ITALUS HORTUS
Vol. 28 (2021), Pages 59-68
doi: 10.26353/j.itahort/2021.3.5968
Brief Research Report

Mulching with almond hull and olive leaves for weed control in fennel (*Foeniculum vulgare* Mill.) cultivation and flower beds

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Received: 31 May; Accepted: 19 December; Published: 31 December 2021

Abstract: Weeds are a major problem in cropping systems and in urban areas. The aim of this study was to assess the effectiveness of organic mulching with olive leaves and almond hulls to control weeds in fennel (*Foeniculum vulgare* Mill.) and in flower beds (urban areas). A 3-cm thick layer of olive leaves or almond hulls was applied as mulching material in fennel. Control consisted of both an unmulched treatment and a weed free control. Moreover, in a flower bed of a railway station, plots mulched with 3 cm layer of olive leaves and almond hulls were compared with an unmulched treatment. Weed infestation was evaluated and the weights of the whole plant and of the marketable part of fennel (*grumolo*) measured. Mulching with olive leaves and almond hulls reduced weed infestation in both vegetable crop and flower beds. However, olive leaves reduced the weights of the whole plant and of the *grumolo*. The adoption of almond hulls and olive leaves as organic mulches could be an effective strategy for weed control. Further investigations should be carried out to assess whether the effectiveness of these mulching materials is mainly due to a mechanical activity or allelopathic compounds also play a significant role in weed suppression.

Keywords: soil management; herbicides; byproduct; crop residues; non-chemical weed control

1. Introduction

Weeds are considered one of the most important biotic constraints to agricultural production having socio-economic impacts (Oerke, 2006; Llewellyn et al., 2016; Gharde et al., 2018). They compete with crops for light, water, nutrients and space, and they may harbor insects and pathogens. This results in a reduction of product yield and quality and thus in a poor inputs economic efficiency (Mahmood et al., 2016) with negative effects on the sustainability of all cropping systems. In addition, weeds are undesirable also in urban areas where they can affect negatively the aesthetic value of the places, damage the pavings, etc. Furthermore, they can release allergenic pollens (Benvenuti, 2004).

Chemical control with herbicides is the most common technique for weeding because it is an easy and cost-effective technique to reduce weed density and biomass and to improve crop yield (Lisek, 2014; Barbaś et al., 2020). However, chemical weeding raises ecological and environmental issues (Russo et al., 2015). Other problems related to chemical weed control are the biochemical and molecular resistance mechanisms acquired by weeds (Yu and Powles, 2014; Nandula et al., 2018) and the progressively decreasing number of active substances registered especially for the use for vegetable crops (Matyjaszczyk, 2011; Santín-Montanyá et al., 2017; Pannacci et al., 2017) and nonagricultural lands (Marble et al., 2015).

Organic mulching is a sustainable soil management technique exerting a satisfying control of the weeds in addition to have positive effects on soil fertility and crop physiology (Ferrara et al., 2012; Russo et al., 2015; Fracchiolla et al., 2020). Crop residues deriving from agronomic practices or agro-industrial process are valuable natural resources and they can be used as organic mulch to manage weeds thanks to their physical and allelochemical action (Saha et al., 2018). Directive 2008/98/EC of the European Parliament and of the Council on waste (European Parliament, 2008) excludes byproducts and residues deriving from agricultural and agro-industrial activities from the scope of waste management if they are reused in agriculture, forestry or for energy production. Therefore, organic mulching with agricultural and agro-industrial residues must be considered as rational and respectful technique for the environment and human health in the agro-ecosystem and in non-agricultural areas.

Organic mulches were evaluated for weed control by many researchers, suggesting promising results. Jafari et al. (2012) and Verdù and Mas (2007) used almond woody endocarps to control weeds in orchards. In addition, Camposeo and Vivaldi (2011) observed weed suppression with de-oiled olive pomace in super high-density olive orchards. Moreover, the inhibition of weeds growing caused by various herbaceous crop residues (e.g. sorghum, sunflower, rice, maize) has also been demonstrated (Mahmood et al., 2016).

