Influence of different soil management practices on ground-flora vegetation in an almond orchard

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Abstract
This paper reports a survey on the weed flora and seed bank in an almond orchard sited in Apulia region (Southern Italy), where the following soil management practices have been compared for over 30 yrs: no-tillage, keeping the soil totally weed-free throughout the year by using pre-emergence herbicides to prevent plant emergence or post-emergence herbicides in case of weeds already emerged; no-tillage, with post-emergence herbicides; no-tillage, with mowing of natural weed flora in spring; cover cropping, with faba bean sown in November and green manured in springtime; conventional soil tillage. The different management techniques influenced significantly the weed flora in experimental plots, both in terms of quantity and quality. The seed bank was clearly impoverished after the long-term applications of pre-emergence herbicides, both in terms of richness and of diversity. During the fall period, the plots of conventional tillage or pre-emergence herbicides had less natural ground-flora than the others. During springtime, prior to the sward control practices, the plots treated by foliar herbicides or mowing had the highest total weed cover. We conclude that post-emergence weed control by mowing or using chemical herbicides or the green manure of the cover crop may be proposed to reduce impact to the soil and to promote the growth of abundant and sufficiently diversified and balanced flora. If appropriately managed, this flora can provide potential ecological services, without competing with the orchard, as suggested by the literature. During the autumn, natural flora can uptake soil nitrogen thus preventing leaching in the rainy season. In springtime, after the sward has been destroyed, natural flora can supply a substantial amount of biomass to the soil. Indicator species analysis was also used to find the species characterizing each treatment and some of their combinations. Weeds belonging to the *Poaceae* botanical family were significantly associated with post-emergence herbicides and mowing treatments. These species produce a substantial amount of biomass and have bunched roots; consequently, they supply beneficial effects by improving porosity and structure of the soil and reducing erosion hazard.

Key words: almond orchards, cover crop, diversity, mowing, no-tillage, weeds, herbicides

Introduction

Adequate weed management may have positive consequences on agriculture sustainability, enhancing agro-ecosystem productivity and also by improving ecological services (Gerowitt et al., 2003). The uncontrolled presence of natural flora in tree orchards, like in any crop, increases competition especially for water and nutrients, with a subsequent reduction of yields and fruit quality. However, weed flora, where appropriately managed, may have many beneficial effects on the agro-ecosystem. Previous studies on the most common tree crops in the Mediterranean region, including olives (Montemurro et al., 2002; Corleto and Cazzato, 2008b; Simoes et al., 2014), wine grapes (Corleto and Cazzato, 2008a; Ferrara et al., 2012), table grapes (Novello et al., 1997), citrus (Colloff et al., 2013) and almond orchards (Ramos et al., 2010), support reducing tillage intensity and the permanent or temporary presence of sward, either sown or natural, especially to preserve soil fertility and to increase the agro-ecosystem's diversity (Marshall et al.,

2003; Norris, 2005; Colloff et al., 2013). The ground flora reduces the soil erosion hazard (Hernandez et al., 2005; Ramos et al., 2010; Chauhan et al., 2012) and improves the chemical, physical and microbiologic fertility of the soil (Ramos et al., 2011; Soriano et al., 2014).

Remarkable results in almond orchards are reported in Spain by Ramos et al. (2010), suggesting that the temporary presence of weeds and the abandoning of frequently tilled management enhance soil properties. In a research on insect pollinators, almond orchards with living ground cover showed positive relationship between native bee abundance and the richness of ground cover plants (Saunders et al.).

The weed communities should ideally combine adequate and positive effects on the agro-environment with only marginal negative competitive effects on orchard (Fracchiolla et al., 2013). Such effects clearly depend upon the eco-physiological and morphological traits of species and their abundance in weed communities (Altieri and Letourneau, 1982; Marshall et al., 2003; Barberi et al., 2010). Consequently, proper weed management should not only take into account the efficacy of weed control but also how the practices affect the weed population (Naylor and Drummond, 2002). This is the reason why integrated weed management (Swanton and Murphy, 1996) considers weeds not as a mere 'target' but as a community that 'needs to be managed' that is composed by individuals interacting with each other, with the crop and with all agro-ecosystem components (Clements et al., 1994; Soriano et al., 2014).

The effects of different management techniques on weed composition have been shown in many cropping systems (Zanin et al., 1997; Fried et al., 2012) and tree crops, such as citrus (Mas et al., 2007), apple orchards (Minãrro, 2012), grapevines (Montemurro et al., 1994; Gago et al., 2007) and olive groves (Allen et al., 2006; Fracchiolla et al., 2013). The results are obviously correlated to the geographic location of the tested fields, although all trials show a marked influence of cultural practices on weed community composition.

