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Integration of competitive cultivars and living mulch in sunflower (*Helianthus annuus* L.): a tool for organic weed control

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Abstract Selection of highly competitive cultivars (Cvs) of sunflower might limit weed growth. However, competitive ability alone may not be sufficient in suppressing weeds in sunflower. Competitive cultivars may have to be combined with other complementary management strategies such as selection of appropriate living mulch species. Two experiments were conducted to evaluate the combined effects of crop cultivar and living mulch on weed growth and sunflower yield. Three sunflower cultivars (Allstar, Azargol, and Farokh) and three living mulch treatments (intercropping of buckwheat, snail medic, and hairy vetch as living mulch) were evaluated in a factorial design. For each cultivar, a plot without living mulch (sole sunflower) was considered as weedy check. The sunflower cultivars significantly differed in their competitive ability against weeds. The Cv. Azargol has a superior competitive ability than Allstar and Farokh, on the basis of its impact on crop grain yield and weed infestation level. The highest grain yield (7126 kg ha^{-1}) was obtained in Cv. Azargol. All living mulch species also reduced weed biomass and density compared to weedy check. This research revealed that use of buckwheat as living mulch caused the most inhibition effect on weed biomass and density. Overall, selection of Azargol as a competitive cultivar and buckwheat as living mulch which provided 96 % control was the best combination method for broadleaf weed control, while Farokh-buckwheat, which provided 77 % weed suppression was more effective combination for grass weeds. Our findings suggest that combining highly competitive sunflower cultivars with proper living mulch species is a feasible weed management strategy; however, selection of both crop cultivar and living mulch species should be adapted based on dominant weed spectrum.

Keywords Competitive ability · Ecological weed management · Grain yield · Living mulch · Organic agriculture · Weed interference

Introduction

Sunflower (*Helianthus annuus* L.) is considered as an important oil seed crop in the world. In 2013, the world's total harvested area of sunflower was 25.6 million hectare, with a total production of 44.8 million tonnes. The average sunflower yield in Iran is 1285 kg ha^{-1}, which is significantly lower than the global average of 1748 kg ha^{-1} (FAOSTAT 2013). Other than environmental variables, the most important constraint to sunflower production is competition from weeds (Suryavanshi et al. 2015).

Currently, herbicides play a major role in weed management of sunflower. However, development of herbicide-resistant weeds and environmental costs of chemical control have increased the necessity to reduce herbicide usage in agriculture (Gonzalez-Andujar et al. 2010; Yousefi and Rahimi 2014). Living mulch crops

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can be an option to solve these problems for sustainable cropping systems (Sarrantonio 1994; Creamer and Baldwin 2000). The idea of planting living mulch crops is to simulate plant succession aimed at replacing an undesired weed population with a desired cover crop (Samarajeewa et al. 2006). Presence of living mulch between the rows of the main crop can suppress weed seed germination and emergence and mitigate crop yield losses (Grimmer and Masiunas 2004; Brennan and Smith 2005). However, interseeding of a crop and living mulches have not always resulted in a positive gain (De Haan et al. 1997). Consequently, the selection of the most appropriate species is crucial for the successful living mulch-crop systems (Mohammadi 2012). Buckwheat (*Fagopyrum esculentum* L.) has been proposed as a summer living mulch crop for weed suppression and improvement of soil fertility as well (Sarrantonio 1994; Golisz et al. 2002).

Buckwheat as a living mulch can reduce weed biomass from 75 to 90 % (Creamer and Baldwin 2000; Iqbal et al. 2003; Kumar et al. 2009). Another valuable crop for use as a living mulch is snail medic (*Medicago scutellata* L.), which, besides being tolerant to shading and fixing nitrogen, can also effectively compete with weeds and reduce their biomass (Sadeghpour et al. 2013). Moynihan et al. (1996) reported that intercropping barley with snail medic reduced weed biomass up to 65 %. The other valuable living mulch species is hairy vetch (*Vicia villosa* L.), which can efficiently suppress weeds via producing high biomass (Borowy 2012) and releasing several allelochemicals (Bradow and Connick 1990).

Despite potential advantages of living mulch, they are hardly practiced to date in annual crops, mainly because of the risk of lower yields compared to traditional cropping systems (Hiltbrunner et al. 2007) and insufficient weed control when they employed alone. Competition from living mulches may result in nutrient deficiency, osmotic stress, and reduced interception of sunlight; reductions in plant functioning may lead to slowed growth, decreased crop biomass, delayed maturity, and reduced yields (Theriault et al. 2009).

