranean Region, where climatic conditions are quite different (e.g., lower rainfall, higher temperatures, lower soil organic content, and considerable variation in the amount of water available for different springs; Costa et al., 2004; INE, 2009; Walter, 1994), making it difficult to extrapolate the conclusions from northern latitudes (Hole et al., 2005).

Two recent studies address the effect of organic farming on arthropods in the Mediterranean region, but not in dryland cereal fields (Cotes et al., 2010; Hadjicharalampous et al., 2002). In this region, only three studies used vascular plants as study subjects. In José-María et al.'s (2010) study, management was the main factor explaining differences among field centres, while Romero et al. (2008) found that organic farming increased weed cover, and species richness and diversity. Another study carried out in four organically managed fields (Caballero-López et al., 2010) showed that plants are highly dependent on farming system, and the arthropod community is conditioned by those plants, which led the authors to conclude that interactions are also important in order to assess the importance of management in cereal crops. Finally, in their recent review, Hole et al. (2005) stated the need of further studies particularly in the Mediterranean region.

In the present study we evaluated the effects of organic farming on biodiversity in a dry cereal farmland in central Spain. The aim was to determine whether there were any differences in the weed and arthropod communities between fields that had been farmed without using synthetic fertilizers and pesticides (organic system), and fields where these chemicals were used (conventional system). Therefore, unlike most previous studies that concentrated on single plant or invertebrate groups, we quantified the effect of the agro-chemical treatment on the abundance (total numbers of individuals), richness (total numbers of species or families), and diversity (Shannon–Wiener index) of all identifiable vascular plants and arthropods found, as well as on the cover of grown cereal and weeds, and on arthropod biomass. Besides, we characterized the factors affecting both weed richness and arthropod biomass, since these are some of the most studied variables in organic farming studies.

2. Methods

2.1. Study area, field selection and farming practices

The study was conducted in 2008 in a Special Protection Area for birds (SPA 139, 'Estepas Cerealistas de los ríos Jarama y Henares') about 25 km north of Madrid (40°42′N, 3°29′E; 682 m.a.s.l.), in central Spain. The terrain is flat to slightly undulated, and it is primarily dedicated to dryland cereal cultivation (wheat *Triticum aestivum* (L.), barley *Hordeum vulgare* (L.), and smaller amounts of common oat *Avena sativa* (L.), together more than 95% of the surface), with minor fields of legumes (*Vicia* spp. and *Medicago sativa* (L.)), olive groves *Olea europaea* (L.) and grapevines *Vitis vinifera* (L.). The brown and acid soil present in the study area and the weather conditions favor a natural vegetation composed by evergreen oak trees (*Quercus ilex* (L.); and their degraded states – *Retama sp.* and *Thymus sp.* scrubland), which instead of forming dense woods have been cleared up to open-wooded area called 'dehesas' used for wood extraction and livestock grazing. Scattered groups of white poplars (*Populus alba* (L.)) are also found in the SPA, although as in the case of oaks, always more than 1 km away from our sampling fields, and thus probably having no influence on them. Most cereal is grown in a traditional two-year rotation system, and harvested during late June-early July. The climate is Mediterranean, with an annual precipitation (mean ± S.D.) of 442.5 ± 125.5 mm and a mean annual temperature of 14.4 °C (maximum and minimum temperatures, respectively, 42.2 °C and −14.8 °C). During the study year, the mean annual precipitation was 484.9 mm and the mean monthly temperature, 14.3 °C (maximum and minimum temperatures, respectively, 39.3 °C and −6 °C). The mean temperature during May is 15.6 ± 1.6 °C, and the mean rainfall, 55.1 ± 41.2 mm. In May 2008 these values were, respectively, 15.5 °C and 64.7 mm, so we can consider our study year as normal. The study area is a SPA for birds because it holds significant populations of globally threatened steppe birds. Therefore, an agri-environmental scheme is running in this area since 2001, as part of the compensatory measures for the construction of a highway crossing its southern margin. Organic farming was one of the conservation actions implemented in a sector of the SPA.

Twenty-eight pairs of fields were randomly selected, where one field of each pair was cultivated without synthetic fertilizers and pesticides (organic system), and the other field with such products (conventional system) (see e.g. Clough et al., 2007b; Pfiffner and Niggli, 1996; Shah et al., 2003). All sampled cereal fields (always dedicated to cereal cultivation) were preceded by a fallow year before the study was carried out, so the initial conditions were the same for all of them and the only difference was that one field of the pair was cultivated organically during the year when our study was conducted. Fields of the same pair were separated by <100 m and shared the major physiographic characteristics (slope, orientation, approximate size, soil type) and farm history. The mean field size was 1.9 ± 0.9 ha, similar to that of a previous study in northern Spain (José-María et al., 2010). Since the maximum distance between fields in our sample was 11 km, we considered that the environmental conditions were the same for all fields.

Farmers were asked to fill out a questionnaire to characterize their usual farming practices, which are compared to those allowed in organic fields (Table 1). Both organic and conventional fields were sown (wheat or barley) between the second week of October and the first week of November 2007, after initial ploughing for soil preparation. Conventional fields were later treated with chemical fertilizers (Table 1) and broad-leaf herbicides, while organic fields did not receive such treatments. The density of seeds (wheat or barley) was the similar in both, organic and conventional fields (T = 1.80, P = 0.12, Table 1).

2.2. Plant and arthropod sampling

Plant sampling was carried out during the third week of May 2008. A 25 cm × 25 cm metal square was thrown randomly 20 times in each field, avoiding the edges and their proximities. Each plant was identified to the species level, the number of individual plants of each species was counted and the corresponding cover for each species estimated as a percent of the square surface. In the case of cereal, the total number of plants was used as an indirect measure of cereal production, since no information about crop could be obtained. To check if plant sampling effort was sufficient, species accumulation curves were generated using the program EstimateS version 8.2 (Colwell, 2009) and fitted by Clench equation (Jimenez-Valverde and Hortal, 2003; Moreno and Halffter, 2001). The Clench equation was defined as $S_n = A \times N/(1 + B \times N)$, where S_n is the number of species observed in each given sample level, A is the increase rate of new species at the beginning of sampling and B is the parameter related to shape of the curve. The asymptote of curve – total number of species predicted – is calculated as A/B.

Table 1
Main characteristics of the farming system used in the 28 pairs of fields.