The effects on weed flora are expected to be more stable if the practices have been carried out over a long period of time. Therefore, the aim of this paper is to compare the influence of different soil management practices, protracted over more than 30 yrs in an almond orchard, on the diversity and composition of weed communities and soil seed bank. The experimental field was located in the South of Italy, under a typical Mediterranean climate, and it was managed with practices with few or no disturbing activities to the soil.

Materials and Methods

The research was conducted in an experimental field including an almond varietal collection, located in 'La Piantata' experimental farm near Bari (South-East of Italy), of the Agricultural Research Council of Italy. Plant spacing was $7 \times 7 \, m^2$ and the crop was rainfed. The soil had a clay texture and a topsoil nearly 0.30 m depth. Within a long-term study started in 1976, the following soil management practices were compared:

- Residual herbicide (ReH): no-tillage, keeping the soil totally weed-free throughout the year by using residual herbicides (pre-emergence) to prevent plant emergence or foliar (post-emergence) herbicides in the case of weeds already emerged (see Appendix).
- Foliar herbicide (FoH): no-tillage, with post-emergence chemical weed control in spring, using foliar herbicides (post-emergence of weeds) (see Appendix).
- Mowing (Mow): no-tillage, with mowing of natural weed flora in spring.
- Cover cropping (Cov): cover cropping, with faba bean (*Vicia faba* L. var. *minor* Beck) sown in November and green manured in springtime at bloom stage.
- Conventional tillage (Til): conventional soil tillage, using traditional techniques in the area where the experimental field is located.

Plots were of 147 m^2 (strip 7 m wide that included one row of almond plants 21 m long) and were arranged in the field following the randomized block experimental design with four replicates. All the treatments were applied to the whole plots, whereas a central area of 56 m^2 (a strip 4 m wide that included a central row of almond plants 14 m long) was identified for soil sampling and flora survey.

Herbicides were diluted in 400 liters ha^{-1} of water and applied with a hand pump sprayer backpack. Active ingredients and doses are listed in the Appendix.

For mowing, a tractor driven rotary cutting with blades mounted on a horizontal axle was used, to cut weeds to a height of about 5 cm above the ground.

In the conventional tillage treatment, several ploughings were performed each year: deep ploughings (about 20 cm depth), from late autumn to early winter to increase the water storage and shallow disk ploughings (10 cm depth) for weed removal in the other periods.

Seed bank analysis

In October 2010, for each replicate and within the sampling area, 10 soil samples were taken randomly and from a depth between 0 and 30 cm, using circular soil probe apparatus of 5 cm in diameter.

For the determination of the seed bank, the direct observation of the plantlets emerging from each soil sample was applied (Roberts and Neilson, 1982).

Soil samples were placed into trays where the soil did not exceed 4 cm depth and was periodically wetted. Trays were kept in the greenhouse for 25 months, under such conditions as not to exceed an internal temperature of 35°C during the hottest periods. Irrigation was periodically stopped to simulate drought periods, so the soil was

mixed up and newly wetted, so as to favor the interruption of dormancy of most seeds (Cantele et al., 1996). In the hottest months (July and August), trays were not irrigated so as to prevent the emergence of new plantlets and avoid their quick decline with the subsequent loss of data. The plantlets emerging from each tray were identified, counted and removed. The data collected for each species were expressed in terms of number of seeds per square meter of soil.

Flora field surveys

In October 2010–2011 and in May 2011–2012, namely at the end of the peak vegetative growth periods and prior to control practices, weed communities were assessed on the sampling area (56 m^2) for each replicate. Percent covers of species were visually estimated; sporadic species were recorded with the arbitrary value of 0.5%. This paper provides the means of cover data recorded for the October (autumn) and May (spring) surveys of each year. Taxonomic nomenclature refers to Conti et al. (2005).

Numerical analysis

For each treatment, the floristic richness (S) of the seed bank and autumn and spring weed flora was calculated as the mean number of vascular plant species and families. The richness was expressed as the mean number of taxa found in the sampling area (56 m^2) of each replication. The diversity of each treatment was estimated by the Shannon–Wiener index (H) which combines evenness and richness of species. The index was calculated as follows: $H = -\sum p_i \ln p_i$, where p_i is the proportion of individuals (for seed bank) or cover (for field surveys) of the ith species.

