Evolution of floristic composition and species diversity of weed community after 10-years of different cropping systems and soil tillage in Mediterranean environment

E CAMPIGLIA[a], E RADICETTI[a]*, R MANCINELLI[a]*

[a] *Department of Agricultural and Forestry Sciences, University of Tuscia, Via S. Camillo de Lellis snc, 01100, Viterbo, Italy*

**Correspondence*: Dr. Emanuele Radicetti, Department of Agricultural and Forestry Sciences, University of Tuscia, via S. Camillo de Lellis, 01100 Viterbo, Italy. Tel.: (+39) 0761 357538; Fax: (+39) 0761 357558; E-mail address: radicetti@unitus.it

Summary

Sustainable cropping systems based on low inputs are gaining attention, even if may determine a change on weed community composition. This study, conducted from 2011 to 2014, evaluates the changes of weed species under different cropping systems [conventional (CONV) and organic (ORG)] and soil tillage [inversion tillage (IT) and non-inversion tillage (NoIT)] in a wheat-tomato-chickpea rotation under Mediterranean environment after 12-years of cultivation. Treatments were replicated three times according to a randomized complete block design. The ORG was managed according to EU regulations. The IT consisted in moldboard plowing to a depth of 30 cm, while the NoIT consisted in subsoiling to a depth of 20 cm. ORG-NoIT showed the highest weed biomass (134.6, 128.3 and 195.4 g m^{-2} of DM in wheat, tomato and chickpea, respectively) and density (66.2, 77.3 and 76.1 plant m^{-2} of DM in wheat, tomato and chickpea, respectively), as well as community richness and Shannon Index. ORG always increases weed biodiversity, even if annual dicots were high in ORG-IT, while perennial broadleaved species in ORG-NoIT. CONV increased the relative frequency of annual (CONV-IT) and perennial (CONV-NoIT) grasses. The negative correlation between perennial weeds and crop yield (r^2=0.2363, p<0.0001) suggests that perennial weeds was partly responsible for the crop yield reduction. Combining organic practices with non-inversion tillage could lead to the establishment of perennial dicots difficult to manage, which requires the adoption of new management practices.

Keywords: Organic farming; Non-inversion tillage; Biodiversity.

Introduction

Biodiversity is perceived as a factor strongly related to the stability of agro-ecosystems and can be viewed as a positive effect even for cropping systems, as long as it does not hinder the production of optimum yields (Legere *et al.*, 2005). Biodiversity in agricultural landscapes has progressively decreased principally due to the simplification of crop rotations and intensification of farming practices (Geiger *et al.*, 2010). Consequently, cropping systems should be reassessed in order to drastically reduce their reliance on external inputs, while maintaining acceptable levels of biodiversity and crop yields (Tilman *et al.*, 2002). In this context, weeds are still one of the main issues in cropping systems, as they are responsible for significant losses in crop yield and quality, even if natural flora is an important component of vegetable biodiversity in agricultural landscapes (Van Elsen, 2000). Weeds also play a key role in supporting biodiversity within the agro-ecosystem, because they often constitute the base of the food chain for herbivores and their natural enemies and support many species of beneficial insects, especially crop pollinators (Marshall *et al*., 2003). Current weed control programs have mainly focused on herbicide, which has led to a rapid evolution of herbicide-resistant weeds and serious environmental concerns (Dalton & Boutin, 2010). Therefore, alternative methods, such as mechanical and cultural weed control, should be widely considered (Halde *et al.*, 2015). However, a quantitative insight of the population dynamics of weeds and their interaction with crops is required in order to develop improved weed management systems with a reduced dependence on herbicides (Hosseini *et al.*, 2014). Several studies have shown how weed occurrence, composition and density are reflections of past and present agricultural practices (Ruisi *et al.*, 2015). Organic cropping systems usually show a higher level of weed infestation although they have a higher species diversity than that observed in conventional cropping systems, probably because mechanical weed control commonly achieves lower control effects than herbicides (Hatcher & Melander, 2003). Furthermore, substituting chemical fertilizers with manure and organic fertilizers generally affect diversity and growth of weeds mainly due to shifts of nutrient availability (Blackshaw *et al.*, 2003). Therefore, organic practices could favor the maintenance of weed diversity and consequently ecosystem services, but they are only feasible for organic producers if they minimize crop losses to an economically acceptable level (Van Elsen, 2000). Similarly, conventional farming systems also vary in their relative influence on weed species diversity and community composition according to the intensity of external input used as well as tillage practices (Ruisi *et al.*, 2015).

Conservation agriculture based on minimum soil disturbance, permanent soil cover and crop rotation, is an innovative approach for managing agro-ecosystems for improved and sustained crop production adopted with the aim of preserve and enhance resource cycling and environmental safety (Hobbs et al. 2004). Although it has been recognized an effective management to increase sustainable crop yield

(Hobbos et al. 2008; Pittelkow et al., 2015), weed management is perceived as one of the most challenge under conservation agriculture management (Farooq et al., 2011). In fact, the reduction of the degree of soil disturbance under conservation agriculture increase weed abundance in respect to tilled cropping systems, particularly for perennial weeds (Tørresen *et al.*, 2003), therefore the adoption of an efficacy weed management strategies is crucial for achieving high crop yield.

Studies regarding the evaluation of cropping systems and soil tillage are essential for gaining insight on the effect on weed community responses, in terms of floristic composition and species diversity, on agro-ecosystems (Halde *et al.*, 2015). In fact, each crop and management practices provide weed growth conditions (Doucet et al. 1999), therefore act as a filter which determine the assembly of weeds based on their functional characteristics, such as annual or perennial weed species (Meiss et al. 2010). In the long term condition, this could change weed species diversity, where well adapted weeds plenty increase and became problematic to manage. According to Lal et al. (2014) long term field experiments are important with a view to evaluating changes in weed community composition and could give insight into long term effects. Nevertheless, few studies have focused on the effects of long-term cropping systems and tillage management on weed species diversity, particularly in the Mediterranean environment. This study hypothesizes that combining organic cropping systems with non-inversion tillage practices may lead to the establishment of a harmful weed flora under Mediterranean environment. The aim of this study was to evaluate weed community and species diversity after 12-years of wheat–tomato–chickpea rotation in response to different cropping systems (conventional *vs*. organic) and soil tillage (inversion *vs*. non-inversion). The specific goals were: (i) to analyze the floristic structure in terms of weed abundance; (ii) to analyze the functional structure in terms of morphotypes (monocotyledonous and dicotyledonous) and life cycle (annual, biennial and perennial); (iii) and to evaluate weed associations and composition.