Increasing crop competitive ability can be viable option to both improve living mulch efficacy and maintaining crop yield. Since crop varieties vary widely in their ability to compete with weeds, improvement of crop competitive ability is possible throughout selection of the more competitive cultivar. For example, in Greece, the use of competitive cultivars alone has been demonstrated to allow for a 50 % reduction in recommended amount of herbicides in wheat (Travlos 2012).

We hypothesize that integration of living mulch with competitive cultivar of sunflower can decrease weed biomass more efficiently. These findings would be useful for improving non-chemical weed management strategies in sunflower production. Therefore, this study was conducted to assess the weed-suppressing ability of buckwheat, snail medic, and hairy vetch intercropped with three different cultivars of sunflower, with the aim to identify an appropriate cultivar and living mulch crop for organic weed management in sunflower.

Materials and methods

Experimental site

Field experiments were conducted at the research field (latitude 36° 41′ N, longitude 48° 27′ E; 1620 m above sea level) of the University of Zanjan, Zanjan, Iran, in spring of 2013 and repeated in 2014. Environmental factors such as soil composition, fertility, temperature, and precipitation vary from year to year and can affect treatment performance; therefore, to avoid incorrect interpretation, the study was conducted for two consecutive years. The 30-year annual mean temperature and precipitation were 11 °C and 293 mm, respectively. Mean monthly temperature data during the growing season, recorded near the experimental area, are given in Table 1. The optimal temperature for growing sunflowers is between 20 and 25 °C (Khajehpour 2007). The crop water requirement was estimated to be 5445.4 m^3 ha^{-1} under Zanjan (Iran) condition (Yousefi and Bosh 2014). The study site has sandy loam texture with soil organic matter content of 1.1 and 0.74 % in 2013 and 2014, respectively. The experimental sites were fallow and cropped with barley in the preceding year of study in 2013 and 2014, respectively. In both years, seedbed preparation included deep plowing (20 to 25 cm) with a moldboard plough during fall, followed by disk harrowing during spring.

Experimental design, treatments, and crop management

The 13 treatments were assigned randomly to blocks in the field. The experiments were arranged as factorial,

Table 1 Average monthly air temperatures (°C) during the sunflower growing season in 2013 and 2014

Month	Temperature (°C)					
	Mean		Maximum		Minimum	
	2013	2014	2013	2014	2013	2014
May	12.7	14.2	19.8	19.4	5.7	9.0
June	19.0	19.9	27.6	27.1	10.3	12.7
July	22.3	21.7	31.6	27.6	13.1	15.9
August	23.2	22.0	31.8	25.1	14.7	19.0
September	21.5	17.9	31.0	23	11.9	12.8
October	14.0	9.8	22.6	15.6	5.3	4.1

randomized complete blocks with three replicates per treatment. Three sunflower cultivars (Allstar, Azargol, Farokh) and three living mulch treatments (intercropping of buckwheat, snail medic, and hairy vetch as living mulch) were evaluated in a factorial design. For each cultivar, a plot without living mulch (sole sunflower) was considered as weedy check. There were also weed-free plots for each cultivar each year; however, from weed-free plots, data of grain yield was not collected in 2014 due to unexpected events.

Since leaf area and plant height are two most important plant traits in determining the outcome of competitive in plant community (Haefele et al. 2004), therefore, selection of sunflower cultivars was based on their leaf area index and plant height. Maximum leaf area indices of Allstar, Azargol, and Farokh Cvs are 3.9, 4.5, and 2.5, respectively. According to Mirshekari (2009), Rezaei Estakhroeih et al. (2014), and Shafieipour et al. (2011), these cultivars can reach up to 160, 175, and 140 cm, respectively.

Plots were four rows 2 m wide by 9 m long. Sunflower was sown at 0.50-m row spacing on May 24, 2013 and May 30, 2014. Buckwheat, hairy vetch, and snail medic were planted manually and simultaneously with sunflower plants in between the rows of sunflowers at seeding rates of 26, 29, and 18 kg ha^{-1}, respectively. Sunflower seedlings were thinned to the target densities (10 plants m^{-2}) at their two to four true-leaf stages. No synthetic chemicals (pesticide and fertilizer) were applied to the plots in both seasons. Tape drip irrigation system (with 4- to 7-day interval) was employed to provide moisture.