For each treatment, the mean sum of the plant cover values in each replicate was indicated as the 'total weed cover'. This index was used to roughly estimate the structure (biomass, stratification, coverage) of weed communities. Occasionally, the total weed cover value exceeded 100% because individual plants can overlap one to each other.

All the values were square root transformed to ensure the homogeneity of variances and submitted to the analysis of variance. The means were compared using the Duncan's test. Tables show the mean data, non-transformed, of replicates.

The indicator species analysis (ISA) (Dufrêne and Legendre, 1997) was used to find the species characterizing each treatment and some of their combinations.

The ISA recently arranged within a statistical framework of methods for assessing the association between species and site groups (De Cáceres and Legendre, 2009), has been widely used in ecology. The strength of the association between a species and a group of sites is measured by the indicator value index (IndVal). The highest IndVal of a species along a site typology identifies
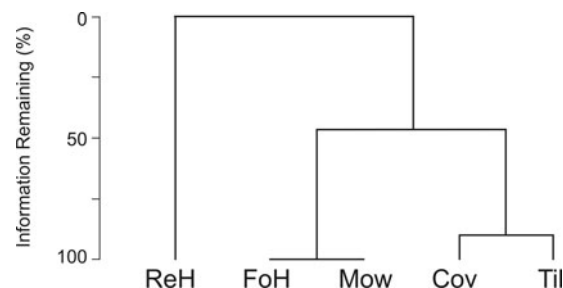
Figure 1. Cluster analysis [flexible beta (β = −0.25), Bray–Curtis distance measure] of the treatments based on the autumn weed surveys. ReH, residual herbicide; FoH, foliar herbicide; Mow, mowing; Cov, cover crop; Til, conventional tillage.

the group of sites for which that species can be considered as an indicator species (IS) (Dufrêne and Legendre, 1997). The IndVal of species i for the group of sites j are calculated as follows: IndVal$_{ij}$ = A$_{ij}$ × B$_{ij}$ × 100; where A$_{ij}$ is the ratio between the mean abundance of species i in the sites of group j and the mean abundance of species i along all the groups of sites. B$_{ij}$ is the ratio between the number of sites of cluster j where the species i is present and the total number of sites in that group. The maximum value of the index (IndVal = 100) is reached for species that are present in only one group and in all of its sites.

The method can be adapted for a randomized block experimental design, as in our case, by a pre-relativization by species within each replicate (i.e., blocked ISA) (McCune and Grace, 2002; McCune and Mefford, 2011). The IndVal were tested for statistical significance ($P \le 0.05$) by using a Monte Carlo test, with 5000 permutations.

To find the IS associated with more than one treatment, the treatments were hierarchically clustered (flexible-beta method, β = −0.25, with Bray–Curtis distance measure) on the basis of both autumn and spring species mean cover. The cluster analyses for autumn and spring data gave very similar results; only the dendrogram for the autumn survey was shown. Significant IS were calculated for the clusters of treatments obtained for every level of the dendrogram. Each significant IS was then assigned to the treatment or group of treatments for which it yielded the highest IndVal (Dufrêne and Legendre, 1997; McCune and Grace, 2002).

All the multivariate analyses described above were carried out by using the software pc-ord v.6.11 (McCune and Mefford, 2011).

Results

The cluster analysis (Fig. 1) clearly differentiated the residual herbicide from the other treatments. The second partitioning level of the dendrogram separated the foliar

Table 1. Autumn surveys: effects of different systems of treatments on total weed cover, richness and diversity[1].

	Treatments[2]				
	ReH	**FoH**	**Mow**	**Cov**	**Til**
Total weed cover (%)	2.7 c	56.8 a	52.3 a	54.4 a	30.9 b
Richness (no. of species)	4.8 c	9.2 b	13.2 a	14.8 a	13.0 a
Richness (no. of families)	4.2 c	9.2 b	11.0 ab	12.2 a	11.2 ab
Shannon–Wiener index	1.6	1.9	1.9	1.8	2.0

[1] Values followed by different letter in each row are significantly different from each other at $P < 0.05$ (Duncan test).
[2] ReH, residual herbicide; FoH, foliar herbicide; Mow, mowing; Cov, cover crop; Til, conventional tillage.

Table 2. Spring surveys: effects of different systems of treatments on total weed cover, richness and diversity[1].