Materials and methods

Description of the study area and climate

A long-term field experiment was established in 2000/2001 at University of Tuscia (Viterbo, lat. 42°25'N., long. 12°04'E., alt. 310 m a.s.l.), with the aim of comparing organic (ORG) *vs*. conventional (CONV) cropping systems and inversion tillage (IT) *vs*. non-inversion tillage (NoIT). This study started after 12-years from the beginning of the long-term experiment and it was conducted throughout three consecutive growing seasons (from 2011/2012 to 2013/2014). The soil is volcanic and classified as *Typic Xerofluvent*. The climate is typical of the Mediterranean environment, with annual rainfall of 752 mm and mean air temperature of 14.2°C.

Field set up and crop management

A 3-year crop rotation [wheat (*Triticum durum* Desf.) – tomato (*Lycopersicon esculentum* Mill.) – chickpea (*Cicer arietinum* L.)], typical of the study are, was established in conventional and organic cropping systems. In ORG, the crop rotation was implemented with vetch (*Vicia sativa* L.) and canola (*Brassica napus* L. var. *oleifera*) cover crops, which were green manured before tomato transplanting and chickpea sowing, respectively. The CONV was managed according to the traditional agricultural practices of the area by using pesticides and synthetic fertilizer, while ORG was managed according to the Council Regulation n.834/2007 regarding organic production. Two soil tillage managements were compared for both cropping systems: (a) inversion tillage which consisted in moldboard plowing application to a depth of 30 cm, (b) non-inversion tillage which consisted in subsoiling application to a depth of 20 cm. All field operation are performed with regular farm machine. The treatments were replicated three times according to a randomized complete block design. Considering that all crops in rotation were cultivated every year, the field experiment included 36 plots (2 cropping systems x 2 soil tillage x 3 crops x 3 blocks). Each experimental plot was 18 x 6 m (108 m^2), and they are separated by 3 m wide alleys to allow equipment operation.

The main agricultural practices applied to the long-term experiment are reported in Table 1. The planting date of the crops varied according to the year, however it was always in November, May and February for wheat, tomato, and chickpea, respectively, while the harvesting date was in July for wheat and chickpea and in August for tomato, respectively. Only tomato was drip irrigated to reintegrate the water lost by evapotranspiration estimated with a class A pan evaporimeter and adjusted using crop coefficient. The same amount of water was applied in all experimental treatments.

Data collection and diversity indices

Every year, weed assessment was performed at physiological maturity for wheat and chickpea, while it was carried out at crop harvesting for tomato. Weed density (identified and counted by species) and weed aboveground biomass were determined simultaneously using a quadrant (0.25 m^2) positioned randomly four times in the central area of each plots and pooled together to calculate weed characteristics per unit area (1 m^2). The weed aboveground biomass was oven dried at 70°C until constant weight.

The number of individuals per unit area (density) was used as the measure of weed abundance, while the number of weed species present in each plot (specie richness) was used as the measure of species diversity. Species richness (S) was calculated using the number of weed species recorded in each plot. Similarly, Shannon's diversity index was estimated as follows (Magurran, 1988):

Shannon's diversity index = $H' = - \Sigma_i PA_i (\ln PA_i)$

where PA_i is the proportional abundance of weed species i ($PA_i = n_i/n_{tot}$) and n_i is the relative frequency of species i and n_{tot} the sum over all species. H' is near to 0 when there are few species in the sample, while H' is maximum when all S species are represented in the sample.

Statistical analysis

The analysis of variance (ANOVA) was performed for each crop with the JMP statistical package, version 4.0. In order to homogenize the variance, after the Bartlett test, the weed density data were transformed before analysis, weed density as square root (x + 0.5), and percentages as angular transformation (Gomez & Gomez, 1984). The data reported in the tables were back transformed. A two-way factorial experimental design was adopted for weed aboveground biomass, weed density, species richness and Shannon's index, where the cropping system was a treatment, the soil tillage management was another treatment and the year was considered as repeated measure. Treatment means were compared with Fisher's protected least significant difference (LSD) test at 0.05 probability level.

Canonical Discriminant Analysis (CDA) was performed in order to evaluate the association between cropping systems and soil tillage groups on the occurrence of weed species (Kenkel *et al.*, 2002).

Weed communities were also described by dividing weed species into eight *a priori* groups defined as functional groups (FGs) (Meiss *et al.*, 2010). Grass species were divided into annual (FG n.7) and perennial (FG n.8), broad-leaved species into annual, perennial (FG n.6) and "intermediate" (FG n.5) (including biennials and species varying between annual and perennial life cycles). Considering that annual broad-leaved species constituted the largest group, they were sub-divided as: upright (FG n.1), erect morphology since the seedling stage, climbing (FG n.2), species that wind themselves around neighboring plants, rosette (FG n.4), circular arrangement of the first leaves near the soil surface, and others (FG n.3), comprising all other morphologies. Relative frequencies of the FGs were calculated by dividing the sum of the frequencies of all species in each FG by the sum of species frequencies across all functional groups.

Results

Influence of cropping system and soil tillage on weed characteristics

In each crop, the weed aboveground biomass was always the highest in the ORG-NoIT (134.6, 128.3 and 195.4 g m^{-2} of DM in wheat, tomato and chickpea, respectively, Fig. 1) followed by ORG-IT, CONV-NoIT and CONV-IT. No differences were observed bewteen CONV-IT and CONV-NoIT in wheat and tomato (on average 60.6 and 47.8 g m^{-2} of DM, respectively), while in chickpea CONV-NoIT showed higher values of weed biomass compared with CONV-IT (148.4 vs. 111.1 g m^{-2} of DM, respectively, Fig. 1). Total weed species observed throughout the experimental period are reported in Table 2. In wheat there were 25 weed species with a lot more dicotyledons than monocotyledons (80% vs. 20%, respectively, Table 3), 19 species were annual weeds while 6 species were perennial. In tomato, a total of 22 weed species were found (18 dicotyledons *vs*. 4 monocotyledons) of which 19 were annual and 3 perennial (Table 3). A total of 22 weed species (20 dicotyledons *vs*. 2 monocotyledons from 11 families were recorded in chickpea, of which 16 species were annual weeds while 6 species were perennial (Table 3).

