Soil Management Systems: Effects on Soil Properties and Weed Flora

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A three-year experiment was conducted in order to evaluate the effects of three different soil management systems in a vineyard (organic mulch with exhausted olive pomace at 6 cm thick, weed mowing and herbicide application) on soil physicochemical characteristics and weed flora. A variety of data was collected throughout the trial, such as soil analyses, weed surveys and phytotoxicity tests. The results show that the exhausted olive pomace was able to increase the K and Mg content and exerted good control over weeds, and also had an effect on the weed flora composition. Although further research is needed, it is possible to conclude that the mode of action of the exhausted olive pomace was both mechanical (thickness of the layer) and phytochemical for the release of phytotoxic compounds (allelochemicals).

INTRODUCTION

It is well known that weeds are responsible for yield losses in vineyards and orchards because they compete with plants for nutrients and water and may reduce crop yields by up to 80% (Cousens & Mortimer, 1995). Traditional control of weeds is by soil tillage, but chemical control of weeds using pre- and post-emergence herbicides is widely used. Chemical control is particularly effective to control weeds in the vine rows, where it is difficult to operate mechanically, whereas vegetation can be controlled easily by mowing or disking in the work row. However, reasons for reducing herbicide use are the widespread appearance of herbicide-resistant weeds (Darmency & Gasquez, 1990; LeBaron & McFarland, 1990; LeBaron, 1991; Henkes, 1997; Powles *et al.*, 1997), the risk of environmental contamination (Carter *et al.*, 1991) and, more recently, the very negative public perception of agrochemicals (Major, 1992) as affecting the environment and food quality.

Mulching consists of spreading a protective layer of a material of different origin and nature over the soil. Several materials can be used for mulching: synthetic (*i.e.* geotextile), organic (*i.e.* straw, pruning residues, etc.,) and living (*i.e.* cover crops).

Weed suppression by living or dead mulches can be due to a mechanical action (*i.e.* the thickness of the layer) and, in some cases, to the release of allelochemicals (Teasdale & Mohler, 2000; Bhowmika & Inderjit, 2003; Moonen & Barberi, 2010). However, because organic mulches decompose over time, they require periodic applications, with consequent costs and the availability of the material becoming a potential problem. On the other hand, organic and living mulches can provide organic matter and nutrients to the soil and enhance soil particle aggregation and water-holding capacity (Haynes, 1980; Merwin *et al.*, 1995; Verdú & Mas, 2007). Moreover, higher yields have been reported in mulched vineyards with respect to conventional vineyards (Van Huystteen & Weber, 1980). The use of mulching materials also should be considered as a tool for the economical and sustainable use of waste materials. Olive mill waste disposal is an important issue for the Mediterranean olive oil-producing countries. In Italy, olive pomace commonly is produced from three-phase systems, which are preferred to two-phase systems because olive pomace is extracted successively with n-hexane for obtaining olive pomace oil. The so-called exhausted olive pomace is then mostly used as fuel for the oil extractors and for domestic heating, since it has a high calorific value. However, this material could find a possible application in organic agriculture, especially in the countries where it is largely produced. In recent years, EU policy to support more sustainable agricultural practices has shown an increased and keen interest in the value of agricultural by-products such as olive pomace. As a consequence, a number of investigations on the agronomic utilisation of olive pomace have been

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undertaken. In particular, the use of olive pomace as soil amendment material, especially after composting, showed positive effects on various soil properties (Saviozzi *et al*., 2001; Rinaldi *et al*., 2003; Brunetti *et al*., 2005; Alburquerque *et al*., 2006; López-Piñeiro *et al*., 2008; Ferrara *et al*., 2012; Gómez-Muñoz *et al*., 2013).

The objective of this study was to compare three different soil management systems in the vine row: (1) exhausted olive pomace mulch; (2) weed mowing; and (3) chemical control (herbicides). Effects on soil chemical properties and weed control efficacy were investigated.

MATERIALS AND METHODS

Plant material and experimental design

The study was carried out from 2008 to 2010 in the repository of table and wine grape cultivars (more than 100 varieties and clones) located in the Department of Soil, Plant and Food Science at the Experimental Agriculture Station of the University of Bari, 'Aldo Moro', in Valenzano (Puglia Region, South-eastern Italy). The vineyard was planted in 2002 and the vines were spaced 1.0 m × 4.0 m, trained onto a Guyot system with a 1103 P rootstock and drip irrigated from May to September (600 to 800 m^3/ha). For each row, a single irrigation pipeline was positioned at a height of 50 cm from the soil with two drippers for each vine (distance 0.5 m each from the vine). Pest control and other vineyard operations were conducted according to local practices. Fertiliser application was suspended for the three years of experimentation in order to better verify the effects of the different weed management practices on the organic and mineral element content of the soil.