	Organic fields	Conventional fields
Sowing density (wheat or barley)	188 ± 16 kg ha^{-1}	197 ± 19 kg ha^{-1}
Fertilization	No	NPK: 350 ± 72 kg ha^{-1}, October CAN (27%): 168 ± 26 kg ha^{-1}, February
Weed control	Weed ploughing	Weed ploughing Clorsulfuron (7%): 2–2.5 g ha^{-1}. April, May and July Clortoluron (50%): 3–4 l ha^{-1} Gardel: 0.2 l ha^{-1} Foramsulfuron: 10 g ha^{-1}. April, May and July Primafuron: 20 g ha^{-1}
Seed origin	Organic	Industrially selected and chemically treated
Ploughing (mouldboard plus weed ploughing)	1–2 times/year	2–4 times/year

We used two different methods to sample arthropods, pitfall traps and sweep nets. Pitfall traps are the most appropriate method to capture terrestrial and soil arthropods (e.g., Clere and Bretagnolle, 2001; Hadjicharalampous et al., 2002; Schmidt et al., 2006), while sweep nets are commonly used for taxa such as Heteroptera that are living well above the ground on the plant canopy, or those that spend much time flying (Frampton and Dorne, 2007). The combination of both methods provides the best possible information about the arthropod fauna (Fauvel, 1999). Within each field, three pitfall traps were placed during the third week of May close to the field center at 10-m intervals. Each trap consisted of a plastic cup (9 cm internal diameter, 14 cm length) sunk into the soil with the aid of a metal cylinder, and filled with 250 ml of 70% ethanol as a preservative solution (Shah et al., 2003). Traps were protected from rainfall and excessive evaporation by plastic dishes suspended on thin sticks at 10 cm over the soil surface. Collections of arthropods were made for 7 days (±2 h). Collected arthropods were stored in 70% ethanol after the sampling period. Five days after collecting the pitfalls, we conducted three sweep-netting transects on each field. Fields of the same pair were sampled one after each other, between 6:00 h and 10:00 h GMT, avoiding inappropriate weather conditions such as wind and temperature below 18 °C or above 25 °C, when arthropods might be inactive (Weibull and Östman, 2003). Each transect consisted of ten movements of the sweep net, from right to left side and vice versa and approximately 2 m wide. Before starting these samplings, all observers spent one day standardizing these sweep net movements to prevent sampling biases due to differences in width, depth and speed, and the same observer always sampled both fields of a pair. The arthropods captured were fixed in 70% ethanol.

2.3. Laboratory procedures and statistical analyses

Plants were identified to the species level and arthropod to the family level, which is useful for all indexes used in this study (abundance, richness and Shannon–Wiener diversity index; Biaggini et al., 2007; Frampton and Dorne, 2007), as well as for biomass calculations (Hódar, 1996). To estimate arthropod biomass we first measured with a digital caliper (0.01 mm precision) the maximum body length of all adult arthropods captured excluding appendices (wings, antennae, ovipositors or legs), and calculated the average body size for each taxonomic group. To estimate the mean biomass of each group, we used the equations given by Hódar (1996), which relate weight to body length in several arthropod groups of the Mediterranean region (general equation: $Y = a^{b1}(x)^{b2}$, where Y is the biomass, x the length, and a, $b1$ and $b2$, specific coefficients for each taxonomic group). Consequently we calculated the biomass of each group in each sampled field (see also Clere and Bretagnolle, 2001; Jiguet et al., 2000).

We compared each index (richness, abundance, diversity and biomass) by means of Generalized Linear Mixed Models (GLMMs) with the field pair as random factor (to control for spatial non-independence in the data; Littel et al., 2006) using the lme4 package (Bates and Maechler, 2010) of R-Program 2.11.1 (R Development Core Team, 2010).

The differences in frequency distribution of the most abundant weed species between organic and conventional management were analyzed using Chi-squared test. Richness, abundance and diversity (plus biomass for arthropods) were calculated independently for plants and for arthropods. Later, these indices were calculated separately for cereal plants, weeds, and all plants (Kleijn et al., 2006; Lundkvist et al., 2008; Sunderland and Samu, 2000). Finally, we calculated these indices again and repeated the GLMMs for the most abundant arthropod orders. To check for dominant groups, we used the index proposed by Berger and Parker (1970). This index accounts for the dominance of the most abundant groups (the higher the value, the more dominant group), considering all species in the assemblage (Caruso et al., 2007). We repeated the diversity calculations excluding dominant arthropod groups.

Since arthropod biomass is expected to be related to vegetation variables (e.g., Clough et al., 2007b), we performed simple correlation analysis to discard, if necessary, some highly correlated variables. Next, we performed Generalized Linear Mixed Models (GLMMs), using field pair as random parameter, with Poisson error distribution and log link function. Biomass was the dependent variable and we included management type (organic or conventional), weed abundance, weed richness, weed diversity and weed cover as plausible independent variables. We performed another GLMM (with field pair as random effect) where weed richness was the dependent variable, and cereal cover and management, plus their interaction, the explanatory variables.

To determine the best predictive models, Akaike's information criterion (ΔAICc < 2) was used. We used AICc because the ratio between the number of observations and estimator variables was under 40 (Barrientos and Bolonio, 2009; Burnham and Anderson, 2002). To look for differences among models with ΔAICc < 2, an ANOVA test was performed. The models were fitted by maximizing the log-likelihood using the Laplacian approximation because this is the most suitable for small sample sizes (Moya-Laraño and Wise, 2007).

3. Results

3.1. Plants

A total of 4940 plants belonging to 51 weed species were recorded (Appendix A). The frequency distribution of these species differed between organic and conventional fields ($\chi^2 = 8467.2$,

Table 2
Most common weed species ordered by the frequency with which they were recorded in organically managed and conventional fields.

Species	Organic fields	Conventional fields
Lolium rigidum (Gaudin)	50.3	80.2
Galium tricornutum (Dandy)	7.1	1.8
Bromus diandrus (Roth)	6.6	4.2
Anacyclus clavatus (Desf.)	4.2	0.7
Conyza canadensis (L.)	4.0	0.6
Raphanus raphanistrum (L.)	3.8	0.6
Avena sterilis (L.)	3.0	3.3
Vicia sativa (L.)	2.8	0.0
Polygonum aviculare (L.)	2.6	2.9
Filago pyramidata (L.)	1.7	0.1
Trifolium angustifolium (L.)	1.7	0.0
Filago lutescens (Jord.)	1.1	1.2
Vicia spp.	0.9	0.1
Picnomon acarna (L.)	0.9	0.8
Lactuca serriola (L.)	0.8	0.2
Ornithopus compressus (L.)	0.7	0.1
Linaria viscosa (L.)	0.7	0.0
Spergula arvensis (L.)	0.7	0.0
Euphorbia serrata (L.)	0.6	0.0
Vicia ervilia (L.)	0.6	0.0
Others	4.9	3.2

Values are percentages of each species found in both field types.

$P < 0.001$; Table 2). Only four weeds were found in organic fields in lower numbers than in conventional fields (*Lolium rigidum* (Gaudin), *Avena sterilis* (L.), *Polygonum aviculare* (L.), and *Filago lutescens* (Jord.); Table 2). According to the Clench equation, we sampled 80% and 89.8% of the total number of predicted species, respectively in organic and conventional fields. The most abundant family was *Gramineae*, with 71.1% of total weeds (respectively, 60.9% and 88.1% in organic and conventional fields). Next were *Compositae*, with 10.4% (respectively, 14.4% and 3.8% in organic and conventional fields) and *Leguminosae*, with 4.3% (respectively, 7.3% and 0.2% in organic and conventional fields). Of 51 weed species identified, 48 were found in organic fields and 28 in conventional fields.

GLMMs showed that weed richness, weed diversity, weed abundance and weed cover were significantly higher in organic than conventional fields (Table 3), whereas cereal plants grew in higher numbers in conventional fields (Table 3). Total plant abundance (cereal plus weeds) was higher in conventional fields, and cereal cover and total cover did not differ between organic and conventional fields (Table 3). Overall, there was a negative relationship between cereal cover and weed richness, although this relationship was only significant for organically managed fields (Fig. 1). The GLMM showed that weed richness was influenced by the management type, cereal cover and their interaction (Appendix B and Table 4). The first two models are equally valid (ANOVA test not significant), but the first including the interaction and had a lower AICc.