Generally, ORG-NoIT showed the highest values of both weed community richness and Shannon Index for all crops (on average 17.4 and 2.21, respectively, Table 4), except for community richness in wheat which was similar between ORG treatments, and for Shannon Index in wheat and chickpea which was similar both ORG treatment and CONV-NoIT (Table 4). Community richness was similar among all crops, even if in ORG treatments it was higher in wheat and tomato than chickpea, while an opposite trend was observed in the CONV treatments. Shannon Index was higher in chickpea than tomato and wheat, except in ORG-NoIT which it was similar between chickpea and tomato crop (on average 2.10 vs. 1.93, respectively, Table 4).

The CDA on the weed species observed in wheat, tomato and chickpea are reported in Fig. 2. The first two canonical variables explained 71%, 62% and 53% of the total variance on cropping system and soil tillage treatments, for wheat, tomato and chickpea, respectively (Fig. 2). In wheat there was a tendency toward differentiation among weed communities according to cropping system and soil tillage management. Genrally, BROST, PHAMI, LOLPE, AVEST and APESV vectors seemed generally associated with both CONV treatments, while CONAR, CIRAR, SYLMA, BIFRA, CAPBP, DIPER, MYGPE, FUMOF and GALAP vectors were in the same orientation space of ORG-NoIT treatment. The CDA analysis on the weed species observed in tomato showed a clear tendency towards differentiation among weed flora composition (Fig. 2). SETVI, ECHCG, DIGSA, and AVEST vectors were in the same orientation space of both CONV treatments, while the other species seem to be associated to ORG, in particular CIRAR, CONAR, TRBTB, HEOEU, POLAV, SONAR, SLYMA, DITST and MERAN vectors seemed to be associated with ORG-NoIT. In chickpea, the CDA analysis on the weed species indicated that ANGAR, PICEC, MALSI, LOLPE, CIRAR and CONAR vectors seemed to be associated to both CONV-NoIT and ORG-NoIT, while the other weed species were in the same orientation space of ORG-IT. Only PAPRH and AVEST seemed to be associated with CONV-IT (Fig. 2).

Weeds on the cropping systems and soil tillage crop managements

Considering the whole crop rotation, the relative frequencies of the *a-priori* defined weed functional groups (FG) varied considerably among the groups due to the combination of cropping systems and soil tillage (Fig.4). Differences were significant for all of the eight FGs. Relative frequencies of upright annual dicots (FGn.1) were high in ORG-IT, intermediate in ORG-NoIT, and low in CONV regardless soil tillage. Moreover, ORG generally increased the relative frequencies of climbing annual dicots, other annual dicots and rosette annual dicots (FG n.2, 3, 4, respectively), compared to CONV (Fig.4). Intermediate dicotyledon frequencies (FG n.5) were generally very low in all cropping systems especially in CONV-IT, while perennial broadleaved species (FG n.6) were more frequent in NoIT regardless the cropping system. CONV increased the relative frequency of annual grasses (FGn.7) especially in IT and of perennial grasses but only in NoIT (Fig.4).

Effect of cropping system and soil tillage on crop yield

Over the study period, crop yields were generally affected by cropping system and for some crops by soil tillage management. Generally, wheat yield in ORG was lower compared with conventional (-27%), while no differences were observed regarding soil tillage. Tomato yield, in terms of marketable fresh fruits, was higher in ORG compared to CONV (+34%), while IT increased the tomato fruit yield compared to NoIT only in CONV (+19%). Chickpea grain yield was significantly reduced in ORG (-19%) and in NoIT (-12%) compared with CONV and IT, respectively. Crop yield was not affected by annual weed species density, while there was a negative correlation between perennial weed species density with crop yield $r^2 = 0.2363$, $p < 0.0001$ suggesting that the increase in perennial weed species was partly responsible for the reduction in crop yield over time (Fig. 4).

Discussion

This study provided valuable insights of weed flora under Mediterranean conditions, under different types of farming systems and soil tillage. Overall, weed density and aboveground biomass were significantly higher under organic and non-inversion tillage for all main crops. However, the fact that there were significant interactions between cropping systems and soil tillage for weed characteristics in all crops in rotation, indicates that the emerged weed flora responds strongly to management events, which determine the actual weed assemblage (Armengot *et al.*, 2011). Although the weed control was applied in both cropping systems, as expected the herbicides used in conventional were more effective in controlling weeds than mechanical means in organic. This was particularly evident in chickpea, which is known to be a weak competitor against weeds (Radicetti *et al*., 2012), in fact it had a higher weed aboveground biomass compared to wheat and tomato when cultivated in organic. The high presence of both winter weeds, such as CAPBP, DIPER, LOLPE, *etc*., and summer weeds, such as

AMARE, CHEAL, POLAV, *etc*., in chickpea reflect the cropping cycle of this legume crop, which is between the end of the winter and the middle of the summer, therefore it is liable to be infested by several ecological groups of weeds. Furthermore, from an agronomic point of view, the difficulties encountered in controlling the weeds in the organic treatments have negative effects especially in the long-term, as the soil seed bank could be significantly increased compared to the conventional treatment as observed by Graziani *et al.* (2012). Consequently, weed management under organic farming should not only rely on direct weed control methods, but also on a system approach including preventive and cultural weed management methods in order to optimize the whole cropping system rather than weed control *per se* and keep the weeds under a manageable threshold (Hatcher & Melander, 2003). However, it is important to note that we adopted the same cropping sequence in order to compare conventional *vs.* organic, but it is well known, in practice, that organic farming systems requires different cropping sequences and cultivars, therefore using a different crop rotation that is more suitable for organic conditions may have resulted in better weed control. Moreover, soil nutrient availability, especially nitrogen, can differ greatly between conventional and organic cropping systems which may have significantly affected weed characteristics (Dyck *et al.,* 1995). In fact, many weed species could accumulate and use nitrogen more efficiently than crops (Blackshaw et al. 2003). This effect was particularly evident in wheat under organic cropping systems, where the quantity of available nitrogen obtained from organic fertilizer was much less than from mineral fertilizer (Campiglia *et al.*, 2015). On the other hand, vetch green manured in organic farming before tomato transplanting, probably allowed for the release of a large amount of mineral nitrogen from the first stage of the crop (Radicetti *et al.*, 2016). In support of this hypothesis, some nitrophilous weed species, such as AMARE, CHEAL, SOLNI, proved to be the most dominant species in organic tomato.