The alleyways between the rows were mowed or disked, whereas the following floor management systems were compared in the rows:

- exhausted olive pomace of 6 cm thick (EOP6) applied under the vines (Fig. 1);
- mowing, two to three times per year (WM);
- chemical control using glyphosate at 1080 g/ha active ingredient, applied two times per year, in autumn and spring (CC).

Each treatment was repeated in six plots, consisting of one row 24.0 m long and 1.0 m wide, in a randomised block design. The application of the exhausted olive pomace was performed at the end of the winter of the year 2007. On the basis of the density of the olive pomace (500 kg/m^3), 720 kg were applied for each plot (replicate).

Soil analyses

Soil chemical analyses were performed each year following internationally recommended procedures (Sparks *et al*., 1996). In particular, soil samples were collected in autumn 2007 and successively in the autumn of each year, from 2008 to 2010, at a distance of around 0.25 m from the vine and the dripper. Plant residual materials were removed accurately, and the soil was air-dried, gently crushed, and passed through a 2 mm sieve. Stones and gravel were removed and determined.

The analysis of particle size was performed using the pipette method according to Gee and Bauder (1986), and the textural classes were determined using the textural triangle of the USDA classification scheme.

Soil pH was determined in water (pH_{H_2O}) and in 0.01 M

FIGURE 1
Exhausted olive pomace of 6 cm thick under the vines of the repository of grape varieties belonging to the Department of Soil, Plant and Food Science, University of Bari.

$CaCl_2$ solution (pH_{CaCl}) with a soil/water ratio of 1:2.5 (w/v) using a pH meter (Crison, Basic 20). The soil salinity was assessed by determination of the electrical conductivity (EC) at 25 °C on an aqueous soil extract (ratio 1:2 w/v) with a conductimeter (XS cond 510). The content of total carbonates was measured using a gas-volumetric method (Dietrich-Fruehling calcimeter), while active carbonate was determined according to the Boischot procedure (Boischot & Hebert, 1947).

Soil organic carbon (C_{org}) was analysed according to the Walkley and Black method as described by Nelson and Sommers (1996). The organic matter (OM) content was calculated by multiplying the determined organic carbon by 1.724.

Total nitrogen (N_{Tot}) was analysed using the Kjeldahl procedure, as described in Bremner (1996). Available phosphorus (P_2O_{5ava}) was determined by the Olsen method (Olsen & Sommers, 1982). The phosphorus content was determined colorimetrically by a spectrophotometer (Megatech SP-930) at 650 nm absorbance using the modified ascorbic acid method (Watanabe & Olsen, 1965).

Exchangeable cations (Ca_{ex}, Mg_{ex}, K_{ex} and Na_{ex}) were determined by means of inductively-coupled plasma – optical emission spectroscopy (ICP-OES) (ICAP 6300, Thermo Electron, UK) after soil extraction with barium chloride and triethanolamine solution buffered at pH 8.2. The data of the soil analysis before the trial are reported in Table 1.

Olive pomace analyses

Exhausted olive pomace (EOP) was air-dried, ground with a mixer mill and passed through a 1 mm sieve. The pH was measured by a glass electrode in distilled water suspension at a 3:50 (w/v) EOP-to-liquid phase ratio. Electrical conductivity (EC) was determined by a conductimeter in a water extract at 1:10 (w/v) EOP-to-liquid phase ratio. Humidity and ash were determined at 105 °C and 550 °C, respectively. Organic carbon (C_{org}) was determined according to the Ciavatta method (Ciavatta *et al*., 1989). Total nitrogen (N_{Tot}) was determined with a nitrogen analyser (Nitrogen Analyzer 2410 Series II Perkin Elmer, USA). Total P (P_{Tot}), total cations and heavy metals were determined after digestion with H_2O_2, HCl and HNO_3 using a microwave digester (MARS Xpress, CEM, USA). The concentration of metals in the digested sample was measured by means of ICP-OES (ICAP 6300, Thermo Electron, UK), and total phosphorous colorimetrically by a spectrophotometer (Megatech SP-930) at 650 nm according to the modified ascorbic acid method. The physicochemical characteristics of the exhausted olive pomace are given in Table 1.

Flora surveys and data processing

Weeds surveys were run between August 2008 and January 2010 in the two peak growth periods of weeds. For each plot, in a central area of 20.0 m × 0.6 m, weed species were identified and for each of them the cover percentage was estimated visually.

