Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/sjar
doi: http://dx.doi.org/10.5424/sjar/2012101-202-11

Spanish Journal of Agricultural Research 2012 10(1): 55-61
ISSN: 1695-971-X
eISSN: 2171-9292

# Epigeic soil arthropod abundance under different agricultural land uses

J. L. Pérez-Bote*, and A. J. Romero

*Área de Zoología, Facultad de Ciencias, Universidad de Extremadura, 06071 Badajoz, Spain*

## Abstract

The study of soil arthropods can provide valuable information how ecosystems respond to different management practices. The objective was to assess the total abundance, richness, and composition of epiedaphic arthropods in different agrosystems from southwestern Spain. Six sites with different agricultural uses were selected: olive grove, vineyards, olive grove with vineyards, wheat fields, fallows (150-300 m long), and abandoned vineyards. Crops were managed in extensive. Field margins were used as reference habitats. At the seven sites a total of 30 pitfall traps were arranged in a 10 × 3 grid. Traps were arranged to short (SD, 1 m), medium (MD, 6 m) and large (LD, 11 m) distance to the field margins in the middle of selected plots. Pitfall traps captured a total of 11,992 edaphic arthropods belonging to 11 different taxa. Soil fauna was numerically dominated by Formicidae (26.60%), Coleoptera (19.77%), and Aranae (16.76%). The higher number of soil arthropods were captured in the field margins followed by the abandoned vineyard. Significant differences were found between sites for total abundance, and zones. However, no significant differences for total abundance were found between months (April-July). Richness and diversity was highest in field margins and abandoned vineyards. Significant differences were found for these variables between sites. Our results suggest that agricultural intensification affects soil arthropods in Tierra de Barros area, a taxonomic group with an important role in the functioning of agricultural ecosystems.

**Additional key words**: abundance; agrosystems; diversity; field margins.

## Resumen

### Abundancia de artrópodos epigeos en parcelas con diferentes cultivos

El estudio de los artrópodos puede aportar información de interés de cómo los ecosistemas responden a las diferentes prácticas de manejo del suelo. El objetivo de este estudio fue determinar la abundancia, la riqueza y la composición de artrópodos epigeos en diferentes agrosistemas del suroeste de España. Se seleccionaron seis parcelas con diferentes usos agrícolas: olivar, viñedo, plantación mixta de viñedo-olivar, cereal, barbecho y viñedo abandonado, utilizándose los linderos como sistemas de referencia. En cada parcela se colocaron 30 trampas de caída en una cuadrícula de 10 × 3, de modo que cada línea de trampas quedó colocada a una distancia corta (SD, 1 m), media (MD, 6 m) o grande (LD, 11 m) de los linderos. Se capturaron un total de 11.992 artrópodos edáficos, pertenecientes a 11 taxa diferentes. Numéricamente la fauna del suelo estaba dominada por Formicidae (26,60%), Coleoptera (19,77%) y Aranae (16,76%). El mayor número de artrópodos se capturó en los linderos y en la viña abandonada, encontrándose diferencias significativas en la abundancia entre las diferentes parcelas y las zonas donde se ubicaron las líneas de trampas. Sin embargo, no se encontraron diferencias entre los distintos meses estudiados (abril-julio). La riqueza y la diversidad fue mayor en los linderos y en la viña abandonada, encontrándose diferencias entre parcelas para estas variables. Nuestros resultados sugieren que la intensificación de la agricultura afecta a los artrópodos en Tierra de Barros, un grupo taxonómico con un importante papel en el funcionamiento de los ecosistemas agrícolas.

**Palabras clave adicionales**: abundancia; agrosistemas; linderos; diversidad.

*Corresponding author: jlperezbote.university@gmail.com
Received: 29-04-11. Accepted: 27-01-12

Abbreviations used: LD (large distance, 11 mm); MD (medium distance, 6 m); S (richness); SD (short distance, 1 m).

## Introduction

Agricultural use covers about or ca. 40% of the European land surface, with values up to 70% in some areas (Hails, 2002). Nowadays, various stakeholders request nonfood services from agricultural areas (*e.g.* hunting, tourism, leisure, production of renewable energy, biodiversity conservation) and, in general, society expects the agricultural landscape to be aesthetically pleasant and environmentally healthy (Brandt *et al*., 2000). Conversion of natural vegetation into agroecosystems and agriculture intensification, have profound impact on soil communities because they involve changes within the primary determinants of soil biodiversity, *e.g.* vegetation and soil microclimate (Wall *et al*., 2001; Decaëns & Jiménez, 2002; Gill *et al*., 2011).