Olive leaves and almond hulls contain high concentration of bio-active phenolic compounds (Briante et al., 2002; Salah, 2012; Sfahlan, 2009) and many studies reported that, thanks to their composition, they are effective in controlling fungi, nematodes and insects (Repullo et al., 2012; Prgomet et al., 2019; Fernandez-Bayo et al., 2020). Polyphenols are a category of secondary metabolites also implicated in plant allelopathy (Li et al., 2010; Weston and Duke, 2003), that is "any direct or indirect harmful effect by one plant (including microorganisms) on another through the production of chemical compounds that escape into the environment" (Rice, 1984). The inhibitory effects of allelopathic compounds on plant growth and seed germination has been proposed also as a tool for weed control (Saha et al., 2018; Boari et al., 2021).

Almond hull and olive leaves are cheap raw materials deriving as by-products of olive mill or obtained during post-harvesting processes of almonds and they are highly available in the Mediterranean area. Due to their characteristics, they could exert both a mechanical and an allelochemical effect on weeds if used as organic mulching. The aim of this study was to evaluate their potential beneficial effects in vegetable crops and flower beds where a few means for weed control are available.

2. Materials and Methods

Two organic mulching materials, olive leaves and almond hulls, were compared to control weeds in fennel crop and in flower beds of an urban areas.

2.1. Mulching materials

The hulls were obtained from the processing of almonds (cv 'Filippo Cea') harvested in a farm located in Casamassima (Bari, Italy). The olive leaves derived from the cleaning process of olives (mostly cv 'Ogliarola barese' and minimally cv 'Coratina') were collected before the grinding in a oil mill located in Sannicadro di Bari (Bari, Italy). The same mulching materials were used in the two trials (fennel and flower beds).

Mulching matherials had different storing times. Almond hulls used in the flower bed trial was obtained in October 2015 and then left in open field until June 2016, when it was put in burlap sacks and stored indoor before being used for the trial. The almond hull used in the fennel experiment was obtained in September 2018 and left in open field until November 2018, when it was used for the trial.

Olive leaves used in the flower bed experiment was left in open field from December 2015 (when olives were processed in the olive mill) until June 2016, when they were collected and stored as described for almond hulls. Olive leaves obtained in December 2017 were used for the fennel experiment and they were left in open field until November 2018 (when the trial started). Considering that fresh olive leaves and almond hulls can be available only in short periods during the year, our study was focused only on stored materials to better simulate their possible commercial use.

2.2. Experiment on flower beds

The trial was carried out in a flower bed of the size of 12 × 9 m separating parking areas of a railway station in Southern Italy (Bari, 41°08’07.1”N, 16.46’53.0”E). The experiment compared the following three treatments: mulching with almond hull or olive leaves and an unmulched control. Ninety square plots with an area of 1 m^2 were arranged according to a completely randomized experimental design (30 plots per treatment). A mulching layer of 3 cm of thickness was applied on 4 July 2016. Weeds were chemically controlled with glyphosate application around one month before applying mulching materials and no new emergences were detected, so that the soil was completely free of weeds when the trial started. On 1 September, 30 November and 8 February (60, 150 and 220 days after mulching application, respectively), surveys of weed infestation were carried out for each plot.

2.3. Experiment on fennel

The study was carried out Southern Italy in an experimental field of University Campus in Bari (Southern Italy, 41°06’33.7”N, 16°52’56.2”E), where *Cucumis melo* L. was grown as previous crop. One week before transplanting, soil was tilled with a rotary tiller to control weeds and to prepare soil for transplanting and incorporating fertilizers (a total of 80 kg ha^{-1} of N and 63 kg ha^{-1} of P_2O_5 in form of organic fertilizer). According to USDA classification, the soil texture was loam, having 46%, 30% and 24% of sand, silt and clay, respectively. Its main chemical properties were 1.46% of organic matter, 1.96 ‰ of total nitrogen, 18.0 mg kg^{-1} of assimilable phosphorus and 739 ppm of exchangeable potassium.

On 19 November 2018, *Foeniculum vulgare* Mill. cv ‘Aurelio’ - NL b 78 (European Commission, 2020) plants were transplanted in plots of 24 m^2 (6 × 4 m) with a density of 8.3 plants m^{-2}, corresponding to planting distances of 0.2 m on the row and 0.6 m between the rows. The trial compared the following four treatments: mulching with almond hull or olive leaves, an unmulched control and an additional control treatment that consisted of plots that were always maintained free of weeds. Ten days after transplanting (before weed emergence), almond hulls and olive leaves were distributed on the plots, forming a 3-cm thick mulching layer. A completely randomized block design with four replications was adopted. During the growing cycle, five irrigations were supplied using the method of micro-sprinkling with a watering volume of 250 m^3 ha^{-1} for a seasonal total of 1250 m^3 ha^{-1}. It was not necessary to apply any pesticides, as no severe fungal or insect attacks were detected.