Greenhouse experiments

Fifty seeds of each of *Chrysanthemum segetum* L., *Sonchus oleraceus* L., *Sinapis arvensis* L., *Digitaria sanguinalis* (L.) Scop., *Festuca arundinacea* Schreber, *Chenopodoim album* L., *Solanum nigrum* L., *Diplotaxis erucoides* (L.) DC. and *Trifolium incarnatum* L. were placed on a soil layer of 5 cm, in trays of 30 × 35 ×11 cm (w × l × h). Species were chosen either according to their botanical family or the size of the seeds.

In four trays the seeds were covered with a layer of 6 cm of exhausted olive pomace, whereas in another four trays they were covered with a 6 cm layer of gravel with a mean particle size of 0.5 cm. Four trays in which the seeds were covered with soil were used as control. Each tray was considered as a single replication.

Trays were placed in a greenhouse and irrigated periodically in order to stimulate germination. After germination the seedlings were counted and removed; the trial was stopped when new seedlings were not observed for at least seven consecutive days. Data were expressed as a reduction of the emergence percentage with respect to the control, according to the formula $(C – T)/C × 100$, where C and T are the number of seedlings in the control and in the treatment respectively.

Statistical analysis

Variance assumptions were verified (homogeneity of variance by Levene's test, normal distribution by the Lillefors test). For data from the soil analyses, analysis of variance was performed at the 0.01 P level and the mean values obtained for the different treatments were statistically separated by using the REGWQ test. For data from the weed surveys, analysis of variance was performed at the 0.05 P level and the mean values obtained for the different treatments were statistically separated using Duncan's test. For the greenhouse experiment, values expressed as reduction of emergence (percentage) were arcsin transformed, analysis of variance was performed at the 0.05 P level and the mean values were compared with the LSD test.

RESULTS AND DISCUSSION

Soil analyses

The soil is loam according to the USDA soil texture classification, following the particle analysis (Table 1). The results of the physicochemical analyses of the soil at 0 to 20 cm showed statistically significant differences only for K and Mg content, for K in the second year and for Mg in the first and second year respectively (Table 2). No differences were observed for parameters such as pH, EC, C_{org} and N_{Tot}, and the only differences between treatments were observed for the concentrations of some of the exchangeable cations. In particular, EOP6 showed the highest values of Mg_{ex} and K_{ex}, as a consequence of their higher content in the olive pomace (Table 1). Major changes for various soil chemical properties were measured after an olive orchard irrigation with treated wastewater (Bedbabis *et al*., 2014a, 2014b). The soil organic matter content in a 'Chardonnay' vineyard in South Africa in the 0 to 150 mm soil layer of the cover crop treatment was significantly higher than that of the mechanically-cultivated control after a period of 10 years (Fourie *et al*., 2007). In our trial we did not observe any significant change because of both the shorter period of time and the fast mineralisation of the organic material (olive pomace, weeds)

TABLE 1
Physicochemical variables of exhausted olive pomace and soil at the beginning of the trial (2007). All concentrations are in mg/kg, unless indicated otherwise (n = 6).

Treatment	2007																			
	Skeleton (g/kg)	Sand (g/kg)	Silt (g/kg)	Clay (g/kg)	pH H_2O (1:2.5)	EC (dS/m)	C_{org} (g/kg)	OM (g/kg)	N_{Tot} (g/kg)	P_{ava}	Ca_{ex}	K_{ex}	Mg_{ex}	Na_{ex}	Cd	Cr	Cu	Ni	Pb	Zn
Pomace					5.7	1.72	473	952	6.7	646	565	681	510	255	< 0.5	10.8	9.4	5.8	1.4	7.9
Soil	281	357	410	233	7.9	0.70	12.0	20.6	1.2	16.5	3 661	408	190	35	0.6	29.3	34.5	24.2	9.8	65.2

TABLE 2
Physicochemical variables of the soil during the three years of three floor-management systems at a depth of 0 to 20 cm. All concentrations are in mg/kg, unless indicated otherwise (n = 6).