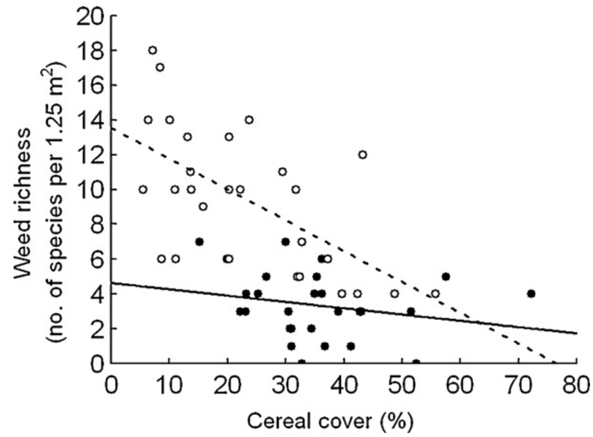

Fig. 1. Relationship between cereal cover (%) and weed richness (no. of species per 1.25 m^2). The correlation was significant for organic fields (open circles; $r = -0.62$, $P < 0.001$), but not for conventional fields (black circles; $r = -0.23$, $P = 0.23$).

Table 4
Parameter estimates from the Generalized Linear Mixed Model with cereal cover (CC), management (MA), and the interaction between cereal cover and management (CC × MA) as factors affecting weed richness.

Parameter	Estimate	SE	*P*
CC	−0.009	0.052	0.452
MA	6.481	2.301	0.007
CC × MA	−1.873	0.325	0.031

Table 5
Differences between conventional and organic fields in abundance, richness, diversity, and biomass of arthropods.

	Organic fields	Organic farming	*Z*	*P*	LL
Abundance	1798.4 ± 1052	1253.9 ± 508	54.66	<0.001	−3861
Richness	45 ± 4.9	42.3 ± 4.29	6.98	0.002	−26.98
Diversity	1.9 ± 0.1	2.2 ± 0.2	−2.57	0.014	−13.61
Biomass[a]	719 ± 153	640 ± 275	1.82	0.08	−16.2

Abundance measured as individuals collected in 3 pitfalls/sweep-nets, richness as number of families collected in 3 pitfalls/sweep-nets, diversity through Shannon–Wiener diversity index, and biomass of arthropods as milligrams in 1 pitfall/sweep-net. Mean values ± SD, statistic (*Z*, GLMM-test), significance of the differences (*P*) and log-likelihood (LL) are given.

[a] One pitfall plus one sweep net transect.

3.2. Arthropods

A total of 82,822 individuals belonging to 150 arthropod families and 21 orders were collected (Appendix C). Arthropods were more abundant in organic fields (50,488 individuals, Table 5). Comparisons between organic and conventional fields showed no significant differences for *Araneae*, *Coleoptera* or *Hemiptera* ($P > 0.41$ in all cases), higher numbers of *Acari*, *Collembola*, *Diptera*, *Hymenoptera*, and *Orthoptera* in organic fields ($P < 0.001$), and

Table 3
Differences between conventional and organic fields in abundance, cover, richness, and diversity of plants.

		Organic fields	Conventional fields	*Z*	*P*	LL
Abundance	Cereal	475.2 ± 242.6	623.6 ± 141.2	−23.6	<0.001	−953.2
	Weeds	132.5 ± 153.8	43.9 ± 75.5	35.38	<0.001	−1214
	Both	607.7 ± 241.9	667.5 ± 125.4	−7.69	<0.001	−785
Cover	Cereal	23.5 ± 14.2	35.7 ± 12.2	−0.39	0.261	−110.8
	Weeds	9.9 ± 9.8	1.9 ± 2.8	12.59	<0.001	−73.6
	Both	33.4 ± 14.1	37.6 ± 11.2	−0.89	0.143	−104.5
Richness	Weeds	9.4 ± 4.0	3.4 ± 1.8	8.63	<0.001	−36.60
Diversity	Weeds	1.4 ± 0.5	0.6 ± 0.5	3.05	0.002	−13.25

Abundance measured as individuals per 1.25 m^2 (twenty 25 cm × 25 cm sampling units), cover as %, richness as species per 1.25 m^2, and diversity through Shannon–Wiener diversity index. Mean values ± SD, statistic (*Z*, GLMM-test), significance of the differences (*P*) and log-likelihood (LL) are given.

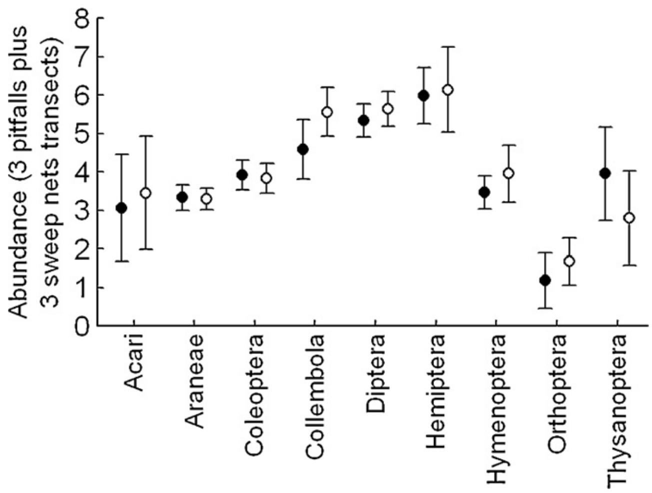

Fig. 2. Numbers of individuals of the main arthropod orders sampled per field (3 pitfalls plus 3 sweep nets transects), in organic (open circles) and conventional fields (black circles). Abundance measured as ln (number of individuals + 1) Means and SD values are given.

higher numbers of *Thysanoptera* in conventional fields ($P < 0.001$) (Fig. 2). Dominance analyses showed that *Collembola, Chloropidae* (*Diptera*), and *Aphididae* (*Hemiptera*) were dominant groups (Berger–Parker index = 0.68 for these three groups together; respectively 0.76 and 0.58 in organic and conventional fields).

The result of the GLMMs showed that richness was higher in organic than in conventional fields (Table 5). After excluding dominant groups, richness was still higher in organic (40.3 ± 1.2) than in conventional fields (37.8 ± 1.1) ($P = 0.02$). No differences were found in family richness for *Araneae* and *Coleoptera* (respectively, $P = 0.56$ and $P = 0.11$, see list of families in Appendix C). For *Hemiptera*, richness was higher in organic fields ($P = 0.01$). As for *Diptera*, richness did not differ between organic and conventional fields ($P = 0.95$).

Diversity values were lower in organic than in conventional fields (Table 5). Within the most abundant orders, diversity was higher in *Coleoptera* in organic fields ($P = 0.01$) and *Diptera* and *Hemiptera* in conventional fields ($P < 0.001$ in both), For *Araneae* we did not find statistical differences ($P = 0.21$). However, excluding dominant groups, organic fields showed higher diversity (respectively for organic and conventional fields: 2.7 ± 0.4 and 2.5 ± 0.3, $P = 0.01$). The differences between diversity indices calculated including and excluding the dominant groups were higher for organic (0.8 ± 0.5) than for conventional fields (0.3 ± 0.4) ($P < 0.001$ in both cases).