The results obtained in this study are in accordance with those of previous studies which indicated that weed abundance and species richness was higher under organic than in conventional systems, regardless of the crop grown (Ryan *et al.*, 2009). These differences were particularly greater for the broad-leaved weed species such as STEME and GALAP in wheat, POLAV and FUMOF in chickpea, AMARE and SOLNI and CHEAL in tomato, suggesting that these species are less able to tolerate intensive land use practices based on herbicide-treated crops (Hyvönen *et al.*, 2003). On the other hand, the success of the monocotyledon species in conventional farming may be due to the use of foliar-applied herbicides, which are generally known to be less efficient on monocotyledons than on dicotyledons (Délye *et al.*, 2008). However, the results of this study highlight the long-lasting negative effects of conventional farming practices on both weed species richness and diversity, especially when herbicides are intensively used (Armengot *et al.*, 2013).

Regarding tillage, the increase of weed aboveground biomass per area unit in non-inversion tillage was mainly due to a greater presence of perennial weeds, which are generally more competitive against the annual crops cultivated in this study. This effect was particularly evident in chickpea, which is a poor competitor with perennial weeds (Radicetti *et al.*, 2012). It is well-known that inversion tillage affects weeds by uprooting, dismembering and burying them deep enough to prevent emergence, by moving their seeds both vertically and horizontally (Chauhan *et al.*, 2012). Any reduction in tillage intensity such as non-inversion tillage, tends to be less invasive and determines more complex weed characteristics compared to highly disturbed environments. In accordance with Armengot *et al.* (2011), our data showed that reduced tillage had a positive effect on weed community richness and the Shannon Index, even if it increased weed density of biennial and perennial weed species as observed by Trichard *et al.* (2013). The presence of perennial weeds, favored by reduced tillage conditions, may negatively affect crop yields, as already observed by several authors (Chauhan *et al.*, 2012; Tørresen *et al.*, 2003). Although crop yield reduction is not only caused by an increase in perennial weeds, it is true that perennial weeds such as LOLPE, CONAR, TAROF and CIRAR were more abundant in chickpea in reduced tillage conditions. Among the perennial weed species with increasing density over crops, CIRAR was one of the most widespread. This weed is a deep-rooted and broad-leaved perennial with rhizomes or creeping roots which can be harmful in reduced tillage systems and can spread across various environments (Tørresen et al., 2003). In this experiment CIRAR increased over time (data not shown) in all main crops in rotation and it is one of the most difficult weeds to control in reduced tillage conditions, especially in organic cropping systems in which chemical control is not allowed. It is important to note that whenever a weed becomes troublesome in a farming system, weed control strategies should be re-addressed in order to mitigate the problem. In our case we have applied the same practices of weed control for 12-years (4 crop rotation cycles) according to experimental protocol, which may have benefited weeds such as CIRAR in non-inversion tillage strategy which were not effectively controlled by the weed control practices adopted. Furthermore, this study evidences that environmental conditions under Mediterranean area associated to low input farming systems, such as organic cropping system managed in non-inversion tillage, may significantly enhance weed species composition and lead to a shift in weed community compared with high input cropping systems. These results are in line with those observed in temperate climate (Trichard *et al.*, 2013) or Boreal (Tørresen *et al.*, 2003). This hypothesis supports the idea that weed control strategies should be flexible over time in response to the appearance of a dominant troublesome weed flora, especially in organic farming where the weed seeds and propagules could increase significantly in the long run. Furthermore, this implies that conservation agriculture practices, based on the reduction of tillage in organic farming, should be carefully evaluated. Our findings suggest that, although organic farming increases weed biodiversity in terms of species richness and diversity, when a short rotation is adopted in the Mediterranean climate, combining organic practices with reduced tillage could lead to the establishment of a harmful weed flora mainly composed of perennial dicots which are difficult to control. Therefore further research is required in order to determine whether longer rotation cycles of more suitable crops and cultivars for organic farming could result in better weed control in reduced tillage conditions.

Acknowledgements

This study was financed by the European Union FP7 Project n. 289277: OSCAR (Optimizing Subsidiary Crop Applications in Rotations).

References

ARMENGOT L, JOSÉ-MARÍA L, BLANCO-MORENO JM, ROMERO-PUENTE A & SANS FX (2011) Landscape and land-use effects on weed flora in Mediterranean cereal fields. *Agriculture, Ecosystems & Environments* **142**, 311–317.

ARMENGOT L, JOSÉ-MARÍA L, CHAMORRO L & SANS FX (2013) Weed harrowing in organically grown cereal crops avoids yield losses without reducing weed diversity. *Agronomy for sustainable development* **33**, 405–411.

BLACKSHAW RE, BRANDT RN, JANZEN HH, ENTZ T, GRANT CA & DERKSEN DA (2003) Differential response of weed species to added nitrogen. *Weed Science* **51**, 532–539.

CAMPIGLIA E., MANCINELLI R, DE STEFANIS E, PUCCIARMATI S & RADICETTI E (2015) The long-term effects of conventional and organic cropping systems, tillage managements and weather conditions on yield and grain quality of durum wheat (*Triticum durum* Desf.) in the Mediterranean environment of Central Italy. *Field Crops Research* **176**, 34–44.

CHAUHAN BS, SINGH RG & MAHAJAN G (2012) Ecology and management of weeds under conservation agriculture: A review. *Crop Protection* **38**, 57–65.

DALTON RL & BOUTIN C (2010) Comparison of the effects of glyphosate and atrazine herbicides on nontarget plants grown singly and in microcosms. *Environmental Toxicology and Chemistry* **29**, 2304–2315.

DÉLYE C, MATÉJICEK A & MICHEL S (2008) Cross-resistance patterns to ACCase-inhibiting herbicides conferred by mutant ACCase isoforms in Alopecurus myosuroides Huds. (black-grass), re-examined at the recommended herbicide field rate. *Pest Management Science* **64**, 1179–1186.