Treatment	2008														
	pH H_2O (1:2.5)	pH $CaCl_2$ (1:2.5)	EC (dS/m)	Total carbonates (g/kg)	Active carbonates (g/kg)	C_{org} (g/kg)	OM (g/kg)	N_{Tot} (g/kg)	C/N	P_{ava}	Ca_{ex}	K_{ex}	Mg_{ex}	Na_{ex}	P_2O_{5ava}
WM[1]	7.9	7.4	0.62	277	34	12.7	21.9	1.2	11.5	15.8	3 621	403	181 B[4]	34	36.2
CC[2]	8.0	7.5	0.64	267	32	13.2	22.7	1.2	11.3	17.8	3 758	429	203 B	32	40.8
EOP6[3]	7.9	7.4	0.74	284	30	12.1	20.8	1.2	10.3	16.3	3 547	445	262 A	34	37.3
	2009														
	pH H_2O (1:2.5)	pH $CaCl_2$ (1:2.5)	EC (dS/m)	Total carbonates (g/kg)	Active carbonates (g/kg)	C_{org} (g/kg)	OM (g/kg)	N_{Tot} (g/ kg)	C/N	P_{ava}	Ca_{ex}	K_{ex}	Mg_{ex}	Na_{ex}	P_2O_{5ava}
WM	7.9	7.3	0.41	266	32	11.9	20.4	1.2	10.0	8.8	3 679	392 B	184 B	38	20.2
CC	7.9	7.4	0.38	263	29	12.4	21.4	1.2	10.5	8.8	3 765	405 B	209 B	41	20.2
EOP6	7.9	7.3	0.38	277	36	11.3	19.4	1.1	10.1	9.8	3 621	514 A	284 A	36	22.5
	2010														
	pH H_2O (1:2.5)	pH $CaCl_2$ (1:2.5)	EC (dS/m)	Total carbonates (g/kg)	Active carbonates (g/kg)	C_{org} (g/kg)	OM (g/kg)	N_{Tot} (g/kg)	C/N	P_{ava}	Ca_{ex}	K_{ex}	Mg_{ex}	Na_{ex}	P_2O_{5ava}
WM	8.1	7.6	0.20	279	35	10.4	17.9	1.0	11.0	8.2	3 656	286	120	39	18.8
CC	8.1	7.5	0.21	243	33	10.2	17.5	1.0	9.9	8.2	4 154	332	121	30	18.8
EOP6	8.2	7.5	0.21	239	34	10.3	17.7	1.0	10.9	7.8	3 981	355	144	34	17.9

[1] WM: weeds mowed; [2] CC: chemical control; [3] EOP6: exhausted olive pomace, 6 cm thick. [4] Means followed by different letters in each column are significantly different (REGWQ, $P \leq 0.01$).

on the soil surface. However, CC required an application of agrochemicals, whereas WM and EOP6 were based on the re-use of organic material with a more sustainable approach. In an agricultural area close to the Puglia region, soil-protecting orchard management (SPOM) actions in kiwi and apricot orchards (*i.e.* cover crop, no tillage, compost application and mulching with pruning residues) increased yield and N, P and K content in the soil with respect to the traditional orchard management practices (*i.e.* soil tillage, removing of pruning residues and mineral fertilisers) commonly adopted in the area (Montanaro *et al*., 2010), but with no effects on soil organic carbon, as also observed in our trial. The different vineyard managements did not have a significant effect on total soil C and no differences could be monitored for years, whereas labile soil C pools respond more rapidly to changes in floor management (Reganold *et al*., 2001; Haynes, 2005).

A similar trend of the soil parameters was observed at 20 to 40 cm (Table 3), with significant differences among treatments only for the content of K_{ex} and Mg_{ex}, with the higher values measured in the EOP6 treatment. The changes in K_{ex} and Mg_{ex} content were significant along the years either for the 0 to 20 (Table 4) or the 20 to 40 cm layer (Table 5). The application of EOP6 increased the K_{ex} and Mg_{ex} content in the upper soil layer one year after application (Table 2); but after three years, in 2010, the K_{ex} and Mg_{ex} levels in EOP6 soil (0 to 20 cm) were similar to that in the CC and WM soil (Table 2), suggesting that K_{ex} and Mg_{ex} had leached from the 0 to 20 cm layer down to the 20 to 40 cm layer (Table 3). A similar trend has been reported after mulching with bark in an apple orchard (Peck *et al*., 2011). Since the vineyard was not fertilised during the three experimental years, significant reductions of P_{ava}, K_{ex}, Mg_{ex} and EC were observed (Tables 4 and 5), probably as a consequence of vine absorption of elements, as recently reported for different grape varieties in Spain (Amorós *et al*., 2013). A long-term apple orchard floor management study reported increases in C, P, Ca, Fe, Mn and pH in the 0 to 20 cm soil layer after 12 to 14 years of biennial bark mulch applications (Yao *et al*., 2006).