Table 2 Analyses of variance (*P* values) of the effects of sunflower cultivar (*C*), living mulch (*L*), and their interaction on the density and biomass of weeds and sunflower grain yield

Treatment	Broadleaved				Grasses				Total				Sunflower grain yield	
	Biomass		Density		Biomass		Density		Biomass		Density			
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Cultivar (*C*)	<0.0001	0.0809	0.1196	0.0070	<0.0001	0.0002	0.2725	0.3787	<0.0001	0.0021	0.0046	0.1396	<0.0001	0.4839
Living mulch (*L*)	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0127	<0.0001	<0.0001	<0.0001	0.0003	0.0169	<0.0001
C × *L*	<0.0001	0.0061	0.0086	<0.0001	<0.0001	<0.0001	0.6706	0.2245	<0.0001	<0.0001	0.0075	0.0265	0.52230	0.0396

Table 3 Mean comparison of sunflower cultivar and type of living mulch effects on the density and biomass of weeds and sunflower grain yield

Treatment	Broadleaved				Grasses				Total				Sunflower grain yield	
	Biomass		Density		Biomass		Density		Biomass		Density			
	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014	2013	2014
Cultivars														
Azargol	210.0 b	35.4 a	138.3 a	83.0 a	101.4 c	27 a	120.9 a	120.5 a	309.4 b	63.8 a	267.3 b	205.2 a	7126.7 a	3060.0 a
Allstar	352.9 a	22.9 a	173.1 a	52.3 b	134.0 b	20 b	145.9 a	60.3 a	499.0 a	43.0 b	327.0 a	117.5 a	5706.0 b	3318.5 a
Farokh	328.6 a	24.3 a	145.1 a	67.0 ab	181.0 a	28 a	125.6 a	122.4 a	546.8 a	53.0 b	278.7 b	206.9 a	5198.9 b	3203.3 a
Living mulch														
Buckwheat	240.8 c	12.8 b	76.2 c	36.7 b	85.9 b	19.5 b	98.8 b	55.3 b	342.1 c	32.3 b	183.0 c	123.7 b	5719.3 b	2599.8 b
Snail medic	312.6 ab	20.1 b	151.9 b	48.1 b	83.3 b	9.5 d	101.6 b	56.7 b	403.9 b	30.2 b	261.4 b	104.8 b	6649.7 a	2774.8 b
Hairy vetch	300.3 b	25.5 b	164.8 b	50.7 b	183.1 a	14.1 c	123.5 b	62.0 b	455.4 b	39.6 b	296.3 b	112.7 b	5675.6 b	4292.0 a
Check	334.9 a	52.0 a	215.9 a	134.7 a	203.7 a	57.0 a	199.4 a	230.3 a	605.2 a	110.4 a	423.3 a	365.0 a	5997.5 b	3109.1 b
Interaction effects	*	*	*	*	*	*	NS	NS	*	*	*	*	NS	*

Means within a column followed by the same letter are not significantly different ($P > 0.05$) according to LSD

Interaction effects denoted by * and NS are significant and non-significant at $P < 0.05$, respectively; significant interactions are presented in the figures

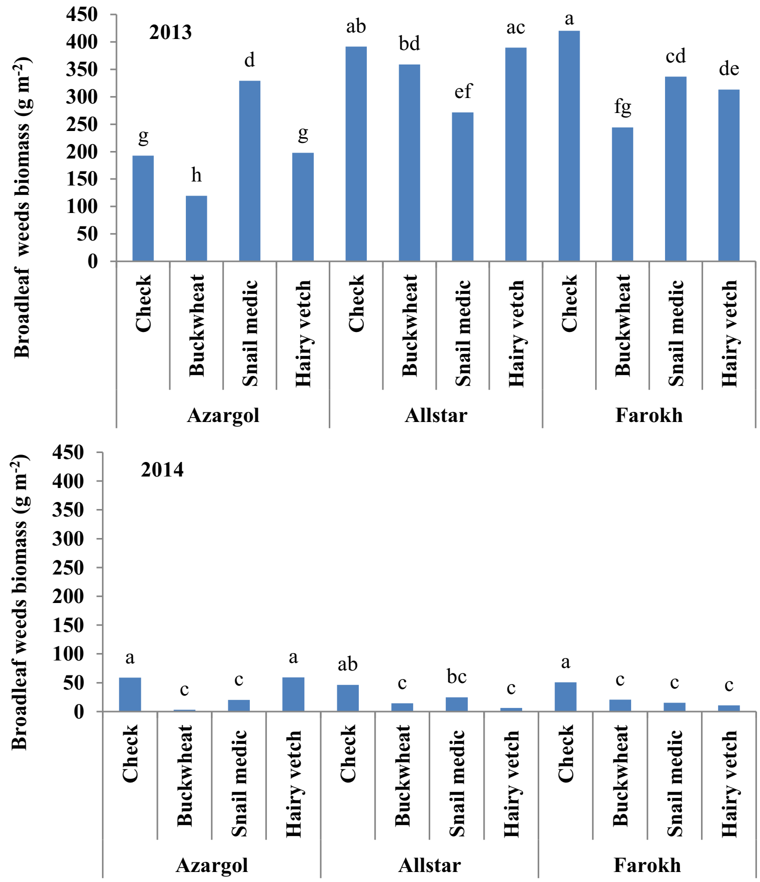


Fig. 1 Broadleaf weed biomass as affected by interaction of sunflower cultivar and type of living mulch in 2013 and 2014. *Means followed by the same letter* are not different based on Fisher's protected LSD test at $P \leq 0.05$