The total estimated biomass of arthropods collected was slightly higher in organic fields than in conventional fields, although the difference was not significant (Table 5). By orders, only *Collembola* showed higher biomass in organic fields ($P < 0.001$), and *Thysanoptera* in conventional fields ($P = 0.002$). We searched for factors affecting arthropod biomass through GLMM. As weed richness was highly correlated with weed abundance ($R = 0.72$, $P < 0.001$) and weed diversity ($R = 0.65$, $P < 0.001$), weed richness was discarded from the plausible factors in GLMM, which included management type, weed abundance, weed diversity and weed cover as fixed factors, and field pair as random factor (Appendix D). Three models could be considered candidate models according to their differences in ΔAICc (<2). The variables included in the best model were management type, weed abundance, and weed diversity (Table 6), with 27.1% of the deviance explained (Appendix D). Model 1 differed from model 2 ($P = 0.03$), which also included weed cover (27.3% of the deviance explained). Model 3 included the interaction

Table 6
Parameter estimates from the Generalized Linear Mixed Model with management (MA), weed abundance (WA) and weed diversity (WD) as factors affecting arthropod biomass.

Parameter	Estimate	SE	*P*
MA	4.091	0.172	<0.001
WA	2.036	0.065	<0.001
WD	3.153	0.139	<0.001

between management and weed diversity (27.3% of the deviance explained).

4. Discussion

In the dryland cereal agroecosystem studied, the first effect of organic farming was on the weeds, with knock-on effects (Hawes et al., 2003) on the arthropod community, associated directly with this resource. Finally, the competition with weeds led into a decreased cereal production, as suggested by the lower number of cereal plants. The positive effect of a reduction in agrochemical applications on weed density has been experimentally demonstrated (e.g., Frampton and Dorne, 2007; Hyvönen and Salonen, 2002; Kleijn et al., 2006). Weed and arthropod communities were also richer in organic fields and, in the case of weeds, more diverse than those of conventional fields. The average increases in weed abundance (202%), richness (176%), diversity (133%) and cover (421%) in organic fields were somewhat higher than those recorded in a dryland cereal area in northern Spain (Caballero-López et al., 2010; José-María et al., 2010; Romero et al., 2008), and considerably higher than those reported for studies carried out at northern latitudes (e.g., Bengtsson et al., 2005; Hole et al., 2005; Moreby et al., 1994). The higher development of weeds in the absence of agrochemical treatment in these Spanish studies as compared to studies carried out at northern latitudes might be explained by several facts. First, the weed flora is more diverse in Mediterranean latitudes (Araújo et al., 2007; Cowling et al., 1996; Thompson, 2005). Second, in most Spain cereal is grown in a traditional two-year rotation system that creates a mosaic of ploughed, cereal and stubble patches, with some fallow fields left untilled for several years. Such system allows uncultivated fields to act as weed reservoirs from which their seeds may easily disperse, building up a rich weed community in organic cereal fields. In the more intensively cultivated cereal farmland in northern countries, these uncultivated weed reservoirs are less frequent, and thus the weed development in organic fields less marked. Third, in our study area fields are small (less than 2 ha) and field boundaries are narrow (mean width = 35 ± 25 cm, mean height = 40 ± 23 cm, $n = 50$, own data), favoring an easy exchange of seeds and arthropods among fields.

A limitation of our study could be that sampling was restricted to a single year of organic farming. However, rather than looking at an equilibrium situation, we were interested in knowing whether a quick response to organic treatment could be observed. Some authors have noticed that rapid positive responses to agri-environmental measures would imply less costs, and that if an agri-environmental measure needs several years to become effective, perhaps it should not be implemented (e.g., Hole et al., 2005). Moreover, the temperature and precipitation values of the study year were within half a standard deviation of the average for the last 30 years, suggesting that the results were probably not influenced by weather conditions. Finally, instead of performing several samplings through the spring, we restricted our sampling to just one time during May, due to the relatively short vegetative period in our study area. The sampling dates were selected to maximize the probability of collecting most weeds and arthropods, which in our study area have very short life cycles as compared to more northern latitudes. Besides, sampling effort for plants was adequate, since we sampled 80% and 89.8% of the species predicted by Clench equation, respectively in organic and conventional fields (Jimenez-Valverde and Hortal, 2003; Moreno and Halffter, 2001).

As in the study of Romero et al. (2008), in our area *Lolium rigidum* (Gaudin) was the only dominant weed in conventional fields, due to its particular resistance to herbicides (Heap, 1997), and *Avena sterilis* (L.) and *Bromus diandrus* (Roth) were also relatively resistant. When herbicides were suppressed, a more complex weed community developed, and the prevalence of *L. rigidum* (Gaudin) decreased significantly, leaving space to other weeds, particularly broad-leaved species which are less resistant to the herbicides used (Kudsk and Streibig, 2003). Among these, several leguminous species were particularly important, since they contribute to nitrogen fixation, and thus to the development of a richer biocenosys. These species were *Vicia sativa* (L.), *V. spp*., *Trifolium angustifolium* (L.) y *Ornithopus compressus* (L.), which together comprised ca. 7% of weeds in organic fields, as compared to only 0.2% in conventional fields. Some legumes are also related to increases in some arthropod groups as flower-consumers, chewing-herbivores and saprophages (Caballero-López et al., 2010).

The best models selected by the GLMMs showed an influence of management type and cereal cover on weed richness, as well as an interaction between both variables. This means that as cereal cover decreased, the richness of the weed community increased, but only in the sample of organically managed fields. Such relationship was not observed in conventional fields where herbicide treatment kept weeds under control. On average, organic farming implied a 24% reduction in the number of cereal plants. Assuming plant numbers are correlated with total cereal crop, organic farming also determined a similar decrease in agricultural production. Such a decrease is slightly higher than the 16.5% reported as mean variation among years in winter cereal production in Spain (MMAMRM, 2010).