	Treatments[2]				
	ReH	**FoH**	**Mow**	**Cov**	**Til**
Total weed cover (%)	19.0 d	115.3 a	109.0 a	41.0 c	72.0 b
Richness (no. of species)	6.2 c	15.5 a	11.2 b	12.2 ab	14.5 ab
Richness (no. of families)	4.5 c	9.2 a	7.0 b	8.7 ab	9.5 a
Shannon–Wiener index	0.8 b	1.9 a	1.7 a	2.1 a	2.3 a

[1] Values followed by different letter in each row are significantly different from each other at $P < 0.05$ (Duncan test).
[2] ReH, residual herbicide; FoH, foliar herbicide; Mow, mowing; Cov, cover crop; Til, conventional tillage.

Table 3. Seed bank: effects of different systems of treatments on total number of seeds, richness and diversity[1].

	Treatments[2]				
	ReH	**FoH**	**Mow**	**Cov**	**Til**
Total number of seeds (n m^{-2})	2524 b	7890 ab	11.678 a	8884 a	9897 a
Richness (no. of species)	6.0 b	15.5 a	16.2 a	15.7 a	13.0 a
Richness (no. of families)	5.0 b	12.0 a	11.5 a	12.2 a	11.5 a
Shannon–Wiener index	1.4 b	2.2 a	2.2 a	2.5 a	2.0 a

[1] Values followed by different letter in each row are significantly different from each other at $P < 0.05$ (Duncan test).
[2] ReH, residual herbicide; FoH, foliar herbicide; Mow, mowing; Cov, cover crop; Til, conventional tillage.

herbicide and mowing treatments from the crop covering and conventional tillage. The last two treatments were separated at the third partitioning level, whereas foliar herbicide and mowing were the most floristically similar treatments.

The residual herbicide was characterized by the lowest diversity, richness and total weed cover, both in autumn and spring surveys (Tables 1 and 2). Also for the seed bank, the values of the Shannon–Wiener and richness indexes were statistically different and lower than in all the other treatments (Table 3). The number of seeds in the seed bank for the residual herbicide was the lowest one, significantly different from all the others with the exception of the foliar herbicide (Table 3).

Regarding the other treatments, in the autumn survey, the lowest total weed cover was recorded for the conventional tillage, whereas the lowest richness value was

calculated for the foliar herbicide (Table 1). During spring surveys (Table 2), the highest mean total weed cover was found for the foliar herbicide and mowing. The lowest mean numbers of botanical species and families (richness) were found in the mowing. The Shannon–Wiener index values calculated for foliar herbicide, mowing, conventional tillage and cover cropping (Table 2), were not statistically different from each other.

Regarding the seed bank, except for the residual herbicide, all the other treatments showed no statistically different values of richness, diversity and number of seeds (Table 3).

IS analysis

In the autumn surveys, the residual herbicide was not associated with any IS, whereas *Avena sterilis*, *Bromus*

Table 4. Autumn surveys: mean cover percentage and the highest indicator value (IndVal) of weed species significantly ($P \leq 0.05$) associated with a treatment or a group of treatments.

| Species | Mean cover percentage (%) | | | | | IndVal | Treatments[1] |
	ReH	FoH	Mow	Cov	Til		
Avena sterilis L.	0.0	27.0	25.0	5.0	1.5	100.0	FoH, Mow, Cov, Til
Bromus sterilis L.	0.2	13.8	12.3	3.4	0.4	97.5	FoH, Mow, Cov, Til
Calendula arvensis L.	1.0	4.0	3.4	4.4	6.5	83.3	FoH, Mow, Cov, Til
Convolvulus arvensis L.	0.0	1.1	2.0	0.0	0.0	100.0	FoH, Mow
Diplotaxis muralis (L.) DC.	0.0	2.9	9.8	0.0	0.0	100.0	FoH, Mow
Hordeum murinum L.	0.0	4.0	1.9	0.0	0.0	100.0	FoH, Mow
Cynodon dactylon (L.) Pers.	0.1	3.4	26.6	0.0	0.3	98.9	FoH, Mow
Galium aparine L.	0.0	3.3	0.5	0.5	0.0	88.1	FoH, Mow
Amaranthus retroflexus L.	0.0	0.3	1.5	31.3	13.0	96.4	Cov, Til
Glebionis segetum (L.) Fourr.	0.0	0.0	0.0	1.7	0.4	87.5	Cov, Til
Lamium amplexicaule L.	0.0	0.0	0.0	0.6	0.2	87.5	Cov, Til
Chenopodium album L.	0.0	0.0	0.8	1.1	0.9	79.8	Cov, Til
Senecio vulgaris L.	0.3	0.0	0.0	0.9	1.6	79.2	Cov, Til
Diplotaxis erucoides (L.) DC.	0.2	0.0	2.6	5.5	4.8	77.3	Cov, Til
Portulaca oleracea L.	0.0	0.4	0.6	0.9	0.9	75.0	Cov, Til
Medicago minima (L.) L.	0.3	0.6	0.5	0.7	0.9	70.9	Cov, Til
Lathyrus sp.	0.0	0.0	0.0	0.5	0.0	100.0	Cov
Fumaria capreolata L.	0.1	0.0	0.0	1.0	0.0	95.0	Cov
Fallopia convolvulus (L.) Á. Löve	0.6	5.6	0.4	0.1	0.5	78.7	FoH
Lolium rigidum Gaudin	0.0	1.5	0.0	0.0	0.6	71.2	FoH
Erodium malacoides (L.) L'Hér.	0.0	0.0	1.7	0.1	0.0	87.5	Mow
Sonchus oleraceus L.	0.0	0.0	0.6	0.3	0.0	76.8	Mow
Heliotropium europaeum L.	0.0	0.0	0.1	0.0	1.0	95.2	Til