There have been numerous reports of widespread negative impacts on local flora and fauna due to agricultural management strategies in several countries (Landis *et al.,* 2000; Sotherton & Self, 2000; Letourneau & Goldstein, 2001; Vickery *et al*., 2001; Moreby *et al*., 2006). This reduction in biodiversity may be related both to the loss of habitats and to the degradation of remaining habitats. Semi-natural habitats within agroecosystems, such as woody hedgerows and field margins, typically support a wider variety of plants than adjacent crop fields (Boutin & Jobin, 1998; Boutin *et al*., 2002). In contrast to the impoverished environment of cultivated fields, marginal habitats may provide homes for several groups of arthropods by contributing to a stable structural habitat and a consistent food source (Duelli *et al.,* 1990; Dennis & Fry, 1992).

While fostering arthropod populations in agricultural environments can be achieved by maintaining semi-natural areas adjacent to crop fields or maintaining healthy plant diversity within fields, the use of pesticides on crops may adversely affect arthropod populations (Sotherton *et al*., 1988).

Biodiversity in agricultural habitats is influenced by the surrounding landscape. The relationship between local species richness and the regional landscape has been addressed for several groups of plants and arthropods in Europe (*e.g.* Roschewitz *et al*., 2005; Schmidt *et al*., 2005). In general, more complex landscapes serve to increase the regional species pool, which translates into a higher biodiversity in crop fields and margins.

The objective of this study was to measure the effect of different agricultural soil uses on arthropod richness, abundance, and composition in a highly exploited region from an agricultural point view as is Tierra de Barros in the south-western Spain.

## Material and methods

Fieldwork was carried out in Tierra de Barros area (1.419 km²) near the city of Almendralejo (south-western Spain, 38° 41’ 26’’ N / 6° 24’ 43’’ W, 337 m a.s.l). The climate is typically Continental-Mediterranean with relatively cold wet winters and dry hot summers (mean temperature: 16.3ºC, rainfall: 432 mm $yr^{-1}$). Its flat to gently undulating landscape is dominated by a mosaic of dry winter cereal crops (wheat, *Triticum aestivum*, and barley, *Hordeum vulgare*), olive groves (*Olea europaea*), and vineyards (*Vitis vinifera*). Cereal crops occupied up to 2071 ha (13.72% of the total area), vineyards covered 7594 ha (50.32% of the total area) and olive groves extended over 4624 of the total area ha (30.64% of the total area). The remaining area corresponded to minor crops (mainly fruit trees), fallows of variable ages, dry pastures, river vegetation and villages. In this area natural habitats are only represented by the filed margins and some patches of riparian vegetation.

The sampling was done monthly between April and July of 2006. Six sites with different agricultural uses were selected: olive grove, vineyards, olive grove with vineyards, wheat fields, fallows (150-300 m long), and abandoned vineyards. All crops were managed in extensive. As field margins are used as reference habitats, in this study a band of 30 × 500 m located near the A6 highway was used as field margin. In this zone vegetation is composed mainly by Gramineae, Leguminoseae, Asteraceae and Rosaceae. Habitat complexity was enhanced by the presence of stones and agricultural debris.

At the seven sites a total of 30 pitfall traps (plastic jar, diameter = 30 cm, height = 15 cm) filled with a 3% formalin solution (Pekár, 2002) and detergent (~1 mL) were arranged in a 10 × 3 grid (Fig. 1). Columns were arranged to short (SD, 1 m), medium (MD, 6 m) and large (LD, 11 m) distance to the field margins in the middle of selected plots, according to Kennedy *et al.* (2001) and Buchholz *et al*. (2010). Traps were collected after 24 h. After each sampling, arthropods were sorted and preserved in ethyl alcohol (70%).