As for arthropods, their abundance increased in organic fields compared to conventional fields (41%). Such increase is similar to those reported in previous studies (Bengtsson et al., 2005; Frampton and Dorne, 2007; Hole et al., 2005). The *Collembola*, *Chloropidae* (*Diptera*), and *Aphididae* (*Hemiptera*) were found to be dominant groups. These species were ca. 20% more abundant in organic fields than in conventional fields, concluding that their proliferation could be a direct consequence of the farming system. Clough et al. (2007b) also found some dominant species of the *Staphylinidae* (*Coleoptera*) and Moreby et al. (1994) found an increase of *Diptera* and *Aphids* (*Hemiptera*), the same orders identified as dominant in the present study. Their higher abundance and proliferation in organic fields could probably be favored by the greater cover in these fields of insect-pollinated weeds, particularly those with flowers, the typical niche of most of these insects. Arthropod richness was a 6.4% higher in organic fields. Most other studies have also recorded richness increases in organically managed fields (Clough et al., 2007a; Hadjicharalampous et al., 2002; Hole et al., 2005; Pfiffner and Niggli, 1996), and the impact of organic management on arthropods has been interpreted as an indirect result of the impact of agro-chemical suppression on the vegetation (Siemann et al., 1998). Finally, multivariate models showed that arthropod biomass was significantly influenced by farming practices, weed abundance and weed diversity. The best model explained only a 27.1% of the total deviance, which suggests that additional variables such as landscape complexity, distance to nearby organic fields, and field size could also be relevant (Clough et al., 2007a; Concepción et al., 2008). The lower arthropod diversity in organic fields is explained by the marked dominance in these fields of a few taxa, mainly *Collembola*, *Chloropidae* (*Diptera*), and *Aphididae* (*Hemiptera*). As argued by Shah et al. (2003), who also found a higher diversity in conventional fields, the Shannon–Wiener diversity index, despite its wide use in biodiversity studies, is particularly sensitive to changes in the abundance of dominant species in a sample. In their study, the diversity decrease in organic fields was due to the abundance of a dominant carabid, *Pterostichus melanarius* (Illiger). Several other studies also showed that organic management systems increased arthropod abundance and richness but not diversity (Booij, 1994; Clark, 1999; Hokkanen and Holopainen, 1986; Kromp, 1999). In our study, the greater abundance in organic fields of the three dominant groups mentioned above was probably related to a higher development of the weeds canopy, since *Chloropidae* adults are flower-consumers and chewing-herbivores, and *Aphididae* are suction-herbivores (Caballero-López et al., 2010). Without considering these dominant groups, the frequency distribution of the remaining species indicated a significantly higher diversity in organic fields. This was consistent with richness values, which were higher in organic than in conventional fields.

Overall, our results confirm findings from previous studies, and suggest that organic farming may contribute to preserve biodiversity in the dryland cereal agroecosystem of our study area. Organic farming could thus be used as a way to minimize the negative impacts of agricultural intensification, and particularly to improve habitat quality for many vertebrate consumers such as several endangered steppe birds inhabiting dry cereal farmland in the Mediterranean region.

Acknowledgements

We thank L.M. Bautista for his help during field work, N. Panizo and R. Sansegundo for their collaboration in weed and arthropod identification, and A. Torres and J. Seoane for advice during statistical analyses. Three anonymous reviewers, the editor and the editor in chief improved the manuscript with their comments. We also thank all farmers participating in this study. Compensatory payments to farmers were financed through a project CSIC-HENARSA which aims to develop an agri-environmental scheme to enhance farmland bird populations in the SPA 139. Additional funding was provided by projects CGL2005-04893 and CGL2008-02567 of the Dirección General de Investigación of the Spanish Ministry for Science and Innovation.

Appendix A.

Complete list of weed species identified, ordered by the frequency with which they were recorded in organically managed and conventional fields. Values are percentages of each species found in both field types.

Species	Organic fields	Conventional fields
Lolium rigidum (Gaudin)	50.3	80.2
Galium tricornutum (Dandy)	7.1	1.8
Bromus diandrus (Roth)	6.6	4.2
Anacyclus clavatus (Desf.)	4.2	0.7
Conyza canadensis (L.)	4.0	0.6
Raphanus raphanistrum (L.)	3.8	0.6
Avena sterilis (L.)	3.0	3.3
Vicia sativa (L.)	2.8	0.0
Polygonum aviculare (L.)	2.6	2.9
Filago pyramidata (L.)	1.7	0.1
Trifolium angustifolium (L.)	1.7	0.0
Filago lutescens (Jord.)	1.1	1.2
Vicia sp	0.9	0.1
Picnomon acarna (L.)	0.9	0.8

Appendix A (*Continued*)

Species	Organic fields	Conventional fields
Lactuca serriola (L.)	0.8	0.2
Ornithopus compressus (L.)	0.7	0.1
Linaria viscosa (L.)	0.7	0.0
Spergula arvensis (L.)	0.7	0.0
Euphorbia serrata (L.)	0.6	0.0
Vicia ervilia (L.)	0.6	0.0
Filago gallica (L.)	0.6	0.0
Convolvulus arvensis (L.)	0.6	1.5
Anagallis arvensis (L.)	0.4	0.3
Carduus tenuiflorus (Curtis)	0.4	0.0
Hordeum murinum (L.)	0.4	0.1
Aegilops geniculata (Roth)	0.2	0.0
Andryala integrifolia (L.)	0.2	0.2
Ranunculus arvensis (L.)	0.2	0.0
Taeniatherum caput-medusae (L.) Nevski	0.2	0.3
Lathyrus sp	0.2	0.0
Anchusa azurea (Mill.)	0.2	0.0
Bromus squarrosus (L.)	0.2	0.0
Adonis aestivalis (L.)	0.1	0.0
Lupinus angustifolius (L.)	0.1	0.1
Centaurea cianus (L.)	0.1	0.0
Chenopodium album (L.)	0.1	0.2
Cnicus benedictus (L.)	0.1	0.1
Papaver rhoeas (L.)	0.1	0.1
Picris echioides (L.)	0.1	0.0
Torilis nodosa (L.)	0.1	0.0
Trifolium campestre (Schred. in Sturn)	0.1	0.0
Senecio vulgaris (L.)	0.1	0.1
Spergularia rubra (L.) J. Presl & C. Presl	0.1	0.0
Arabidopsis thaliana (L.) Heynh. in Holl & Heynh.	0.0	0.0
Ononis spinosa (L.)	0.0	0.0
Sherardia arvensis (L.)	0.0	0.0
Sonchus oleraceus (L.)	0.0	0.0
Taraxacum officinale (Weber)	0.0	0.0
Amaranthus albus (L.)	0.0	0.2
Cynodon dactylon (L.) Pers.	0.0	0.1
Rumex pulcher (L.)	0.0	0.1
Veronica hederifolia (L.)	0.0	0.2

Appendix B.

Results of Generalized Linear Mixed Models (GLMMs) where management (MA) and cereal cover (CC) were factors affecting weed richness. Field pair was the random factor. The best models (1 and 2) were determined according to the lowest corrected Akaike's Information Criterion (AICc) and ANOVA test (*P* is given, when ΔAICc between one model and the best was less than two). The percentage of the explained deviance, degrees of freedom (d.f.) and model log-likelihood (LL) are also given.

Model Number	AICc	ΔAICc	Explained deviance	d.f.	LL	*P*
1. CC + MA + CC × MA	82.3	0.00	56.8	5	−35.6	0.12
2. CC + MA	83.4	1.10	54.6	4	−37.4	<0.001
3. MA	83.7	1.43	52.9	3	−38.8	
4. CC	169.6	87.39	0.8	3	−81.8	

Appendix C.

Arthropod orders and families identified, and number of individuals collected in organic and conventional fields.