Weed infestation was surveyed on 3 April 2019, at the maximum vegetative growth. Fennel was harvested at the commercial maturity stage on 10 May 2019. In order to evaluate possible negative effects of the mulching on the cultivated plant, the bulbs (*grumolo*) and the whole above ground part of ten plants were weighted in each plot.

2.4. Weed survey method

In both trials, infestation was evaluated following the Braun-Blanquet phytosociological method of abundance-dominance (Braun-Blanquet, 1932). The method is based on the assumption that two species can occupy the same space both with numerous small individuals and with fewer, but larger individuals. Thus, a different index is visually assigned to each species according to their abundance and cover. In order to run statistical analysis, cover-abudance degrees were transformed in percentage cover values (ordinal scale) by using the midponts of each cover interval, as in Lepš and Hadincová (1992). Table 1 shows the criteria for assigning the discrete indexes and the relative midpoints.

2.5. Main climate data recorded during the experiments

Climate data related to the trial on flower beds were provided by the Servizio Agrometeorologico Regionale – ARIF, Puglia (lacation of the weather station: 41° 6’57.60”N; 16°49’12.00”E), while those

Table 1. Criteria for assigning the discrete indexes and the relative midpoints used for their transformation.

Cover-Abundance Index	Criteria	Midpoints of the cover range (%)
5	Any number of individuals covering 75-100% of the area	87.5
4	Any number of individuals covering 50 - 75% of the area	62.5
3	Any number of individuals covering 25-50% of the area	37.5
2	Very numerous or covering at least 5-25% of the area	17.5
1	Plentiful but of small cover value or higher cover with few plants. In any case, cover < 5%	5.0
+	Sparsely or very sparsely present, cover very small	0.1

related to the experiment on fennel were collected by a whether station located within the experimental field. During the trial on flower beds, the highest rainfall was recorded in September 2016 (Table 2), whereas June and July were the least rainy months and, together with August, were the ones with the highest air temperatures. During the experiment on fennel, the highest rainfalls were recorded in November and January. In this this latter month, the lowest mean air temperature was also recorded (7.2 °C). In the others months, air temperatures ranged between 10.3 °C (December) and 19.6 °C (May)

Table 2. Monthly total rainfall and average temperatures recorded during the trials. The difference from the average values calculated for the period between 2005 and 2015 is shown in brackets.

		Months	Total rainfall (mm)	Mean air temperature (°C)
Flower bed[1]	2016	June	6 (-24)	23.3 (-0.4)
		July	2 (-12)	26.7 (-0.2)
		August	43 (+27)	25.2 (-1.7)
		September	119 (+71)	21.7 (-1.8)
		October	41 (-13)	18.2 (-0.9)
		November	50 (-13)	14.5 (-0.6)
		December	14 (-48)	9.3 (-2.3)
	2017	January	98 (+46)	6.6 (-3.3)
		February	35 (-4)	11.4 (+0.6)
Fennel[2]	2018	November	86 (+23)	14.0 (-1.1)
		December	62 (0)	10.3 (-1.3)
	2019	January	82 (+30)	7.2 (-2.7)
		February	15 (-24)	12.0 (+1.2)
		March	25 (-27)	13.9 (+1.3)
		April	27 (-12)	15.4 (-0.3)
		May	20 (-13)	19.6 (+0.1)

[1]Source: Servizio Agrometeorologico Regionale – ARIF, Puglia.
[2]Source: weather station at the experimental field.

2.6. Statistical analyses

All the data were subjected to analysis of variance (ANOVA) with the significance level set at $p<0.05$. Duncan's multiple-range test was used to identify significantly different means.

3. Results

3.1. Flower bed trial

In the first survey (60 days after application) (Table 3), only three weed species were recorded: *Convolvulus arvensis* L., *Conyza canadensis* L. and *Cyperus esculentus* L. Only the mean cover percentage of *C. canadensis* was statistically higher in unmulched treatment than in the mulched plots.