DYCK E, LIEBMAN M & ERICH M (1995) Crop-weed interference as influenced by a leguminous or synthetic fertilizer nitrogen source: I. Doublecropping experiments with crimson clover, sweet corn, and. *Agriculture, Ecosystems & Environments* **56**, 93–108.

GEIGER F, BENGTSSON J, BERENDSE F et al. (2010) Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. *Basic Applied Ecology* **11**, 97–105.

GOMEZ KA & GOMEZ AA (1984) Statistical Procedures For Agricultural Research. John Wiley Sons Inc.

GRAZIANI F, ONOFRI A, PANNACCI E, TEI F & GUIDUCCI M (2012) Size and composition of weed seedbank in long-term organic and conventional low-input cropping systems. *European Journal of Agronomy* **39**, 52–61.

HALDE C, BAMFORD KC & ENTZ MH (2015) Crop agronomic performance under a six-year continuous organic no-till system and other tilled and conventionally-managed systems in the northern Great Plains of Canada. *Agriculture, Ecosystems & Environments* **213**, 121–130.

HATCHER P & MELANDER B (2003) Combining physical, cultural and biological methods: prospects for integrated non-chemical weed management strategies. *Weed Research* **43**, 303–322.

HOSSEINI P, KARIMI H, BABAEI S, MASHHADI HR & OVEISI M (2014) Weed seed bank as affected by crop rotation and disturbance. *Crop Protection* **64**, 1–6.

HYVÖNEN T, KETOJA E, SALONEN J, JALLI H & TIAINEN J (2003) Weed species diversity and community composition in organic and conventional cropping of spring cereals. *Agriculture, Ecosystems & Environments* **97**, 131–149.

KENKEL NC, DERKSEN DA, THOMAS AG & WATSON PR (2002) Multivariate analysis in weed science research. *Weed Science* **50**, 281–292.

LÉGÈRE A, STEVENSON FC & BENOIT DL (2005) Diversity and assembly of weed communities:contrasting responses across cropping systems. *Weed Research* **45**, 303-315.

MAGURRAN AE (1988) Ecological diversity and its measurements. Princet. Univ. Press. New Jersey.

MARSHALL EJP, BROWN VK, BOATMAN ND, LUTMAN PJW, SQUIRE GR & WARD LK

(2003) The role of weeds in supporting biological diversity within crop fields: The role of weeds in supporting biological diversity within crop fields. *Weed Research* **43**, 77–89.

MEISS H, MÉDIÈNE S, WALDHARDT R et al. (2010) Perennial lucerne affects weed community trajectories in grain crop rotations. *Weed Research* **50**, 331–340.

RADICETTI E, MANCINELLI R & CAMPIGLIA E (2012) Combined effect of genotype and inter-row tillage on yield and weed control of chickpea (*Cicer arietinum* L.) in a rainfed Mediterranean environment. *Field Crop Research* **127**, 161–169.

RADICETTI E, MANCINELLI R, MOSCETTI R & CAMPIGLIA E (2016) Management of winter cover crop residues under different tillage conditions affects nitrogen utilization efficiency and yield of eggplant (*Solanum melanogena* L.) in Mediterranean environment. *Soil, Tillage & Research* **155**, 329–338.

RUISI P, FRANGIPANE B, AMATO G et al. (2015) Weed seedbank size and composition in a long-term tillage and crop sequence experiment. *Weed Research* **55**, 320–328.

RYAN MR, SMITH RG, MORTENSEN DA et al. (2009) Weed-crop competition relationships differ between organic and conventional cropping systems. *Weed Research*. **49**, 572–580.

TILMAN D, CASSMAN KGK, MATSON PA, NAYLOR R & POLASKY S (2002) Agricultural sustainability and intensive production practices. *Nature* **418**, 671–677.

TØRRESEN KS, SKUTERUD R, TANDSÆTHER HJ & HAGEMO MB (2003) Long-term experiments with reduced tillage in spring cereals. I. Effects on weed flora, weed seedbank and grain yield. *Crop Protection* **22**, 185–200.

TRINCHARD A, ALIGNIER A, BIJU-DUVAL L & PETIT S (2013) The relative effects of local management and landscape context on weed seed predation and carabid functional groups. *Basic and Applied Ecology* **14**, 235-245.

VAN ELSEN T (2000) Species diversity as a task for organic agriculture in Europe. *Agriculture, Ecosystems & Environments* **77**, 101–109.

Table 1 Agricultural practices applied to the conventional and organic cropping systems.

	Conventional cropping system			Organic cropping system		
Main crop	Wheat	Tomato	Chickpea	Wheat	Tomato	Chickpea
Cultivar	Colosseo	San Marzano	Sultano	Colosseo	San Marzano	Sultano
Seeding rate	450 plants m^{-2}	3 plants m^{-2}	60 plants m^{-2}	450 plants m^{-2}	3 plants m^{-2}	60 plants m^{-2}
Row spacing	12.5cm	150cm	50cm	12.5cm	150cm	50cm
Fertilizers	80 kg P_2O_5 ha^{-1} as perphosphate 120 kg N ha^{-1}: (30 kg ha^{-1} as $Ca(NO_3)_2$ + 90 kg ha^{-1} as NH_4NO_3)	80 kg P_2O_5 ha^{-1} as perphosphate 100 kg N ha^{-1} as NH_4NO_3	90 kg P_2O_5 ha^{-1} as perphosphate	80 kg P_2O_5 ha^{-1} 120 kg N ha^{-1}: (Guanito+DX10)	80 kg P_2O_5 ha^{-1} as phosphorite 100-160 kg N ha^{-1}: (Vetch green manure)	90 kg P_2O_5 ha^{-1} as phosphorite 20-30 kg N ha^{-1}: (Canola green manure)
Cover crop	No cover crop			Hairy vetch + Oilseed Rape		
Seeding rate				Hairy vetch: 60 kg ha^{-1}; Oilseed Rape: 15 kg ha^{-1}		
Period of cultivation				Hairy vetch: September – May; Oilseed Rape: September – February		
Weed management	Chemical			Mechanical		
	post-emergence: Mesosulfuron-Metile 3% + Iodosulfuron Metil Sodium 3%	post-emergence: Flufenacet 42% + Metribuzin 14%	pre-emergence: Aclonifen 49.6%	post-emergence: tine-harrowing	post-emergence: inter-row cultivation	post-emergence: inter-row Cultivation
Period of application	March	June	February	January and February	July	April
Number of application	1	1	1	2	1	1
Crop stage	End of crop tillering	Beginning of crop flowering	Before crop sowing	Beginning and end of crop tillering	Full flowering	Beginning of crop flowering

Table 2 Weed species observed during the 3-year study period, bayer code, family and functional group number: 1 = Annual dicots, upright; 2 = Annual dicots, climbing; 3 = Annual dicots, other; 4 = Annual dicots, rosette; 5 = Intermediate dicots; 6 = Perennial dicots; 7 = Annual grasses; 8 = Perennial grasses.