[1] ReH, residual herbicide; FoH, foliar herbicide; Mow, mowing; Cov, cover crop; Til, conventional tillage.

sterilis and *Calendula arvensis* characterized the other treatments. The number of species associated with the clusters Cov + Til and FoH + Mow were eight and five, respectively, with seven IS of single treatments (Fig. 1, Table 4). The highest IndVal were recorded for *Convolvulus arvensis*, *Cynodon dactylon*, *Diplotaxis muralis* and *Hordeum murinum* (associated with the cluster FoH + Mow) and *Amaranthus retroflexus* (Cov + Til), *Lathyrus* sp. (Cov) and *Heliotropium europaeum* (Til).

In the spring surveys, only two significant IS (*Arenaria leptoclados* and *Erigeron Canadensis*) were recorded for the residual herbicide. *A. sterilis* and *B. sterilis* were associated with the other four treatments (Table 5). The clusters Cov + Til and FoH + Mow were characterized by an equal number of IS. The highest IndVal were recorded for *H. murinum*, *Galium aparine* and *Sherardia arvensis* (FoH + Mow) and *Fumaria capreolata*, *Lamium amplexicaule* and *Veronica hederifolia* (Cov + Til). Among the single treatments, the conventional tillage was floristically differentiated by four significant IS (*C. arvensis*, *Diplotaxis erucoides*, *Lolium rigidum*, *Senecio vulgaris*); two IS were recorded for mowing and foliar herbicide.

The data concerning the seed bank (Table 6) showed that only *A. leptoclados* was significantly associated with the residual herbicide, whereas the other treatments had five significant IS, among which *C. arvensis* (IndVal = 93.8) and *Portulaca oleracea* (93.8) with the highest IndVal. The significant IS associated with Fow + Mow were *Euphorbia helioscopia*, *B. sterilis* and *Sonchus oleraceus*, whereas *Capsella bursa-pastoris* characterized Cov + Til. Few other significant IS resulted associated with single treatments. However, we cannot exclude that the lower number of species with significant treatment associations in the seedbank is due to a greater variability observed in data recorded in the soil sampling than in those of aboveground visual surveys.

Discussion and Conclusions

Among the five treatments compared in this paper, the residual herbicide was the most differentiated for low levels of total weed cover, richness and diversity. The ISA selected very few species significantly associated with this treatment. Moreover, the seed bank, which showed slight differences among the other treatments, was clearly impoverished after the long-term applications of residual herbicides. On the other hand, another study (De Giorgio and Lamascese, 2005) on the almond tree productivity in the same experimental plots, recorded the highest yield for this treatment (4.86 kg per tree). For the foliar herbicide, cover cropping and conventional

Table 5. Spring surveys: mean cover percentage and the highest indicator value (IndVal) of weed species significantly ($P \leq 0.05$) associated with a treatment or a group of treatments.