Table 3. Weed cover in flower bed 60 days after mulching application.

Species	Mean cover (%)*		
	Unmulched treatment	Mulching	
		Almond hull	Olive leaves
Convolvulus arvensis L.	3.4	3.1	4.2
Conyza canadensis L.	7.4 a	1.3 b	0.5 b
Cyperus esculentus L.	2.1	2.8	3.9
Total infestation	12.9	7.2	8.6

*Within each row, mean followed by different letters are significantly different ($p \leq 0.05$; Duncan's test).

After 150 days from the application of mulching (Table 4), also the following weed species were detected: *Anagallis arvensis* L., *Bromus sp.* L. and *Oxalis pes-caprae* L. In addition, *C. arvensis* was not found because this species had already finished its life cycle and was dead by the time of this meansurment. With the exception for *C. esculentus* and *O. pers-caprae*, the cover percentage of the other species and of the total infestation was significantly higher in unmulched treatment than in the mulched plots. No significant differences were recorded between plots mulched with olive leaves and with almond hull for *A. arvensis*, *Bromus sp.*, *C. canadensis* and total infestation.

Table 4. Weed cover in flower bed 150 days after mulching application.

Species	Mean cover (%)*		
	Unmulched treatment	Mulching	
		Almond hull	Olive leaves
Anagallis arvensis L.	3.4 a	0.0 b	0.0 b
Bromus sp. L.	27.6 a	0.6 b	0.2 b
Conyza canadensis L.	21.2 a	0.0 b	0.2 b
Cyperus esculentus L.	5.3	5.8	9.4
Oxalis pes-caprae L.	2.7	5.3	2.8
Total infestation	60.2 a	11.7 b	12.6 b

*Within each row, mean followed by different letters are significantly different ($p \leq 0.05$; Duncan's test).

In the last survey (220 days after mulcing application) (Table 5), an increased number of species was detected, with the presence of *Medicago polymorpha* L., *Rumex obtusifolius* L., *Scorpiurus muricatus* L. and *Sonchus oleraceus* L. In addition, *C. esculentus* was not found because it had already concluded its life cycle by the time of this measurement. With the exception for *M. polymorpha*, *O. pes-caprae* and *R. obtusifolius*, the cover percentage of all the other species was significantly higher in the unmulched treatment than in the mulched plots with no significant differences between the plots mulched with the two materials. Furthermore, total infestation was different for unmulched and mulching treatments and no significant differences were observed between almond hull and olive leaves treatment.

Table 5. Weed cover in flower bed 220 days after application of mulching.

Species	Mean cover (%)*		
	Unmulched treatment	Mulching	
		Almond hull	Olive leaves
Anagallis arvensis L.	4.8 a	0.0 b	0.0 b
Bromus sp. L.	29.0 a	1.1 b	1.7 b
Conyza canadensis L.	22.4 a	0.0 b	0.4 b
Medicago polymorpha L.	0.9	0.0	0.0
Oxalis pes-caprae L.	3.9	7.2	3.8
Rumex obtusifolius L.	1.0	1.3	0.6
Scorpiurus muricatus L.	0.9 a	0.0 b	0.0 b
Sonchus oleraceus L.	3.1 a	0.2 b	0.0 b
Total infestation	66.0 a	9.8 b	6.5 b

*Within each row, mean followed by different letters are significantly different ($p \leq 0.05$; Duncan's test).

3.2. Fennel trial

The weed infestation in the experimental field was composed by *Stellaria media* Mill., *Veronica hederifolia* L., *Polygonum aviculare* L., *Fumaria officinalis* L., *Lamium amplexicaule* L., *Senecium vulgaris* L., *Papaver rhoeas* L. (Table 6). The mean cover percentage of all species was significantly the highest in the unmulched treatment, while no difference was found between the plots mulched with hull and those mulched with olive leaves.

Table 6. Effects of mulching on weed cover in fennel.