Order	Family	Organic fields	Conventional fields
Acari	*Gamasidae*[a]	2550	1639
	Oribatida[b]	23	4
Araneae	*Anyphaenidae*		2
	Atypidae	23	12
	Ctenizidae		1
	Dictynidae	1	
	Gamasidae	1	1
	Linyphiidae	467	530
	Lycosidae	66	89
	Oonipidae	2	3
	Oxyopidae	17	17
	Palpimanidae	2	5
	Pholcidae		1
	Sicariidae		1
	Theraphosidae	2	
	Telemidae	1	
	Theraphosidae		1
	Theridiidae	31	17
	Titanoecidae		1
	Thomisidae	33	39
	Uloboridae		1
	Zoridae	77	50
	Zoropsidae	61	62
Coleoptera	*Aesalidae*		3
	Anthribidae	4	
	Anthicidae	59	25
	Brostrichidae	1	
	Bruchidae	2	
	Byrrhidae	1	
	Cantharidae	73	82
	Carabidae	287	305
	Cerambycidae	28	8
	Chrysomelidae	84	69
	Ciidae	1	
	Coccinelidae	162	153
	Curculionidae	119	145
	Dermestidae	15	12
	Dryopidae	5	1
	Elateridae	40	9
	Erotylidae		1
	Gyrinidae		2
	Histeridae		1
	Lampyridae	12	9
	Malachidae	3	4
	Meloidae	1	
	Nitidulidae	54	56
	Omaliinae		2
	Scarabeidae	40	19
	Scydmaenidae	2	1
	Staphylinidae	140	250
	Silphidae	204	287
	Silvanidae	1	2
	Tenebrionidae	2	
	Trogidae	2	7
Collembola[b]	*Collembola*	9558	3630
Diplura	*Campodeidae*	9	70
	Japygidae	2	1
Diptera	*Acroceridae*	40	28
	Anthomiidae	1	
	Asilidae	41	93
	Bibionidae	5	2
	Camillidae	253	452
	Cecidomyiidae	534	365
	Ceratopogonidae	2	
	Chloropidae	6496	3147
	Conopidae	65	28
	Culicidae	38	67
	Dixidae		1
	Fanniidae	1	
	Heleomyzidae		2
	Hippoboscidae	75	49

Appendix C (*Continued*)

Order	Family	Organic fields	Conventional fields
	Lauxaniidae	11	23
	Lonchopteridae	2	
	Milichiidae		1
	Muscidae	183	277
	Mycethophilidae	2	
	Otitidae	3	1
	Phoridae	82	156
	Pipunculidae	229	242
	Platystomatidae	19	2
	Psilidae	21	40
	Ptychopteridae	18	13
	Sarcophagidae	2	
	Scathophagidae	92	105
	Scatopsidae	4	2
	Scenopinidae		1
	Sepsidae		8
	Sphaeroceridae	1	3
	Stratiomyidae	7	18
	Syrphidae	99	237
	Tabanidae	3	17
	Tachinidae		1
	Tethritidae	1	
	Therevidae		3
	Trichoceridae	112	301
	Trigonalidae	85	111
	Vermileonidae	55	52
	Xylophagidae		8
Embioptera	*Oligotomidae*		1
Hemiptera	*Acanthosomidae*	28	5
	Alydidae	19	1
	Anthocoridae		2
	Aphididae	23,014	13,130
	Aphrophoridae	815	1674
	Cicadellidae	2	
	Cicadidae	247	261
	Cimicidae	1	6
	Delphacidae	2	
	Lygaeidae	15	5
	Miridae	44	1
	Nabidae	191	36
	Pentatomidae	56	2
	Pseudococcidae		1
	Psyllidae		6
	Reduviidae	12	1
	Rhopalidae	6	
	Scutelleridae	3	1
Hymenoptera	*Andrenidae*	1	
	Apidae	2	
	Cynipidae		2
	Evaniidae		4
	Formicidae	1863	867
	Pamphiliidae		1
	Pompilidae		2
	Sapygidae		4
	Siricidae	1	
	Trichogrammatidae		21
	Vespidae		2
	Xyelidae		3
Isopoda	*Philosciidae*	2	1
Lepidoptera	*Papilionidae*		3
	Pyralidae	2	1
Mecoptera	*Boreidae*		3
	Panorpidae	2	1
Miriapoda[c]	*Diplopoda*[b]	4	5
Neuroptera	*Ascalaphidae*	3	1
	Hemerobiidae	4	3
	Myrmeleonidae	3	2
Odonata	*Coenagrionidae*		1
Opinilionida	*Phalangiidae*	5	7
Orthoptera	*Acrididae*	45	36
	Gryllidae	56	13
	Pamphagidae		2
	Tettigoniidae	25	20
	Trydactylidae	1	4
	Gryllotalpidae	30	19

Appendix C (*Continued*)

Order	Family	Organic fields	Conventional fields
Psocoptera	*Psocidae*		2
Siphonaptera	*Hystrichopsyllidae*	109	174
Thysanoptera	*Thripidae*	1015	2510
Thysanura	*Lepismatidae*	10	1
Total		50,488	32,334

[a] SubOrder.
[b] Class.
[c] SubPhylum.

Appendix D.

Results of Generalized Linear Mixed Models (GLMMs) where management (MA), weed abundance (WA), weed diversity (WD), and weed cover (WC) were factors affecting arthropod biomass. Field pair was the random factor. The best model was determined according to the lowest corrected Akaike's Information Criterion (AICc) and ANOVA test (*P* is given, when ΔAIC between one model and the best was less than two). The percentage of the explained deviance, degrees of freedom (d.f.) and model log-likelihood (LL) are also given.

Model number	AICc	ΔAICc	Explained deviance	d.f.	LL	*P*
1. MA + WA + WD	1684.6	0	27.1	5	−834.7	0.03
2. MA + WA + WD + WC	1685.6	0.98	27.3	6	−833.0	1
3. MA + WA + WD + MA × WD	1685.6	0.98	27.3	6	−833.2	
4. MA + WA + WD + WC + MA × WD	1687.0	2.40	27.4	7	−831.5	
5. MA + WD + MA × WD	1715.6	31.00	25.6	5	−849.9	
6. MA + WA + MA × WA	1785.6	101.00	21.1	5	−885.1	
7. MA + WA	1802.0	117.40	22.1	4	−894.8	

References

Araújo, M.B., Lobo, J.M., Moreno, J.C., 2007. The performance of Iberian protected areas to conserve terrestrial biodiversity. Conserv. Biol. 21 (6), 1423–1432.

Barrientos, R., Bolonio, L., 2009. The presence of rabbits adjacent to roads increases polecat road mortality. Biodivers. Conserv. 18, 405–418.

Bates, D., Maechler, M., 2010. lme4: Linear mixed-effects models using S4 classes. R package version 0.999375-37. http://CRAN.R-project.org/package=lme4.

Beecher, N.A., Johnson, R.J., Brandle, J.R., Case, R.M., Young, L.J., 2002. Agroecology of birds in organic and nonorganic farmland. Conserv. Biol. 16, 1620–1631.

Bengtsson, J., Ahnström, J., Weibull, J., 2005. The effects of organic agriculture on biodiversity and abundance: a meta-analysis. J. Appl. Ecol. 42, 261–269.

Berger, W.H., Parker, F.L., 1970. Diversity of planktonic foraminifera in deep-sea sediments. Science 168, 1345–2134.

Biaggini, M., Consorti, R., Dapporto, L., Dellacasa, M., Paggetti, E., Corti, C., 2007. The taxonomic level order as a possible tool for rapid assessment of arthropod diversity in agricultural landscapes. Agric. Ecosyst. Environ. 122, 183–191.