### Statistical analysis

Data were tested for normality using the Kolmogorov-Smirnov test ($p < 0.05$) and tested with F and student t test ($p < 0.05$). The number of individuals captured by pitfall traps at different sites, zones and

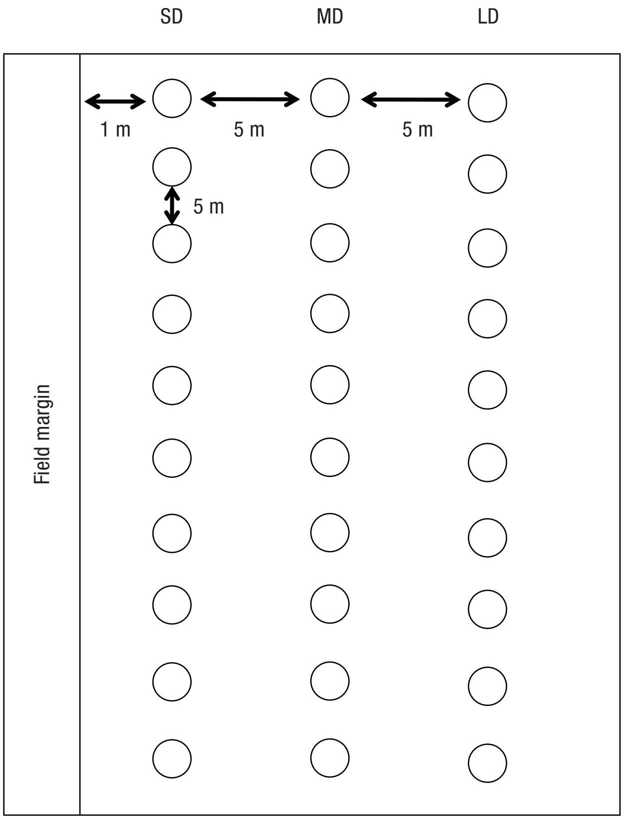


**Figure 1.** Arrangement of thirty pitfall traps in selected sites. Columns were arranged to short (SD, 1 m), medium (MD, 6 m) and large (LD, 11 m) distance to the field margins in the middle of selected plots.

months were compared by a one-way ANOVA. Post hoc comparisons of means were done using the Tukey test. The Z-test for two proportions was used to compare the abundance of arthropods between sites. This analysis was performed using SPSS 19.0 package for Windows (SPSS Inc. USA). For each group, taxa diversity and evenness were calculated following Shannon and Pielou indexes respectively. Richness index (S) was also calculated based on the number of different taxa per trap. Diversity indices among samples were compared using Shannon diversity t test ($p < 0.05$). All tests were performed using the statistical software PAST (Hammer *et al*., 2001).

## Results

Pitfall traps captured a total of 11,992 edaphic arthropods belonging to 11 different taxa: Formicidae, Acari, Collembola, Coleoptera, Araneae, Hemiptera, Isopoda, Myriapoda, Blattodea, Embioptera and Dermaptera (Table 1). Besides those taxa, pitfall traps captured 178 adult individuals belonging to the taxa Diptera, Hymenoptera, Orthoptera, and Thysanoptera which are not true soil inhabitants and were not considered in the analysis. Soil fauna was numerically dominated by Formicidae (26.60%) of all organisms captured, Coleoptera (19.77%), Araneae (16.76%),

**Table 1.** Total number of specimens, richness, diversity and evenness of soil arthropods captured in the different agrosystems studied

| | Abandoned vineyard | Olive grove | Vineyard | Olive grove + Vineyard | Fallow | Wheat field | Field margin |
|---|---|---|---|---|---|---|---|
| Formicidae | 990 | 74 | 311 | 379 | 53 | 215 | 1,168 |
| Acari | 180 | 245 | 158 | 417 | 123 | 48 | 368 |
| Collembola | 350 | 147 | 221 | 250 | 74 | 68 | 497 |
| Coleoptera | 270 | 105 | 368 | 698 | 243 | 146 | 541 |
| Araneae | 530 | 285 | 428 | 126 | 37 | 112 | 492 |
| Hemiptera | 167 | 69 | 105 | 117 | 35 | 45 | 288 |
| Isopoda | 45 | 15 | 6 | 26 | 8 | 6 | 66 |
| Myriapoda | 29 | 1 | 2 | 0 | 3 | 2 | 52 |
| Blattodea | 23 | 1 | 1 | 1 | 0 | 1 | 64 |
| Embioptera | 23 | 0 | 1 | 0 | 0 | 0 | 32 |
| Dermoptera | 16 | 0 | 0 | 1 | 0 | 2 | 22 |
| Total | 2,623 | 942 | 1,601 | 2,015 | 576* | 645* | 3,590 |
| Richness | 11 | 9 | 10 | 9 | 8 | 10 | 11 |
| Shannon's diversity index | 1.787 | 1.718 | 1.728 | 1.669 | 1.610 | 1.712 | 1.912 |
| Pielou's eveness index | 0.542 | 0.619 | 0.629 | 0.589 | 0.615 | 0.554 | 0.625 |

*: significant at $p < 0.05$, Tukey-test.