Botanical name	Weed code	Functional group (FG)
Amaranthus hybridus L.	AMACH	1
Amaranthus retroflexus L.	AMARE	1
Anagallis arvensis L	ANGAR	3
Apera spica-venti (L.) P. Beauv.	APESV	7
Avena sterilis L.	AVEST	7
Bifora radians M. Bieb.	BIFRA	1
Bromus sterilis L.	BROST	7
Capsella bursa-pastoris (L.) Medicus	CAPBP	5
Chenopodium album L.	CHEAL	1
Chrysanthemum segetum L. Four.	CHYSE	4
Cirsium arvense (L.) Scop.	CIRAR	6
Convolvulus arvensis L.	CONAR	6
Cyanus segetum Hill	CENCY	1
Datura stramoniium L.	DATST	1
Digitaria sanguinalis (L.) Scop.	DIGSA	7
Diplotaxis eurocoides(L.) de Candoll	DIPER	4
Echinocloa crus-galli (L.) P. Beauv.	ECHCG	7
Fallopia convolvolus (L.) A. Löve	POLCO	2
Fumaria officinalis L.	FUMOF	1
Galium aparine L.	GALAP	2
Heliotropium europaeum L.	HEOEU	4
Lolium perenne L.	LOLPE	8
Malva sylvestris L.	MALSI	6
Matricaria chamomilla L.	MATCH	1
Mercurialis annua L.	MERAN	1
Myagrum perfoliatum L.	MYGPE	4
Papaver rhoeas L.	PAPRH	4
Phalaris minor Retzius	PHAMI	7
Picris echioides (L.) Gärtner	PICEC	4
Polygonum aviculare L.	POLAV	3
Portulaca oleracea L.	POROL	3
Rapistrum rugosum L. Allioni	RASRU	4
Senecio vulgaris L.	SENVU	1
Setaria viridis (L.) P. Beauv.	SETVI	7
Sinapis arvensis L.	SINAR	4
Solanum nigrum L.	SOLNI	1
Sonchus arvensis L.	SONAR	6
Stellaria media L. (Vill.)	STEME	3
Sylibum marianum (L.) Gärtner	SYLMA	5
Taraxacum officinalis Weber	TAROF	6
Tribolus terrestris L.	TRBTB	2
Veronica hederifolia L.	VERHE	3
Viola arvensis Murray	VIOAR	1

Table 3 Weed density per species in wheat, chickpea and tomato. Data were combined for the 2011/2012, 2012/2013 and 2013/2014 growing seasons. CONV = Conventional cropping system; Org = Organic cropping system; IT = Inversion tillage; NoIT = Non-Inversion tillage; SED = Standard errors of difference.

Symbol	Wheat				Tomato				Chickpea			
	CONV		ORG		CONV		ORG		CONV		ORG	
	IT	NoIT	IT	NoIT	IT	NoIT	IT	NoIT	IT	NoIT	IT	NoIT
	Plants m^{-2}											
AMACH					1.4	1.8	5.4	3.7				
AMARE					4.8	3.3	10.4	7.2	0.6	0.2	1.2	1.0
ANGAR	0.3	0.1	2.2	3.0	0.8	0.3	1.7	1.3	0.6	1.0	0.3	0.2
APESV	0.8	1.2	0.2	0.7								
AVEST	5.3	4.9	1.1	1.9	2.8	5.4	1.4	1.6	10.7	7.4	5.0	5.4
BIFRA			0.4	1.0								
BROST	1.7	1.1	0.1	0.6								
CAPBP	0.2	1.0	1.0	2.3						0.4	1.4	1.9
CHEAL					1.4	1.2	11.4	5.7	0.2	0.4	0.9	0.2
CHYSE	0.2	0.1	3.9	3.2								
CIRAR	0.1	2.2	0.3	6.0	0.1	3.9	0.6	8.3		3.4		4.1
CONAR		0.3	0.3	2.1		2.9	0.8	8.2		1.2	0.2	4.0
CENCY	0.4		1.0	1.1								
DATST							0.2	0.8				
DIGSA					5.9	8.2	3.0	3.9				
DIPER	0.1	0.1	0.8	2.2					0.1	0.3	1.7	0.8
ECHCG					3.1	4.8						
POLCO			1.1	1.8	0.1	0.3	2.4	1.8	0.9	1.3	1.2	0.7
FUMOF	0.1		3.4	5.0	0.4		5.3	4.4	1.7	0.6	11.3	6.4
GALAP	1.2	1.1	5.7	7.1								
HEOEU							0.7	2.3				
LOLPE	2.8	4.6	1.1	2.9					1.4	6.1	1.7	5.3
MALSI										1.3		2.3
MATCH	0.2		2.0	2.2					1.3	0.7	0.4	0.7
MERAN							2.8	4.6				
MYGPE		0.1	0.9	1.0								
PAPRH	0.6	1.0	4.7	3.8					5.6	4.7	1.2	0.9
PHAMI	4.0	3.8	0.4	0.1								
PICEC									1.8	1.6	0.8	1.8
POLAV						0.6	1.4	4.6	5.3	3.3	12.4	10.7
POROL					0.4	0.3	2.8	1.6				
RASRU			2.8	3.1					0.4	0.4	1.1	0.8
SENVU					0.6	0.7	4.7	3.2				
SETVI					4.4	2.6	1.7	1.3				
SINAR	0.9	0.6	1.3	2.7					1.3	0.7	6.6	8.6
SOLNI					1.6	1.6	8.2	5.3				
SONAR					0.7	1.0	2.0	3.6	1.6	3.6	6.8	9.7
STEME	1.6	1.7	4.6	6.9								
SYLMA	0.2	0.9	0.7	1.2	0.2		0.6	1.1	0.1	0.4	0.4	0.4
TAROF									2.4	4.4	6.8	10.7
TRBTB						0.1	1.1	2.9				
VERHE	0.8	1.6	3.8	1.3					0.3	0.1	0.6	0.6
VIOAR	0.1	0.8	3.0	2.6								
SED	*0.4*	*0.5*	*0.7*	*0.7*	*0.5*	*0.6*	*0.9*	*1.0*	*0.5*	*0.7*	*0.7*	*0.8*