Booij, K., 1994. Diversity patterns in carabid assemblages in relation to crops and farming systems. In: Desender, K., Dufrêne, M., Loreau, M., Luff, M.L., Maelfait, J.P. (Eds.), Carabid Beetles: Ecology and Evolution. Kluwer Academic Publishers, Dordrecht, pp. 425–431.

Burnham, K.P., Anderson, D.R., 2002. Model Selection and Multimodel Inference. Springer, New York.

Caballero-López, B., Blanco-Moreno, J.M., Pérez, N., Pujade-Villar, J., Ventura, D., Oliva, F., Sans, F.X., 2010. A functional approach to assessing plant–arthropod interaction in winter wheat. Agric. Ecosyst. Environ. 137, 288–293.

Caruso, T., Pigino, G., Bernin, F., Bargagli, R., Migliorini, M., 2007. The Berger–Parker index as an effective tool for monitoring the biodiversity of disturbed soils: a case study on Mediterranean oribatid (Acari: Oribatida) assemblages. Biodivers. Conserv. 16, 3277–3285.

Chamberlain, D.E., Joys, A., Johnson, P.J., Norton, L., Feber, R.E., Fuller, R.J., 2010. Does organic farming benefit farmland birds in winter? Biol. Lett. 6, 82–84.

Clark, M.S., 1999. Ground beetle abundance and community composition in conventional and organic tomato systems of California's Central Valley. Appl. Soil Ecol. 11, 199–206.

Clere, E., Bretagnolle, V., 2001. Disponibilité alimentaire pour les oiseaux en milieu agricole: biomasse et diversité des arthropodes capturés par la méthode des pots-pièges. Rev. Ecol-Terre Vie. 56, 275–297.

Clough, Y., Holzschuh, A., Gabriel, D., Purtauf, T., Kleijn, D., Kruess, A., Steffan-Dewenter, I., Tscharntke, T., 2007a. Alpha and beta diversity of arthropods and plants in organically and conventionally managed wheat fields. J. Appl. Ecol. 44, 804–812.

Clough, Y., Kruess, A., Kleijn, D., Tscharntke, T., 2005. Spider diversity in cereal fields: comparing factors at local, landscape and regional scales. J. Biogeogr. 32, 2007–2014.

Clough, Y., Kruess, A., Tscharntke, T., 2007b. Organic versus conventional arable farming systems: Functional grouping helps understand staphylinid response. Agric. Ecosyst. Environ. 118, 285–290.

Concepción, E.D., Díaz, M., Baquero, R.A., 2008. Effects of landscape complexity on the ecological effectiveness of agri-environment schemes. Landscape Ecol. 23, 135–148.

Colwell, R.K., 2009. EstimateS: Statistical estimation of species richness and shared species from samples. Version 8.2. User's Guide and application published at: http://purl.oclc.org/estimates.

Costa, M., Morla, C., Sainz, H., 2004. Los bosques ibéricos: una interpretación geobotánica. Planeta, Barcelona.

Cotes, B., Campos, M., Pascual, F., Pedro, A., Ruano, F., 2010. Comparing taxonomic levels of epigeal insects under different farming systems in Andalusian olive agroecosystems. Appl. Soil Ecol. 44, 228–236.

Cowling, R.M., Rundel, P.W., Lamont, B.B., Arroyo, M.K., Arianoutsou, M., 1996. Plant diversity in Mediterranean-climate regions. Trends Ecol. Evol. 11 (9), 362–366.

Diekötter, T., Wamser, S., Wolters, V., Birkhofer, K., 2010. Landscape and management effects on structure and function of soil arthropod communities in winter wheat. Agric. Ecosyst. Environ. 137 (1–2), 108–112.

Donald, P.F., Sanderson, F.J., Burfield, I.J., Van Bommel, F.P.J., 2006. Further evidence of continent-wide impacts of agricultural intensification on European farmland birds. Agric. Ecosyst. Environ. 116, 189–196.

EEA, 2004. High Nature Value Farmland – Characteristics, Trends and Policy Challenges. European Environment Agency, Copenhagen.

Fauvel, G., 1999. Diversity of Heteroptera in agrosystems: role of sustainability and bioindication. Agric. Ecosyst. Environ. 74, 275–303.

Firbank, L.G., 2009. It's not enough to develop agriculture that minimizes environmental impact. Int. J. Agr. Sustain. 7, 1–2.

Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, F.S., Coe, M.T., Daily, G.C., Gibbs, H.K., Helkowski, J.H., Holloway, T., Howard, E.A., Kucharik, C.J., Monfreda, C., Patz, J.A., Prentice, I.C., Ramankutty, N., Snyder, P.K., 2005. Global consequences of land use. Science 309, 570–574.

Frampton, G.K., Dorne, J.L.C.M., 2007. The effects on terrestrial invertebrates of reducing pesticide inputs in arable crop edges: a meta-analysis. J. Appl. Ecol. 44, 362–373.

Fuller, R.J., Norton, L.R., Feber, R.E., Johnson, P.J., Chamberlain, D.E., Joys, A.C., Mathews, F., Stuart, R.C., Townsend, M.C., Manley, W.J., Wolfe, M.S., Macdonald, D.W., Firbank, L.G., 2005. Benefits of organic farming to biodiversity vary among taxa. Biol. Lett. 1, 431–434.

Gabriel, D., Roschewitz, I., Tscharntke, T., Thies, C., 2006. Beta diversity at different spatial scales: plant communities in organic and conventional agriculture. Ecol. Appl. 16, 2011–2021.

Gabriel, D., Sait, S.M., Hodgson, J.A., Schmutz, U., Kunin, W.E., Benton, T.G., 2010. Scale matters: the impact of organic farming on biodiversity at different spatial scales. Ecol. Lett. 13, 858–869.

Geiger, F., Bengtsson, J., Berendse, F., Weisser, W.W., Emmerson, M., Morales, M.B., Ceryngier, P., Liira, J., Tscharntke, T., Winqvist, C., Eggers, S., Bommarco, R., Pärt, T., Bretagnolle, V., Plantegenest, M., Clement, L.W., Dennis, C., Palmer, C., Oñate, J.J., Guerrero, I., Hawro, V., Aavik, T., Thies, C., Flohre, A., Hänke, S., Fischer, C., Goedhart, P.W., Inchausti, P., 2010. Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic Appl. Ecol. 11 (2), 97–105.

Gibson, R.H., Pearce, S., Morris, R.J., Symondson, W.O.C., Memmott, J., 2007. Plant diversity and land use under organic and conventional agriculture: a whole-farm approach. J. Appl. Ecol. 44, 792–803.

Hadjicharalampous, E., Kalburtji, K.L., Mamolos, A.P., 2002. Soil arthropods (Coleoptera. Isopoda) in organic and conventional agroecosystems. Environ. Manage. 29 (5), 683–690.

Hawes, C., Haughton, A.J., Osborne, J.L., Roy, D.B., Clark, S.J., Perry, J.N., Rothery, P., Bohan, D.A., Brooks, D.R., Champion, G.T., Dewar, A.M., Heard, M.S., Woiwod, I.P., Daniels, R.E., Young, M.W., Parish, A.M., Scott, R.J., Firbank, L.G., Squire, G.R., 2003. Responses of plants and invertebrate trophic groups to contrasting herbicide regimes in the farm scale evaluations of genetically modified herbicide-tolerant crops. Phil. Trans. R. Soc. Lond. B 358, 1899–1913.