Acari (12.83%), Collembola (13.40%) and Hemiptera (6.89%). Myriapoda, Blattodea, Embioptera, and Dermaptera collectively accounted for 3.74% of the total collected.

The higher number of soil arthropods were captured in the field margins followed by the abandoned vineyard (Table 1). Significant differences were found between sites for total abundance ($F$ = 2.555; df = 6; $p$ = 0.026). Tukey's pairwise comparisons showed significant differences between field margins and fallows and wheat fields. The percentage in abundance of main groups of arthropods at different sites respect to field margin is shown in Figure 2. Significant differences for total abundance were also found between zones ($F$ = 3.655; df = 2; $p$ = 0.03), being the traps located nearest to the margin (SD) where more arthropods were captured (Table 2). Tukey's pairwise comparisons showed significant differences between SD and LD ($p$ = 0.04). More arthropods were caught in July. However, no significant differences for total abundance were found between months ($F$ = 0.522; df = 3; $p$ = 0.669).

Richness was highest (n=11) in field margins and abandoned vineyards. Diversity was higher in field margins followed by abandoned vineyards whereas evenness was higher in field margins followed by fallow (Table 1). However, no significant differences were found for diversity between these two sites (Diversity t-test, $p$ = 0.385). In relation to date of capture, both diversity and evenness were higher in April (Table 2), and lower in July. Finally, both diversity and evenness were higher in the line of traps located to medium distance from the margins (Table 2). Diversity was significantly higher at medium distance that at short distance from the margins (Diversity t-test, $p$ < 0.001).

## Discussion

As expected, in this study field margins supported the most abundant and diverse community of soil arthropods followed by the abandoned vineyard. The arthropod community was dominated by Formicidae, Coleoptera and Aranae in terms of abundance. The dominance of Formicidae and Coleoptera has been indicated as a general trait of ground dwelling assemblages in the Mediterranean and dessert assemblages (Doblas-Miranda *et al*., 2007). Even in Mediterranean agrosystems these groups dominates in the soil arthropod fauna (Morris & Campos, 1999; Santos *et al*., 2007). The presence of other groups is heterogeneous and may depend of the geographic situation, the management regime and the surrounding vegetation (Morris & Campos, 1999).

Plant diversity has long been recognized as an important factor determining the diversity of organisms