Table 4 The interaction effect of cropping system x soil tillage x crop on weed community richness and Shannon index. Values belonging to the characteristic and treatment with different letters are statistically diffetent according to LSD (0.05) in rows for crop treatments (upper case letter) and in columns for each cropping system x soil tillage (lower case letter).

	Conventional		Organic	
	Inversion Tillage	Non-Inversion Tillage	Inversion Tillage	Non-Inversion Tillage
		Community richness (n.)		
Wheat	9.0^{bC}	11.0^{bB}	17.2^{aA}	18.6^{aA}
Tomato	9.9^{abC}	11.8^{abC}	15.8^{aB}	18.7^{aA}
Chickpea	10.7^{aC}	13.2^{aB}	12.7^{bB}	15.0^{bA}
		Shannon Index (H’)		
Wheat	1.65^{bB}	1.94^{bA}	1.96^{bA}	2.09^{bA}
Tomato	1.64^{bC}	1.83^{bC}	2.04^{abB}	2.30^{aA}
Chickpea	1.94^{aB}	2.08^{aAB}	2.13^{aA}	2.25^{aA}

Figure 1 The effect of cropping system x soil tillage on the weed aboveground biomass. Values belonging to the crop with different letters are statistically different according to LSD (0.05).

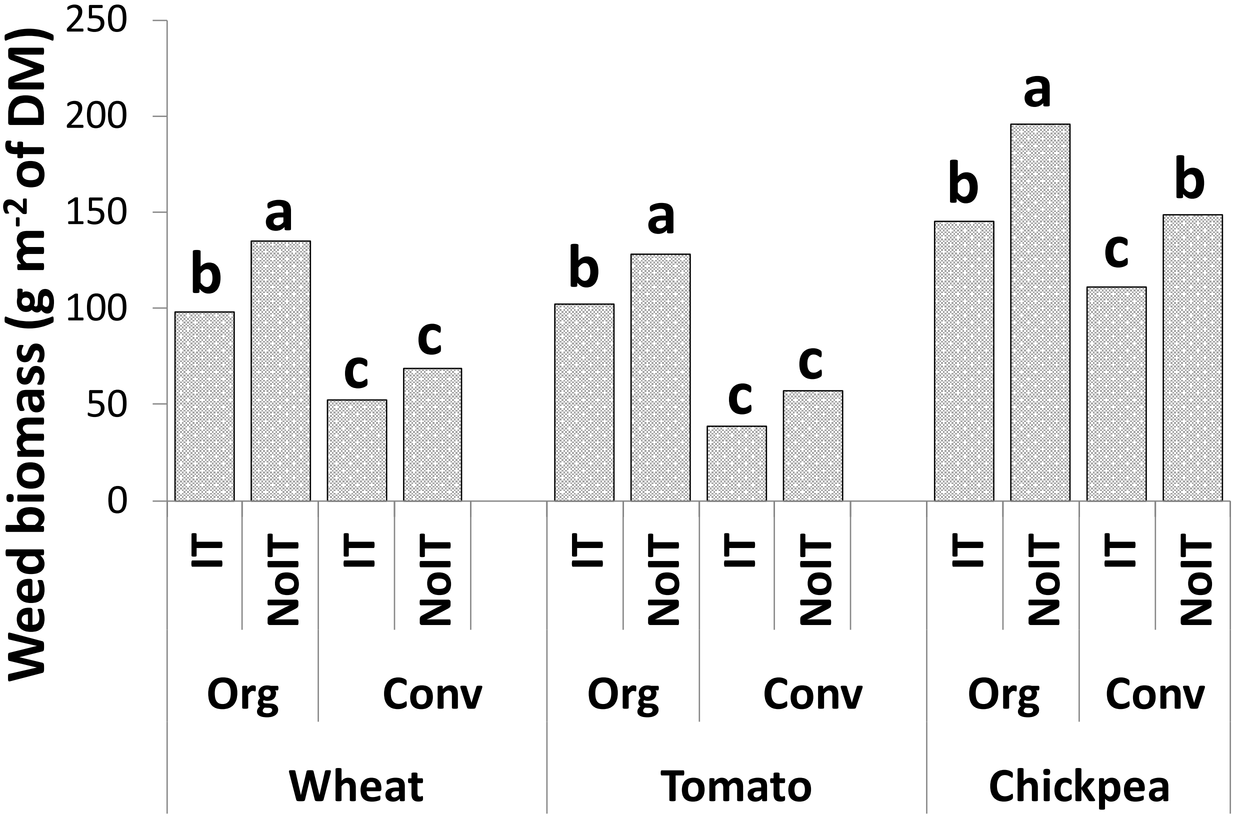

Figure 2 CDA analysis of the weed species observed in wheat, tomato and chickpea. Data were combined across the growing seasons. CONV = Conventional cropping system; ORG = Organic cropping system; IT = Inversion tillage; NoIT = Non-Inversion tillage. See Table 2 for a description of symbols for weed species.