EOP6 increased the content of both K_{ex} and Mg_{ex} with respect to WM and CC (Tables 4 and 5), as a consequence of the concentration of these elements in the exhausted olive pomace (Table 1). After three years the soil chemical response to the different treatments was limited, with only four soil parameters showing significant differences (Tables 4 and 5). Similar limited results were observed in a recent experiment in an almond orchard in Spain, where the soil properties showed significant differences only when cover treatments (*i.e.* cover crops, native vegetation) were compared to tillage systems, with the cover crops improving soil stability (Ramos *et al*., 2011). This positive result of mulching could be important in the case of soils subjected to rock fragmentation, a common agricultural practice in Puglia before establishing table grape vineyards (Ferrara *et al*., 2012). Differences among cover treatments were detected for enzymatic activity, whereas chemical and physical parameters did not show differences (Ramos *et al*., 2011). No significant variations were observed for the heavy metal concentrations in the soil after three years (data not shown) because of the low amount of metals, both in the exhausted olive pomace and in the soil (Table 1). These results indicate that the application of exhausted olive pomace as mulching material is not a concern with regard to either heavy metal accumulation in the soil or effects on microorganisms.

In a corn field, cover crops and manure did not significantly affect the soil organic content after a four-year experiment, but the labile C fraction was significantly increased by cover crops (Jokela *et al*., 2009), also improving aggregate stability and microbial biomass. However, cover crops were beneficial for corn silage systems, but it may take more than four years for some soil quality indicators to respond fully (Jokela *et al*., 2009). This also is a possible explanation for the limited changes in soil organic matter and other chemical parameters measured in our experiment.

The use of olive mill wastes as mulching material have shown positive effects on soil organic content (Altieri & Esposito, 2008; López-Piñeiro *et al*., 2008), physical properties (El-Asswad *et al*., 1993; Mellouli *et al*., 1998; Kavdir & Killi, 2007; Al-Widyan *et al*., 2010), and mineral elements (Montemurro *et al*., 2004; Cucci *et al*., 2008; López-Piñeiro *et al*., 2008; Uygur & Karabatak, 2009). The application of the exhausted olive pomace as mulch could be a positive way to dispose of this material in olive oil-producing countries and to add some mineral elements for vine nutrition, as being applied as mulch at an amount similar to that used in the trial caused no negative effects either to the vine or to the soil.

The weeds, either chemically (CC) or mechanically controlled (WM), can compete with the vines for nutrients and water, thus affecting berry growth and ripening, especially in a situation of water stress (Monteiro & Lopes, 2007). However, weed competition can balance the vegetative and reproductive activities of the grapevine, with consequent better light exposure of the clusters (reduced foliage); 'Cabernet Sauvignon' and 'Pinot noir' light-exposed clusters resulted in higher anthocyanins, phenolics and sugar and greater size (Dokoozlian & Kliewer, 1996). But mulching also can be used to reduce weed competition with the vine and to inhibit weed seedling emergence (Fourie, 2010).

The exhausted olive pomace increased two mineral elements in the soil (K and Mg), whereas other mulching materials such as wood chip increased both active and slow soil C pools, total soil C and N, earthworm activity, fruit yield and tree growth in an apple orchard (TerAvest *et al*., 2011). Exhausted olive pomace mulch is not used in vineyards, but effective weed suppression has recently been reported in a wine grape vineyard in the Puglia region (Ferrara *et al*., 2012). Weed reduction in orchards mulched with various biomasses has been reported recently in a study conducted in the USA (Granatstein & Mullinix, 2008), and the use of bark mulch was effective in increasing the soil organic matter with respect to mechanical weed control in an apple orchard (Peck *et al*., 2011).

In recent research in two Californian vineyards, the use of a mulch from mowed cover crops in the alleys was very effective in weed suppression, and it was reported that grape yields and profits under a mulched cover crop system were similar to, and often exceeded, what was observed in conventional tillage and herbicide systems (Steinmaus *et al*., 2008).

TABLE 3
Physicochemical variables of the soil during the three years of three floor-management systems at a depth of 20 to 40 cm. All concentrations are in mg/kg, unless indicated otherwise (n = 6).