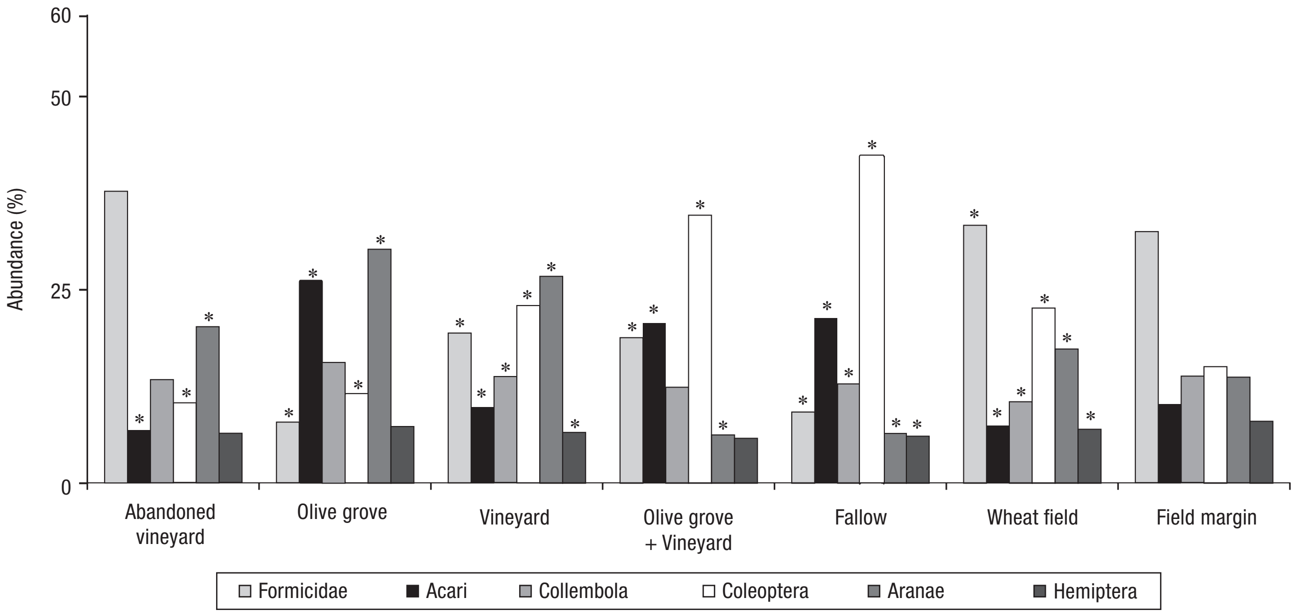


**Figure 2.** Comparison of captures (in percentage) by site respect to field margins for the most abundant taxa of soil arthropods captured (*: significant at $p$ < 0.05, Z-test).

**Table 2.** Total number of specimens, richness, diversity and evenness of soil arthropods captured in the different months and by distance to the field margins

| | April | May | June | July | SD | MD | LD |
|---|---|---|---|---|---|---|---|
| Formicidae | 442 | 585 | 918 | 1,245 | 1,978 | 698 | 514 |
| Acari | 232 | 289 | 785 | 233 | 965 | 385 | 189 |
| Collembola | 589 | 430 | 273 | 315 | 935 | 425 | 247 |
| Coleoptera | 394 | 495 | 632 | 850 | 1,180 | 663 | 528 |
| Araneae | 321 | 375 | 425 | 889 | 1,452 | 425 | 133 |
| Hemiptera | 152 | 175 | 235 | 264 | 418 | 196 | 212 |
| Isopoda | 48 | 49 | 38 | 37 | 103 | 46 | 23 |
| Myriapoda | 44 | 22 | 13 | 10 | 43 | 17 | 29 |
| Blattodea | 35 | 14 | 22 | 20 | 46 | 26 | 19 |
| Embioptera | 19 | 20 | 8 | 9 | 29 | 13 | 14 |
| Dermoptera | 11 | 11 | 8 | 11 | 21 | 13 | 7 |
| Total | 2,287 | 2,465 | 3,357 | 3,883 | 7,170 | 2,907 | 1,915* |
| Richness | 11 | 11 | 11 | 11 | 11 | 11 | 11 |
| Shannon's diversity index | 1.944 | 1.906 | 1.795 | 1.708 | 1.840 | 1.878 | 1.849 |
| Pielou's eveness index | 0.635 | 0.611 | 0.547 | 0.505 | 0.572 | 0.594 | 0.577 |

SD: short distance; MD: medium distance; LD: large distance; *: significant at $p < 0.05$, Tukey test.

at higher trophic levels (Harvey *et al*., 2008). The intimate relationship between plant and arthropods composition is complex and beyond the scope of this study. However, in this study a clear influence of 'habitat complexity' on abundance soil arthropods has been demonstrated. Thus our results are agree with those reported by Attwood *et al*. (2008), that observed a general decline in arthropod richness with increasing land-use and management intensity. These authors suggested that the broad process of agricultural intensification from intact, indigenous vegetation associations, through fragmented mixed-agricultural landscapes, to highly intensive, monotypic grazing or cropping systems can lead to a reduction in biological diversity via a range of impacts and threats. There is a number of possible explanations for higher arthropod richness in systems with less intensive land uses (Attwood *et al*., 2008). Areas of low to moderate modification/intensification (such as native vegetation and pasture) are likely to have greater habitat complexity, due in part to less exposure to intensive and uniform management than many cropping systems. Therefore, in complex land uses, niche opportunities are likely to be numerous, whilst fewer niches may be available in structurally and compositionally less complex systems. Consequently, opportunities for coexistence through resource partitioning, are likely to be reduced in simplified systems, resulting in lowered species richness. More complex habitat composition and structure may allow greater access to a wider range of alternative food resources (Langellotto & Denno, 2004), thus supporting more omnivorous and non-obligate predatory taxa. Another potential explanation for greater richness in less disturbed habitats is that in frequently or intensely disturbed environments, community composition cannot progress beyond early pioneer stages. This frequent 'resetting of the successional clock' in areas of high disturbance results in environments that favor early successional species, while disadvantaging later successional species (Büchs *et al*., 2003). If the disturbance is sufficiently severe and frequent (such as in intensive cropping), it could feasibly exclude all but the most ruderal of taxa, thus potentially leading to overall lower species numbers.