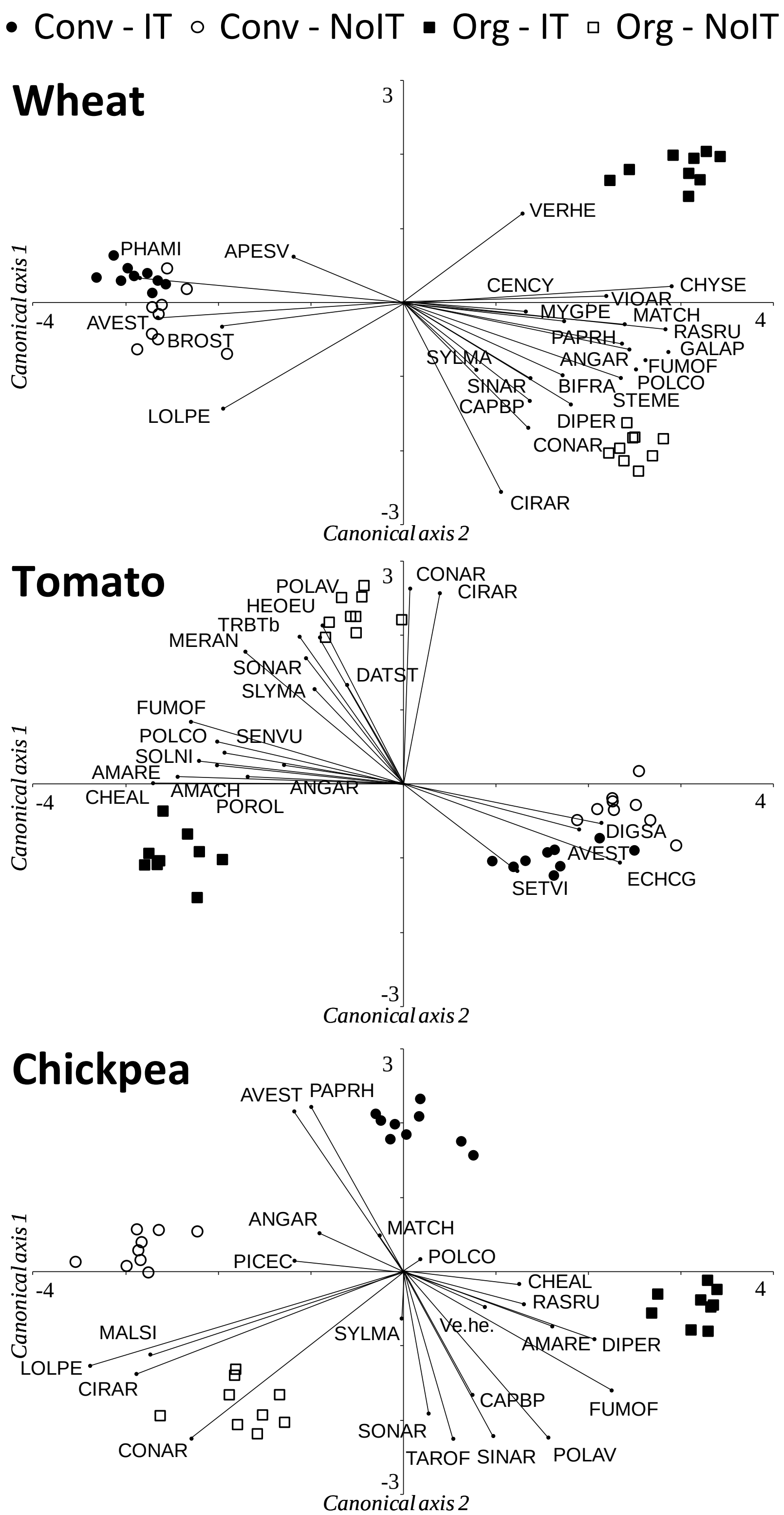

Figure 3 Relative frequencies of functional groups of weed species across main crops in field groups representing the interaction cropping systems and tillage management. The graph shows the mean relative frequencies of each functional group (FG) and the standard errors within each boundary. Nb.Sp. = number of weed species in the FG. Mean frequencies not labeled by the same letter are significantly different between the treatments. CONV = Conventional cropping system; ORG = Organic cropping system; IT = Inversion tillage; NoIT = Non-inversion tillage.

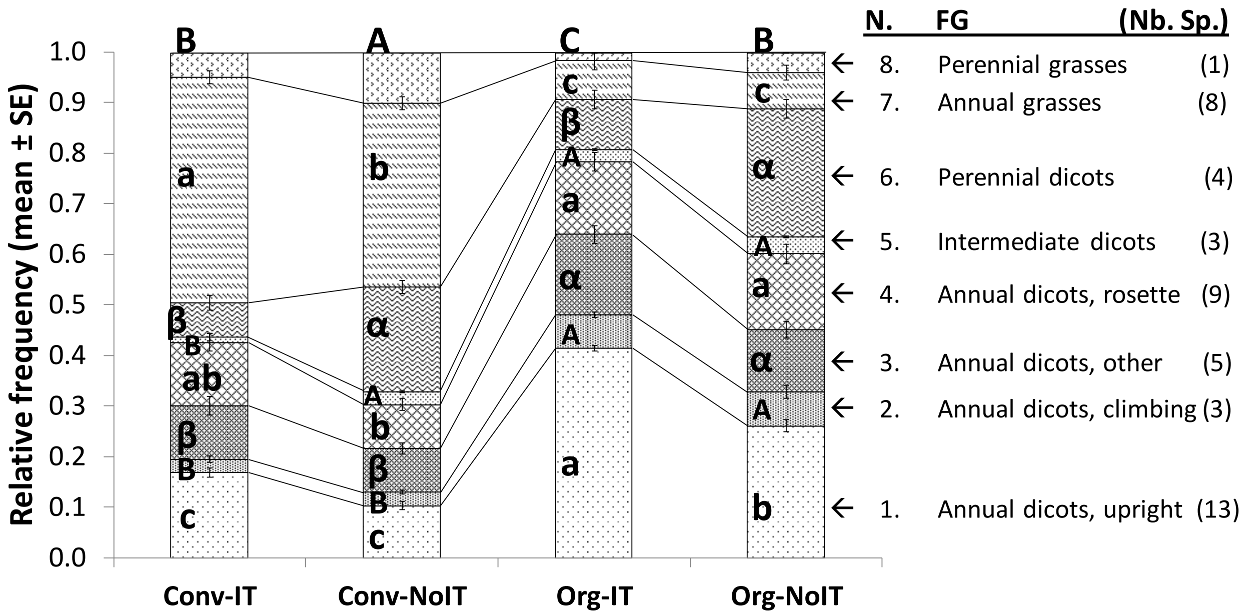

Figure 4 The relationship between crop yield and annual weed density (functional groups 1, 2, 3, 4, 5, and 7) and crop yield and perennial weed density (functional groups 6 and 8).