Species	Mean cover percentage (%)					IndVal	Treatments[1]
	ReH	FoH	Mow	Cov	Til		
Arenaria leptoclados (Rchb.) Guss.	13.9	0.0	0.0	0.0	0.0	100.0	ReH
Erigeron canadensis L.	1.6	0.0	0.0	0.0	0.0	75.0	ReH
Bromus sterilis L.	0.3	35.6	33.1	3.9	3.0	98.7	FoH, Mow, Cov, Til
Avena sterilis L.	0.0	42.5	47.5	6.3	3.1	93.8	FoH, Mow, Cov, Til
Hordeum murinum L.	0.1	15.8	14.4	0.0	0.0	99.1	FoH, Mow
Galium aparine L.	0.1	7.9	2.4	0.0	0.0	97.6	FoH, Mow
Sherardia arvensis L.	0.0	1.8	2.1	0.1	0.1	95.9	FoH, Mow
Medicago minima (L.) L.	0.1	3.3	1.9	0.1	0.1	92.6	FoH, Mow
Geranium dissectum L.	0.0	2.6	0.8	0.0	0.0	87.5	FoH, Mow
Convolvulus arvensis L.	1.3	3.0	5.4	0.0	0.8	72.6	FoH, Mow
Lathyrus sp.	0.0	1.4	0.9	0.0	0.0	62.5	FoH, Mow
Fumaria capreolata L.	0.0	0.0	0.0	7.4	17.5	100.0	Cov, Til
Lamium amplexicaule L.	0.0	0.0	0.0	4.4	15.1	100.0	Cov, Til
Veronica hederifolia L.	0.1	0.0	0.0	2.0	7.3	96.5	Cov, Til
Capsella bursa-pastoris (L.) Medik.	0.0	0.4	0.0	0.6	2.9	92.5	Cov, Til
Glebionis segetum (L.) Fourr.	0.0	0.9	0.3	7.0	3.3	89.8	Cov, Til
Stellaria media (L.) Vill.	0.0	0.8	1.1	3.3	3.1	79.7	Cov, Til
Scandix pecten-veneris L.	0.0	0.0	0.1	0.6	0.5	65.5	Cov, Til
Vicia sativa L.	0.0	1.4	0.0	0.0	0.0	100.0	FoH
Papaver rhoeas L.	0.0	6.9	0.0	3.9	0.1	64.1	FoH
Euphorbia helioscopia L.	0.0	0.5	5.1	0.0	0.0	91.8	Mow
Malva sylvestris L.	0.0	0.0	0.8	0.0	0.0	75.0	Mow
Senecio vulgaris L.	0.0	0.0	0.0	0.1	5.2	97.7	Til
Diplotaxis erucoides (L.) DC.	0.0	0.0	0.0	0.6	8.0	92.9	Til
Lolium rigidum Gaudin	0.0	0.9	0.0	0.1	2.6	84.8	Til
Calendula arvensis L.	0.3	1.3	1.3	1.4	4.5	59.7	Til

[1] ReH, residual herbicide; FoH, foliar herbicide; Mow, mowing; Cov, cover crop; Til, conventional tillage.

Table 6. Seed bank: average number of seeds per square meter and indicator value (IndVal) of weed species significantly ($P \leq 0.05$) associated with a treatment or a group of treatments.

Species	Number of seeds (n m^{-2})					IndVal	Treatments[1]
	ReH	FoH	Mow	Cov	Til		
Arenaria leptoclados (Rchb.) Guss.	1095	178	242	25	64	91.1	ReH
Calendula arvensis L.	0.0	331	1720	548	153	93.8	FoH, Mow, Cov, Til
Portulaca oleracea L.	0.0	1363	2331	943	1070	93.8	FoH, Mow, Cov, Til
Diplotaxis erucoides (L.) DC.	0.0	382	102	713	267	81.2	FoH, Mow, Cov, Til
Medicago disciformis DC.	0.0	675	382	242	1121	81.2	FoH, Mow, Cov, Til
Lamium amplexicaule L.	0.0	420	242	611	1580	75.0	FoH, Mow, Cov, Til
Bromus sterilis L.	51	420	790	166	38	80.8	FoH, Mow
Sonchus oleraceus L.	102	446	280	267	153	53.0	FoH, Mow
Euphorbia helioscopia L.	0	191	76	38	0	40.6	FoH, Mow
Capsella bursa-pastoris (L.) Medik.	0	0	38	484	229	61.2	Cov, Til
Fumaria capreolata L.	89	25	115	650	127	72.7	Cov
Lolium rigidum Gaudin	0	0	102	166	0	59.4	Cov
Erodium malacoides (L.) L'Hér.	0	0	204	25	0	67.9	Mow
Amaranthus retroflexus L.	0	0	166	280	1248	70.3	Til

[1] ReH, residual herbicide; FoH, foliar herbicide; Mow, mowing; cov, cover crop; Til, conventional tillage.