Treatment	pH H_2O (1:2.5)	pH $CaCl_2$ (1:2.5)	EC (dS/m)	Total carbonates (g/kg)	Active carbonates (g/kg)	C_{org} (g/kg)	OM (g/kg)	N_{Tot} (g/kg)	C/N	P_{ava}	Ca_{ex}	K_{ex}	Mg_{ex}	Na_{ex}	P_2O_{5ava}
2008															
WM[1]	7.9	7.4	0.73	243	35	10.8	18.5	1.2	10.4	14.5	3 719	333	151 B[4]	36	33.2
CC[2]	8.0	7.4	0.56	237	32	11.8	20.3	1.2	10.4	12.3	3 903	375	212 AB	38	28.2
EOP6[3]	8.0	7.4	0.62	248	30	11.1	19.1	1.0	10.6	13.5	3 716	389	286 A	33	30.9
2009															
	pH H_2O (1:2.5)	pH $CaCl_2$ (1:2.5)	EC (dS/m)	Total carbonates (g/kg)	Active carbonates (g/kg)	C_{org} (g/kg)	OM (g/kg)	N_{Tot} (g/kg)	C/N	P_{ava}	Ca_{ex}	K_{ex}	Mg_{ex}	Na_{ex}	P_2O_{5ava}
WM	8.0	7.3	0.36	240	33	10.9	18.7	1.1	9.9	8.6	3 886	298	179 B	39	19.7
CC	7.9	7.4	0.43	263	31	12.0	20.6	1.2	10.1	9.8	4 023	305	185 B	35	22.5
EOP6	7.9	7.4	0.34	237	34	10.9	19.3	1.1	10.3	8.9	3 607	347	279 A	33	20.4
2010															
	pH H_2O (1:2.5)	pH $CaCl_2$ (1:2.5)	EC (dS/m)	Total carbonates (g/kg)	Active carbonates (g/kg)	C_{org} (g/kg)	OM (g/kg)	N_{Tot} (g/kg)	C/N	P_{ava}	Ca_{ex}	K_{ex}	Mg_{ex}	Na_{ex}	P_2O_{5ava}
WM	8.2	7.6	0.21	238	34	10.3	17.7	0.9	12.0	6.3	3 961	232 B	129 B	35	14.4
CC	8.1	7.6	0.19	236	31	10.7	18.4	1.1	10.0	6.9	4 051	219 B	126 B	33	15.8
EOP6	8.2	7.6	0.20	232	35	9.3	16.0	0.9	10.8	6.0	3 852	291 A	163 A	37	13.7

[1] WM: weeds mowed; [2] CC: chemical control; [3] EOP6: exhausted olive pomace, 6 cm thick. [4] Means followed by different letters in each column are significantly different (REGWQ, $P \leq 0.01$).

TABLE 4
Influence of treatments and years on physicochemical variables of the soil at a depth of 0 to 20 cm. All concentrations are in mg/kg, unless indicated otherwise (n = 6).

FACTOR	pH H_2O (1:2.5)	pH $CaCl_2$ (1:2.5)	EC (dS/m)	Total $CaCO_3$ (g/kg)	Active calcium (g/kg)	C_{org} (g/kg)	OM (g/kg)	N_{Tot} (g/kg)	C/N	P_{ava}	Ca_{ex}	K_{ex}	Mg_{ex}	Na_{ex}	P_2O_{5ava}
Year															
2008	7.9	7.4	0.67 A[4]	276	32	12.7	21.8	1.2	11.0	16.6 A	3 642	425 A	215 A	33	38.0 A
2009	7.9	7.3	0.39 B	269	32	11.9	20.4	1.2	10.2	9.1 B	3 688	437 A	226 A	38	20.8 B
2010	8.1	7.5	0.21 C	254	34	10.3	17.7	1.0	10.6	8.1 B	3 930	324 B	128 B	34	18.6 B
Treatment															
WM[1]	8.0	7.4	0.41	274	34	11.7	20.1	1.1	10.8	10.9	3 652	360 B	162 B	37	25.0
CC[2]	8.0	7.4	0.41	258	31	11.9	20.5	1.2	10.6	11.6	3 892	389 B	178 B	34	26.5
EOP6[3]	8.0	7.4	0.44	267	33	11.2	19.3	1.1	10.4	12.6	3 716	438 A	230 A	34	28.9

[1] WM: weeds mowed; [2] CC: chemical control; [3] EOP6: exhausted olive pomace, 6 cm thick. [4] Means followed by different letters in each column are significantly different (REGWQ, $P \leq 0.01$).

TABLE 5
Influence of treatments and years on physicochemical variables of the soil at a depth of 20 to 40 cm. All concentrations are in mg/kg, unless indicated otherwise (n = 6).

FACTOR	pH H_2O (1:2.5)	pH $CaCl_2$ (1:2.5)	EC (dS/m)	Total $CaCO_3$ (g/kg)	Active calcium (g/kg)	C_{org} (g/kg)	OM (g/kg)	N_{Tot} (g/kg)	C/N	P_{ava}	Ca_{ex}	K_{ex}	Mg_{ex}	Na_{ex}	P_2O_{5ava}
Year															
2008	7.9	7.4	0.64 A[4]	242	32	11.2	19.3	1.1	10.8	13.4 A[1]	3 780	366 A	216 A	35	30.7 A
2009	7.9	7.3	0.37 B	247	32	11.4	19.5	1.1	10.1	9.1 B	3 839	317 B	214 A	35	20.8 B
2010	8.2	7.6	0.20 C	235	33	10.1	17.4	1.0	10.9	6.4 C	3 955	247 C	139 B	35	14.7 C
Treatment															
WM[1]	8.0	7.4	0.43	240	34	10.6	18.3	1.1	10.8	9.8	3 855	287 B	153 B	36	22.5
CC[2]	8.0	7.4	0.39	245	31	11.5	19.8	1.2	10.2	9.6	3 993	300 B	174 B	35	22.0
EOP6[3]	8.0	7.5	0.38	239	33	10.5	18.1	1.0	10.9	9.4	3 725	342 A	243 A	34	21.5