Common crop management practices such as deep tillage, agro-chemical application and mechanical harvesting may all serve to increase the frequency and severity of disturbance regimes (Thorbek & Bilde, 2004). We do not have analyzed the influence of these factors in our study. However, we have studied tilled and non-tilled systems. Sharley *et al.* (2008) demonstrated that tillage within vineyards systems disrupted a number of beneficial invertebrate groups, including ants, centipedes, and millipedes. Ant assemblages were particularly disrupted by tillage. Santos *et al.* (2007) found a similar conclusion in an olive grove ecosystem: if olive grove is frequently disturbed sensitive species of ants will be progressively eliminated.

In our study traps located near the field margins captured more arthropods than those located at medium and large distances. This is according with previous studies that demonstrated that semi-natural habitats bordering crop fields provide stable shelter, food sources, and microclimate to a wide range of arthropods (*e.g.* Smith *et al.*, 2008). Thus, more arthropods can be captured near the hedgerows.

Seasonal conditions at the study site were not pronounced and so no significant differences in abundance and diversity between sampling periods were expected. Strong seasonality is a feature of most ecosystems, particularly in Mediterranean habitats, where the seasonal fluctuations of temperature and rainfall create marked pulses of productivity and animal activity (Blondel & Aronson, 1999). The seasonal and annual variability of the assemblage has potentially important implications on community dynamics in the study systems, since the changes in species composition and trophic structure of soil invertebrate assemblages may affect species interactions and food web dynamics over time (Doblas-Miranda *et al*., 2007).

Our results suggest that agricultural intensification affects soil arthropods in Tierra de Barros area. Arthropods are important drivers of ecosystem functions as nutrient cycling, pest control, pollination and maintenance of soil structure. So, strategies for addressing the conservation of arthropods in agricultural landscapes must be promoted.

## Acknowledgements

This study was founded by DEMA (Defensa y Estudio del Medio Ambiente), Almendralejo, Badajoz (Spain) through the Project LIFE 05/NAT/F/000134 'Renforcement et conservation du falcon crécerellette dans l'Aude (Fr) et l'Extremadure (Es)'. The authors are grateful to J.M. Torrejón and the members of DEMA that helped in field work.

## References

Attwood SJ, Maron M, House APN, Zammit C, 2008. Do arthropod assemblages display globally consistent responses to intensified agricultural land use and management? Global Ecol Biogeogr 17: 585-599.

Blondel J, Aronson J, 1999. Biology and wildlife of the Mediterranean Region. Oxford Univ Press, Oxford, UK, 328 pp.

Boutin C, Jobin B, 1998. Intensity of agricultural practices and effects on adjacent habitats. Ecol Appl 8: 544-557.

Boutin C, Jobin B, Bélanger L, Choinière L, 2002. Plant diversity in three types of hedgerows adjacent to crop fields. Biodivers Conserv 11: 1-25.

Brandt J, Tress B, Tress G (eds), 2000. Multifunctional landscapes: interdisciplinary approaches to landscape research and management. Conf Multifunctional Landscapes, Centre for Landscape Research, Roskilde, Denmark, 18-21 October.

Buchholz S, Jess AA, Hertenstein F, Schirmel J, 2010. Effect of the color of pitfall traps on their capture efficiency of carabid beetles (Coleoptera: Carabidae), spiders (Araneae) and other arthropods. Eur J Entomol 107: 277-280.

Büchs W, Harenberg A, Zimmermann J, Weib B, 2003. Biodiversity, the ultimate agri-environmental indicator? Potential and limits for the application of faunistic elements as gradual indicators in agroecosystems. Agr Ecosyst Environ 98: 99-123.

Decaëns T, Jiménez JJ, 2002. Earthworm communities under an agricultural intensification gradient in Colombia. Plant Soil 240: 133-143.