Species	Mean cover (%)*			
	Unmulched treatment	Mulching		Weed free control
		Almond hull	Olive leaves	
Stellaria media L.	17.5 a	5.0 b	3.4 b	0.0 c
Veronica hederifolia L.	30.8 a	3.4 b	3.4 b	0.0 b
Polygonum aviculare L.	5.0 a	0.1 b	0.1 b	0.0 b
Fumaria officinalis L.	37.5 a	9.2 bc	13.3 b	0.0 c
Lamium amplexicaule L.	54.2 a	0.1 b	5.0 b	0.0 b
Senecio vulgaris L.	5.0 a	0.1 b	1.7 b	0.0 b
Papaver rhoeas L.	5.0 a	0.0 b	0.0 b	0.0 b

*Within each row, mean followed by different letters are significantly different ($p \leq 0.05$; Duncan's test).

Whole plant weight was highest in the weed free control, although not different with respect to plants of the plots mulched with almond hull (Table 7). No statistical difference in plant weight was found between the plots mulched with olive leaves and that in the unmulched treatment. The weight of the *grumolo* was statistically lower in plots mulched with olive leaves than in the weed free control and it was also not different from unmulched treatment. In the plots mulched with hull, the weight of the *grumolo* was not different from weed free control and was higher than in the unmulched treatment. In addition, no significant differences were recorded in the weight of the *grumolo* between plots mulched with olive leaves and almond hull.

Table 7. Effects of mulching on yield parameters of fennel.

Mulching	Mean weight* (kg)	
	Whole plant	*Grumolo*
Weed free control	0.68 a	0.46 a
Almond hull	0.60 a	0.42 ab
Olive leaves	0.45 b	0.31 bc
Unmulched treatment	0.36 b	0.22 c

*Within each row, mean followed by different letters are significantly different ($p \leq 0.05$; Duncan's test).

4. Discussion

When used as mulching materials in flower beds, both almond hull and olive leaves showed acceptable effectiveness even after seven months from the application. The mulching had no effects only on perennial species such as hemicryptophytes (e.g. *R. obtusifolius*) or geophytes such as *O. pes-caprae*. Skroch et al. (1992) and Anzalone et al. (2010) also reported that perennial species such as *Cyperus esculentus* L. or *Cyperus rotundus* L were not suppressed by mulching. It can be hypothesized that the reserve compounds contained in the bulbs enable the plants to easily resprout and overcome the mulching layer.

The weed infestation in fennel was significantly reduced compared to the unmulched treatment, both in the plots mulched with almond hull and in those with olive leaves. These results confirm the effectiveness of organic mulch material in controlling weeds as previously reported, for example, in tomato (Anzalone et al., 2010), in bean and garlic (Jodaugienė, 2006) and in maize (Mahmood et al., 2016). In the plots mulched with almond hull, a reduction of weed infestation and a related higher yield were found. This result is probably due to the reduction of the competition between crop and weeds. Khuram et al. (2009) and Patel et al. (2017) reported that this crop is very sensitive to weed competition, although they referred to the seed yield. Nevertheless, in the plots mulched with olive leaves, the weight of whole plant and of the *grumolo* were not different from the unmulched treatment and were lower than weed free control. Since the level of infestation was not different between the two types of mulching, we can suppose that olive leaves released higher amounts of allelopathic compounds able to affect fennel growth. Phytotoxicity of olive tree residues (Repullo et al., 2012) and their polyphenolic compounds were reported by some authors (Capasso et al., 1992; Alliotta et al., 2002; Scognamiglio et al., 2012). Our study indicates that it could be interesting to study strategies for the practical use of by-products materials for weed management, especially in vegetable crops where the availability of registered herbicides is scarce or absent (Matyjaszczyk, 2011; Santín-Montanyá et al., 2017) and the adoption of alternative weed control methods is highly recommended (Fracchiolla et al., 2020; Pannacci et al., 2017). Mulching with this natural materials could be integrated with the adoption of mechanical or physical methods. For example, Boari et al. (2021) proposed the use of organic material (dry biomass of *Dittrichia viscosa* (L.) Greuter) on the row, while mechanical methods can be used intra-row where it is easier to operate.

5. Conclusions

Although with some limitations, the findings of this study allow to conclude that these materials could be used also to manage weeds in both agricultural lands and urban areas, where European regulations have further limited the use of herbicides (European Commission, 2017). Moreover, our study shows that almond hulls and olive leaves can be succesfully used as mulching materials even when they are stored for several months after they are obtained. Further studies should investigate if their effectiveness is mainly due to a mechanical activity or allelopathic compounds also play a concrete role in weed suppression.

Funding: This research received no external funding.

Conflicts of Interest: The authors declare no conflict of interest.

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