[1] WM: weeds mowed; [2] CC: chemical control; [3] EOP6: exhausted olive pomace, 6 cm thick. [4] Means followed by different letters in each column are significantly different (REGWQ, $P \leq 0.01$).

Grape growers generally control weeds under vines with cultivation and/or herbicides, with high economic and environmental 'costs'. In particular, cultivation can significantly change soil characteristics and root growth, as a consequence successively influencing soil nitrogen (N) dynamics and loss (Jackson *et al*., 2003).

Weed survey

The results of the weed surveys conducted during the three years are reported in Table 6. In the first survey (2008-08-01), the most abundant weeds were *Bidens tripartita* L., *Chenopodium album* L. and *Convolvulus arvensis* L. The lowest cover percentage of *B. tripartita* L. was estimated in the plots mulched with EOP6 (3.3%); with regard to *C. album* L., the lowest infestation was found in both EOP6 and WM plots. On 2008-10-21 the lowest covering of *Calendula arvensis* L. (3.0%) was in the EOP6 plot, whereas the lowest cover percentage of *Hordeum murinum* L. was estimated in both the CC and EOP6 plots. In the survey of 2009-06-30, the presence of *Avena sterilis* L., *Chondrylla juncea* L., *Conyza canadensis* (L.) Cronq. and *Sonchus tenerrimus* L. measured in the CC and EOP6 plots was significantly lower than the values measured in the WM management plot. The cover percentages of *B. tripartita* L. and *C. album* L. were lower under EOP6 management, but not statistically different from the values in WM management. The cover percentage of *Cirsium arvense* (L.) Scop. was significantly higher in EOP6 with respect to CC and WM on 2009-06-30 (27.9%), whereas it was significantly higher than CC and similar to WM on 2010-01-08 (10.5%). Moreover, in this last survey, the cover percentage of *C. canadensis* (L.) Cronq. estimated in the WM and EOP6 plots was significantly lower with respect to values measured in the CC management plot (6.3%).

Greenhouse experiments

The emergence of *C. segetum* Hill, *S. oleraceus* L., *S. arvensis* L. and *T. incarnatum* L. was reduced by both EOP6 and gravel, although with different effectiveness (Table 7). Only EOP6 was able to partly reduce the emergence of *D. sanguinalis* and *F. arundinacea* (67.6% and 38.7% respectively). The emergence of *C. segetum* Hill, *S. oleraceus* L. and *S. arvensis* L. was completely inhibited (100.0%) by the exhausted olive pomace, whereas gravel reduced the emergence of weeds by 61.5, 40.0 and 68.9% respectively (Table 7). The emergence of *T. incarnatum* L. was reduced by 59.8% and by 12.8% with EOP6 and gravel respectively.

For all these species, the inhibition observed with EOP6 was statistically higher than in the control (gravel), although the thickness of these two materials were similar. This observation might lead us to assume that the olive pomace could act both physically (thickness) and chemically, through phytotoxic compounds released during its degradation, as already reported for rye mulch on *Amaranthus retroflexus* L. and *Portulaca oleracea* L. (Schulz *et al*., 2012).

The emergence of *C. album* L., *S. nigrum* L. and *D. erucoides* L. was not affected by EOP6 and the control (data not shown). The different responses of the test species could be due to morphological characteristics of the seeds and

TABLE 6
Ground cover of weeds (%) in the rows subjected to three floor-management systems during the three-year trial.