tillage, the yields per tree ranged between 4.05 and 3.56 kg; whereas the lowest yield was recorded for the mowing (2.72 kg per tree) (De Giorgio and Lamascese, 2005). Although these data referred to are the means of the period 1988–2000 (De Giorgio and Lamascese, 2005) and need to be updated, we might conclude that the treatment providing the lowest level of diversity (i.e., the less sustainable practice) is the most productive. However, emphasis should be placed on the off-farm environmental benefits of adopting conservative agriculture techniques that provide adequate level of biodiversity and low impact to the soil (Holland, 2004). From this point of view, the agroecological role of weed flora communities (Buhler, 2002; Chauhan et al., 2012) should be prioritized and weed management should be integrated with other cultural practices in order to optimize the whole cropping system rather than solely weed control (Elmore, 1996; Bàrberi, 2002).

During autumn months, the residual herbicide and conventional tillage were the less infested (cf. Table 1: total weed cover). This effect does not constitute a benefit (Montemurro and Fracchiolla, 2013); as a matter of fact, the presence of the sward in the autumn-winter period does not cause any damage and is rather desirable because it prevents soil erosion processes that are particularly common in many Mediterranean areas (García-Ruiz, 2010; Novara et al., 2011). Moreover, it is important to consider the high capacity of the natural flora to takeup soil nitrogen (Blackshaw et al., 2003) thus preventing in the rainy season leaching processes that might cause pollution (Constantin et al., 2010).

In springtime, prior to sward control operations, the plots treated by foliar herbicide and mowing showed the highest total weed cover, thus supplying a substantial amount of biomass to the soil, after sward had been destroyed. Among the species associated with these treatments, a large contribution to the total weed cover come from three *Poaceae: B. sterilis, A. sterilis* and *H. murinum.*

These species produce a substantial amount of biomass and have bunched roots; consequently they supply beneficial effects by improving porosity and structure of the soil and reducing erosion hazard. However, they can strongly compete with almond trees for soil water, particularly in rainfed orchards placed in Mediterranean conditions with pronounced summer drought. The lowest yield, recorded for the mowing treatment by De Giorgio and Lamascese (2005), is explained as a consequence of a greater competition for water. In this respect, a realistic proposal that could be verified by further studies would be to keep the orchard fully free of weeds during the drought period to minimize the negative effects of water competition, while benefiting from the positive effects of the sward (Ramos et al., 2010; Fracchiolla et al., 2013).

Besides the 'timing', another core concern is the techniques of weed removal. Post-emergence weed control by mowing or using chemical herbicides or the green manure of the cover crop may be proposed to reduce impact to the soil and to promote the growth of abundant and sufficiently diversified and balanced flora. Although the research has not regarded the effects on the agro-ecological system and on the physico-chemical soil properties, this flora can definitely have beneficial effects, following the indications provided by the literature.

This paper reports data of a trial that has merely involved the comparison of single weed control practices repeated for several years. On the other hand, several studies support the idea that each single practice should be considered only as a component of a more general system of diversified strategies of integrated weed management (Buhler, 2002; Chauhan et al., 2012). For example, mowing could be adopted to quickly suppress groundcover at the beginning of the drought period and chemical weeding can be used to cheaply control subsequent regrowing. The sowing of the cover crop could be performed to promote natural soil fertility and to introduce a further different management technique in the whole cropping system. One remaining question is the effects, both on- and off-farm, of adopting a combination of management practices on weed flora, productivity and biodiversity for a sustainable rural land use.

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Appendix

List of herbicides (active ingredients) used for the residual herbicides and foliar herbicides treatments. For each year, applications are indicated by the active ingredient [month, dose (kg ha^{-1})].