Dennis P, Fry GLA, 1992. Field margins: Can they enhance natural enemy population densities and general arthropod diversity on farmland? Agr Ecosyst Environ 40: 95-115.

Doblas-Miranda E, Sánchez-Piñero F, González-Megías A, 2007. Soil macroinvertebrate fauna of a Mediterranean arid system: Composition and temporal changes in the assemblage. Soil Biol Biochem 39: 1916-1925.

Duelli P, Studer M, Marchand I, Jacob S, 1990. Population movements of arthropods between natural and cultivated areas. Biol Conserv 54: 193-207.

Gill HK, McSorley R, Branham M, 2011. Effect of organic mulches on soil surface insects and arthropods. Fla Entomol 94: 226-232.

Hails RS, 2002. Assessing the risks associated with new agricultural practices. Nature 418: 685-688.

Hammer Ø, Harper DAT, Ryan PD, 2001. PAST: Paleontological statistics software package for education and data analysis. Palaeontologia Electronica 4: 1-9.

Harvey JA, Van Der Putten WH, Turin H, Wagenaar R, Bezemer TM, 2008. Effects of changes in plant species richness and community traits on carabid assemblages and feeding guilds. Agr Ecosys Environ 127: 100-106.

Kennedy PJ, Conrad KF, Perry JN, Powell D, Aegerter J, Todd AD, Walters KFA, Powell W, 2001. Comparison of two field-scale approaches for the study of effects of insecticides on polyphagous predators in cereals. Apl Soil Ecol 17: 253-266.

Landis DA, Wratten SD, Gurr GM, 2000. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu Rev Entomol 45: 175-201.

Langellotto GA, Denno RF, 2004. Responses of invertebrate natural enemies to complex-structured habitats: a meta-analytical synthesis. Oecologia 139: 1-10.

Letourneau DK, Goldstein B, 2001. Pest damage and arthropod community structure in organic *versus* conventional tomato production in California. J Appl Ecol 38: 557-570.

Moreby SJ, Aebischer NJ, Southway SE, Sotherton NW, 2006. A comparison of the flora and arthropod fauna of organically and conventionally grown winter wheat in southern England. Ann Appl Biol 125: 13-27.

Morris T, Campos M, 1999. Predatory insects in olive-grove soil. Zool Baetica 10: 149-160.

Pekár S, 2002. Differential effects of formaldehyde concentration and detergent on the catching efficiency of surface active arthropods by pitfall traps. Pedobiologia 46: 539-547.

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.

Santos SAP, Cabanas JE, Pereira JA, 2007. Abundance and diversity of soil arthropods in olive grove ecosystem (Portugal): effect of pitfall trap type. Eur J Soil Biol 43: 77-83.

Schmidt MH, 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.

Sharley DJ, Hoffmann AA, Thomson LJ, 2008. The effects of soil tillage on beneficial invertebrates within the vineyard. Agr Forest Entomol 10: 233-243.

Smith J, Potts S, Eggleton P, 2008. The value of sown grass margins for enhancing macrofaunal biodiversity in arable systems. Agr Ecosyst Environ 127: 119-125.

Sotherton NW, Self MJ, 2000. Changes in plant and arthropod biodiversity on lowland farmland: An overview. In: Ecology and conservation of lowland farmland birds (Aebischer NJ, Evans AD, Grice PV, Vickery JA, eds.). British Ornithologists Union, Tring, UK, pp: 26-35.

Sotherton NW, Dover JW, Rands NWR, 1988. The effects of pesticide exclusion strips on faunal populations in Great Britain. Ecol Bull 39: 197-199.

Thorbek P, Bilde T, 2004. Reduced numbers of generalist arthropod predators after crop management. J Appl Ecol 41: 526-538.

Vickery JA, Tallowin JR, Feber RE, Asteraki EJ, Atkinson PW, Fuller RJ, Brown VK, 2001. The management of lowland neutral grasslands in Britain: Effects of agricultural practices on birds and their food resources. J Appl Ecol 38: 647-664.

Wall DH, Adams GA, Parsons AN, 2001. Soil biodiversity. In: Global biodiversity in a changing environment (Chapin FS, Sala OE, Huber-Sannwald E, eds.). Springer Verlag, NY, pp: 47-82.