Heap, I.M., 1997. The occurrence of herbicide-resistant weeds worldwide. J. Pestic. Sci. 51 (3), 235–243.

Hódar, J.A., 1996. The use of regression equations for estimation of arthropod biomass in ecological studies. Acta Oecol. 17, 421–433.

Hokkanen, H., Holopainen, J.K., 1986. Carabid species and activity in biologically and conventionally managed cabbage fields. J. Appl. Entomol. 102, 353–363.

Hole, D.G., Perkins, A.J., Wilson, J.D., Alexander, I.H., Grice, P.V., Evans, A.D., 2005. Does organic farming benefit biodiversity? Biol. Conserv. 122 (1), 113–130.

Hyvönen, T., Salonen, J., 2002. Weed species diversity and community composition in cropping practices at two intensity levels – a six-year experiment. Plant Ecol. 154, 73–81.

INE, 2009. Climatología. Anuario Estadístico de España. www.ine.es/jaxi/menu.do?type=pcaxis&path=/t43/a012/a1998&file=pcaxis (Last access 20.02.10).

Jiguet, F., Arroyo, B., Bretagnolle, V., 2000. Lek mating systems: a case study in the Little Bustard *Tetrax tetrax*. Behav. Process. 51, 63–82.

Jimenez-Valverde, A., Hortal, J., 2003. Las curvas de acumulación de especies y la necesidad de evaluar la calidad de los inventarios biológicos. Rev. Ibér. Aracnol. 8, 151–161.

José-María, L., Armengot, L., Blanco-Moreno, J.M., Bassa, M., Xavier Sans, F., 2010. Effects of agricultural intensification on plant diversity in Mediterranean dryland cereal fields. J. Appl. Ecol. 47, 832–840.

Kleijn, D., Baquero, R.A., Clough, Y., Diaz, M., Esteban, J., Fernandez, F., Gabriel, D., Herzog, F., Holzschuh, A., Johl, R., Knop, E., Kruess, A., Marshall, E.J.P., Steffan-Dewenter, I., Tscharntke, T., Verhulst, J., West, T.M., Yela, J.L., 2006. Mixed biodiversity benefits of agri-environment schemes in five European countries. Ecol. Lett. 9, 243–254.

Kromp, B., 1999. Carabid beetles in sustainable agriculture: a review on pest control efficacy, cultivation impacts and enhancement. Agric. Ecosyst. Environ. 40, 71–93.

Kudsk, P., Streibig, J.C., 2003. Herbicides: a two-edged sword. Weed Res. 43 (2), 90–102.

Littel, R.C., Milligen, G.A., Stroup, W.W., Wolfinger, R.D., Schabenberger, O., 2006. SAS for Mixed Models, 2nd ed. SAS Institute Inc., Cary, NC.

Lundkvist, A., Salomonsson, L., Karlsson, L., Gustavsson, A.M.D., 2008. Effects of organic farming on weed flora composition in a long term perspective. Eur. J. Agron. 28, 570–578.

Millennium Ecosystem Assessment, 2005. Ecosystems and Human Well-being: Biodiversity Synthesis. World Resources Institute, Washington, DC.

MMAMRM, 2010. Balances de Gestión de Cereales. www.mapa.es/es/agricultura/pags/cereales/Nacional/ConjuntoCereales.htm (Last access 20.02.10).

Moreby, S.J., Aebischer, N.J., Southway, S.E., Sotherton, N.W., 1994. A comparison of the flora and arthropod fauna of organically and conventionally grown winter wheat in southern England. Ann. Appl. Biol. 125, 13–27.

Moreno, C.E., Halffter, G., 2001. On the measure of sampling effort used in species accumulation curves. J. Appl. Ecol. 38, 487–490.

Moya-Laraño, J., Wise, D.H., 2007. Two simple strategies to increase the power of experiments with multiple response variables. Basic Appl. Ecol. 8, 398–410.

Pfiffner, L., Niggli, U., 1996. Effects of biodynamics, organic and conventional farming on ground beetles (Col. Carabidae) and other epigeic arthropods in winter wheat. Biol. Agric. Hortic. 12, 353–364.

Piha, M., Tiainen, J., Holopainen, J., Vepsalainen, V., 2007. Effects of land-use and landscape characteristics on avian diversity and abundance in a boreal agricultural landscape with organic and conventional farms. Biol. Conserv. 140, 50–61.

R Development Core Team, 2010. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria, www.R-project.org (Last access 10.02.11).

Romero, A., Chamorro, L., Sans, X., 2008. Weed diversity in crop edges and inner fields of organic and conventional dryland winter cereal crops in NE Spain. Agric. Ecosyst. Environ. 124, 97–104.

Roschewitz, I., Gabriel, D., Tscharntke, T., Thies, C., 2005. The effects of landscape complexity on arable weed species diversity in organic and conventional farming. J. Appl. Ecol. 42, 873–882.

Royal Society, 2009. Reaping the Benefits: Science and the Sustainable Intensification of Global Agriculture. The Royal Society, London.

Schmidt, M.H., Clough, Y., Schulz, W., Westphalen, A., Tscharntke, T., 2006. Capture efficiency and preservation attributes of different fluids in pitfall traps. J. Arachnol. 34, 159–162.

Schmidt, M.H., Roschewitz, I., Thies, C., Tscharntke, T., 2005. Differential effects of landscape and management on diversity and density of ground-dwelling farmland spiders. J. Appl. Ecol. 42, 281–287.

Shah, P.A., Brooks, D.R., Ashby, J.E., Perry, J.P., Woiwod, I.P., 2003. Diversity and abundance of the coleopteran fauna from organic and conventional management system in southern England. Agr. Forest. Entomol. 5, 51–60.

Siemann, E., Tilman, D., Haarstad, J., Ritchie, M., 1998. Experimental tests of the dependence of arthropod diversity on plant diversity. Am. Nat. 152, 738–750.

Sunderland, K., Samu, F., 2000. Effects of agricultural diversification on the abundance, distribution, and pest control potential of spiders: a review. Entomol. Exp. Appl. 95, 1–13.

Thompson, J.D., 2005. Plant Evolution in the Mediterranean. Oxford University Press, Oxford.

Walter, H., 1994. Vegetation of the Earth and Ecological Systems of the Geo-biosphere, 3rd ed. Heidelberg Science Library, Springer-Verlag, Germany.

Weibull, A.C., Östman, Ö., 2003. Species composition in agroecosystems: the effect of landscape, habitat, and farm management. Basic Appl. Ecol. 4, 349–361.

Weibull, A.C., Ostman, Ö., Granqvist, A., 2003. Species richness in agroecosystems: the effect of landscape, habitat and farm management. Biodivers. Conserv. 12, 1335–1355.

Wilson, J.D., Evans, A.D., Grice, P.V., 2009. Bird Conservation and Agriculture. Cambridge University Press, Cambridge.

Wilson, J.D., Evans, A.D., Grice, P.V., 2010. Bird conservation and agriculture: a pivotal moment? Ibis 152, 176–179.