TREATMENTS											
	2008-08-01										
	Total infestation	*Bidens tripartita*	*Chenopodium album*	*Convolvulus arvensis*	Others[5]						
WM[1]	61.0 b[4]	30.8 a	11.2 b	6.7	12.3						
CC[2]	105.5 a	43.3 a	45.8 a	8.8	7.6						
EOP6[3]	42.2 b	3.3 b	17.5 b	13.3	8.1						
	2008-10-21										
	Total infestation	*Calendula arvensis*	*Convolvulus arvensis*	*Hordeum murinum*	Others						
WM	77.0 a	19.2 a	8.2	17.5 a	32.3						
CC	61.8 a	14.5 a	10.2	3.3 b	33.8						
EOP6	39.5 b	3.0 b	12.8	1.2 b	22.5						
	2009-06-30										
	Total infestation	*Avena sterilis*	*Bidens tripartita*	*Chenopodium album*	*Chondrylla juncea*	*Cirsium arvense*	*Conyza canadensis*	*Convolvulus arvensis*	*Sonchus oleraceus*	*Sonchus tenerrimus*	Others
WM	190.9 a	75.0 a	5.0 b	7.5 b	13.3 a	10.4 b	20.0 a	10.0	22.1	27.5 a	0.1
CC	160.9 ab	27.1 b	41.2 a	42.5 a	0.1 b	4.2 b	7.1 b	15.4	12.5	8.3 b	2.5
EOP6	125.9 b	25.8 b	15.0 b	2.9 b	5.8 b	27.9 a	0.1 b	15.8	17.9	9.2 b	5.5
	2010-01-08										
	Total infestation	*Avena sterilis*	*Bromus inermis*	*Cirsium arvense*	*Conyza canadensis*	*Hordeum murinum*	*Lolium multiflorum*	*Medicago* spp.	*Mercurialis annua*	*Stellaria media*	Others
WM	126.2 a	8.0	10.6	11.2 a	10.2 a	15.6	7.8	2.4 b	11.0 a	14.2 a	35.2
CC	93.6 b	12.5	9.3	6.3 b	4.3 b	12.3	6.5	0.1 b	6.3 b	7.7 b	28.3
EOP6	82.4 b	10.0	4.3	10.5 a	8.3 a	13.0	6.0	5.0 a	4.3 b	1.7 c	19.3

[1] WM: weeds mowed; [2] CC: chemical control; [3] EOP6: exhausted olive pomace, 6 cm thick. [4] Means followed by different letters in each column are significantly different (Duncan's test, $P \leq 0.05$).

[5] Others include weeds with very low and patchy covering: *Amaranthus retroflexus* L., *Chondrylla juncea* L., *Cirsium arvense* (L.) Scop., *Cynodon dactylon* L., *Heliotropium europaeum* L., *Setaria verticillata* L., *Solanum nigrum* L. (survey of 2010-08-01); *Bidens tripartita* L., *Cirsium arvense* (L.) Scop., *Conyza canadensis* (L.) Cronq., *Digitaria sanguinalis* (L.) Scop., *Diplotaxis erucoides* (L.) DC., *Mercurialis annua* L., *Solanum nigrum* L., *Sonchus tenerrimus* L. (survey of 2008-10-21); *Lactuca serriola* L., *Solanum nigrum* L. (survey of 2009-06-30); *Calendula arvensis* L., *Solanum nigrum* L., *Sonchus spp.*, *Veronica hederifolia* L. (survey of 2010-01-08).

TABLE 7
Effect of 6 cm thick exhausted olive pomace (EOP6) and gravel on reduction of seed emergence (%) with respect to the control (soil) in the greenhouse experiment.

Species	Gravel	EOP6[1]
Chrysanthemum segetum L.	61.5 b[2]	100.0 a
Sonchus oleraceus L.	40.0 b	100.0 a
Sinapis arvensis L.	68.9 b	100.0 a
Digitaria sanguinalis (L.) Scop.	0.0 b	67.6 a
Festuca arundinacea Schreber	0.0 b	38.7 a
Trifolium incarnatum L.	12.8 b	59.8 a

[1]EOP6: exhausted olive pomace, 6 cm thick. [2] Means followed by different letters in each row are significantly different (LSD test, $P \leq 0.05$).

seedlings, or specific physiological aspects (Inderjit & Duke, 2003).

CONCLUSIONS

Soil management with the exhausted olive pomace showed positive effects on some soil chemical parameters, in particular the increase in K and Mg content. As expected, the other two soil management systems did not show any influence on soil chemical properties. Exhausted olive pomace was able to control the emergence of many weeds and, in each survey, showed effects similar to those obtained with both chemical and mechanical weed control. These results are very remarkable because soil mulched with exhausted olive pomace was not subjected to other treatments or the reapplication of the material for three years, whereas in the other treatments weeds were chemically or mechanically controlled repeatedly over the years. In olive oil-producing countries (Italy, Spain, Greece, etc.), olive pomace originates from three-phase systems and is extracted successively for obtaining olive pomace oil. The exhausted olive pomace could be used as fuel or, as demonstrated in our research, can be used as mulching material to exert good control over weeds as part of more sustainable management of the vineyard.

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