Residual herbicide treatment: 1976 – Bromacil (January, 2.0); Propyzamide + Simazine (November, 1.0 + 1.5). 1977 – Diclhobenil (October, 3.375). Paraquat (February, 0.47). 1979 – Paraquat (February, 0.47); Chlopropham + Diuron (February, 2.45 + 2.45); Dalapon (May, 0.04). 1980 – Bromacil (January, 2.0); Propyzamide + Simazine (1.0 + 1.5). 1981 – Diclhobenil (October, 3.375). 1983 – Paraquat (February, 0.47); Chlopropham + Diuron (March, 2.45 + 2.45). 1984 – Bromacil (January, 2.0); Paraquat (May, 0.925). 1985 – Propyzamide + Simazine (February, 1.0 + 1.5); Paraquat (May, 0.925); Diclhobenil (October, 3.375). 1986 – Paraquat (April, 0.925). 1987 – Paraquat (March, 0.47); Chlopropham + Diuron (April, 0.245 + 0.245); Paraquat (May, 0.47). 1988 – Bromacil (February, 2.0); Propyzamide + Simazine (November 1.0 + 1.5). 1989 – Diclhobenil (October, 3.375). 1990 – Chlopropham + Diuron (October, 2.45 + 2.45). 1992 – Glyphosate + Simazine (February, 1.08 + 3.0). 1993 – Glyphosate + Simazine (January, 1.08 + 3.0). 1994 – (February, Glyphosate + Simazine, 1.08 + 3.0). 1995 – Glyphosate + Simazine (May, 1.08 + 3.0). 1996 – Glyphosate + Simazine (November 1.08 + 3.0). 1997 – Paraquat (April, 0.925). 1998 – Glyphosate (October, 1.54). 1999 – Glyphosate (April, 1.23). Glyphosate (October, 1.5). Oxadiazon + Glyphosate (November, 0.5 + 0.25). 2000 – Glyphosate (May, 1.23); Oxadiazon + Glyphosate (October, 2.0 + 1.0). 2001 – Oxadiazon + Glyphosate (January, 2.0 + 1.0); Oxadiazon (May, 1.7); Diquat + Paraquat (May, 0.35 + 0.7); Oxadiazon (November, 1.7). 2002 – Diquat + Paraquat (May, 0.35 + 0.7); Diquat + Paraquat (October, 0.13 + 0.33). 2003 – Glyphosate (April, 1.53); Diquat + Paraquat (July, 0.04 + 0.12); Oxadiazon + Glyphosate (September, 2.0 + 1.0). 2004 – Diquat + Paraquat (April, 0.32 + 0.67). 2005 – Oxadiazon + Glyphosate (February, 2.0 + 1.0); Diquat + Paraquat (April, 0.13 + 0.33). 2006 – Oxadiazon + Glyphosate (April, 2.0 + 1.0); Glyphosate + Oxyfluorfen (October, 0.9 + 0.07). 2007 – Glyphosate + Oxyfluorfen (April, 0.9 + 0.07); Glyphosate (October, 0.108). 2008 – Glyphosate + Oxyfluorfen (May, 0.9 + 0.07); Glyphosate (November, 0.108). 2009 – Glyphosate + Flazasulfuron (May, 0.108 + 0.06). 2010 – Glyphosate + Flazasulfuron (May, 0.108 + 0.06).

Foliar herbicide treatment: 1976 – Paraquat (May, 0.925). 1977 – Paraquat (May, 0.925). 1978 – Paraquat (May, 0.925). 1979 – Paraquat (May, 0.925). 1980 – Paraquat (May, 0.925). 1981 – Paraquat (April, 0.925). 1982 – Paraquat (May, 0.925). 1983 – Paraquat (April, 0.925). 1984 – Paraquat (May, 0.925). 1985 – Paraquat (May, 0.925). 1986 – Paraquat (May, 0.925). 1987 – Paraquat (May, 0.925). 1988 – Paraquat (February, 0.925). 1989 – Paraquat (May, 0.925). 1990 – Paraquat (April, 0.925). 1991 – Paraquat (May, 0.925). 1992 – Paraquat (May, 0.925). 1993 – Paraquat (May, 0.925). 1994 – Paraquat (January, 0.925). 1995 – Diquat + Paraquat (May, 0.35 + 0.7). 1996 – Diquat + Paraquat (November, 0.35 + 0.7). 1997 – Paraquat (April, 0.925). 1998 – Diquat + Paraquat (May, 0.35 + 0.7). 1999 – Paraquat (May, 0.925). 2000 – Paraquat (May, 0.925). 2001 – Paraquat (May, 0.925). 2002 – Diquat + Paraquat (May, 0.29 + 0.6). 2003 – Diquat + Paraquat (November, 0.29 + 0.6). 2004 – Diquat + Paraquat (May, 0.29 + 0.6). 2005 – Diquat + Paraquat (May, 0.29 + 0.6). 2006 – Diquat + Paraquat (April, 0.29 + 0.6); Glufosinate ammonium (December, 0.9). 2007 – Glufosinate ammonium (October, 0.9). 2008 – Glufosinate ammonium (May, 0.9); Glufosinate ammonium (September, 0.9). 2009 – Glufosinate ammonium (May, 0.9). 2010 – Carfentrazone ethyl (May, 0.19).