Data collection

Weed evaluations (weed counts, weed weights) were taken once, approximately 105 days after planting at sunflower maturity. Similarly, weeds of all treatments were cut at ground level from a 0.5-m^2 area in center of each plot. Weeds were separated by species, counted, and dried at 75 °C for 48 h for biomass determination. For assessing the effect of the treatments on crop yield, at the same plots, 10 plants of each sunflower cultivar were harvested manually at full maturity stage (119 days after planting). The crop was hand clipped from a 2-m section of the two center rows of each plot, and seeds were separated and dried at 75 °C to a constant weight.

Statistical analysis

The data were analyzed using PROC GLM in SAS software (version 9.1; SAS Institute Inc., Cary, NC). Before analyzing the data, the assumption of a homogeneous variance was tested using the Kolmogorov-Smirnov normality test. For the significant differences, means were separated by *t* tests ($P \leq 0.05$) when *F* tests were significant at $P \leq 0.05$.

Results

Weed flora

Overall, 11 annual and 4 perennial species from 10 families were recorded in the experimental site in 2 years. In 2013, the most predominant weed species were redroot pigweed (*Amaranthus retroflexus* L.), barnyard grass (*Echinochloa crus-galli* (L.) P. Beauv.), morning glory (*Convolvulus arvensis* L.), common cocklebur (*Xanthium strumarium* L.), green foxtail (*Setaria viridis* (L.) Beauv), and common lambsquarters

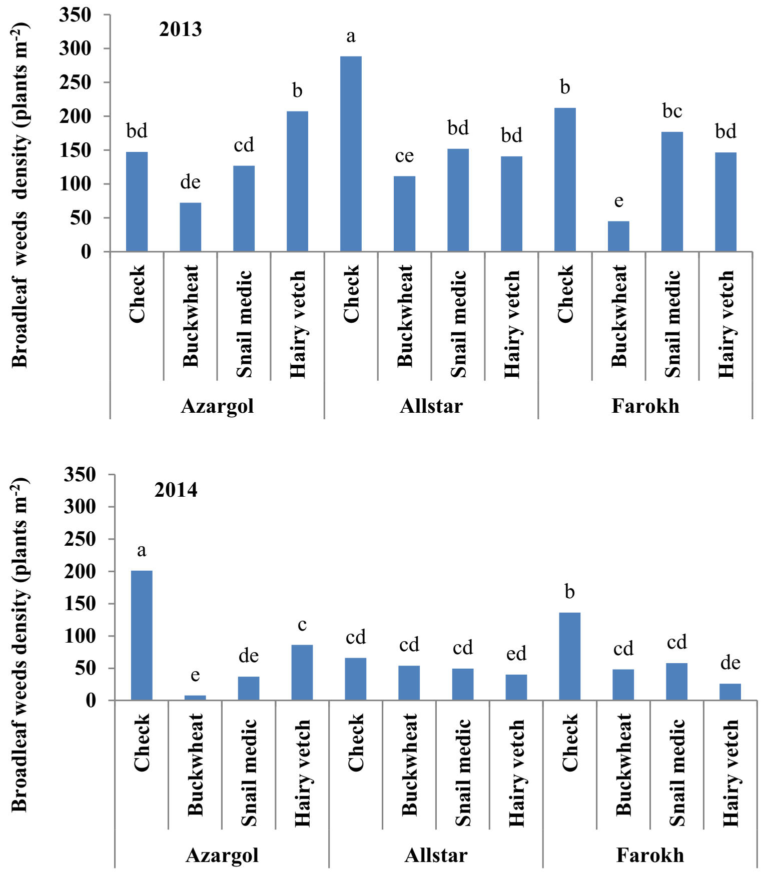


Fig. 2 Broadleaf weed density as affected by interaction of sunflower cultivar and type of living mulch in 2013 and 2014. *Means followed by the same letter are not different based on Fisher's protected LSD test at* $P \leq 0.05$

(*Chenopodium album* L.), while in 2014, redroot pigweed, barnyard grass, common cocklebur, and common lambsquarters were more predominant.

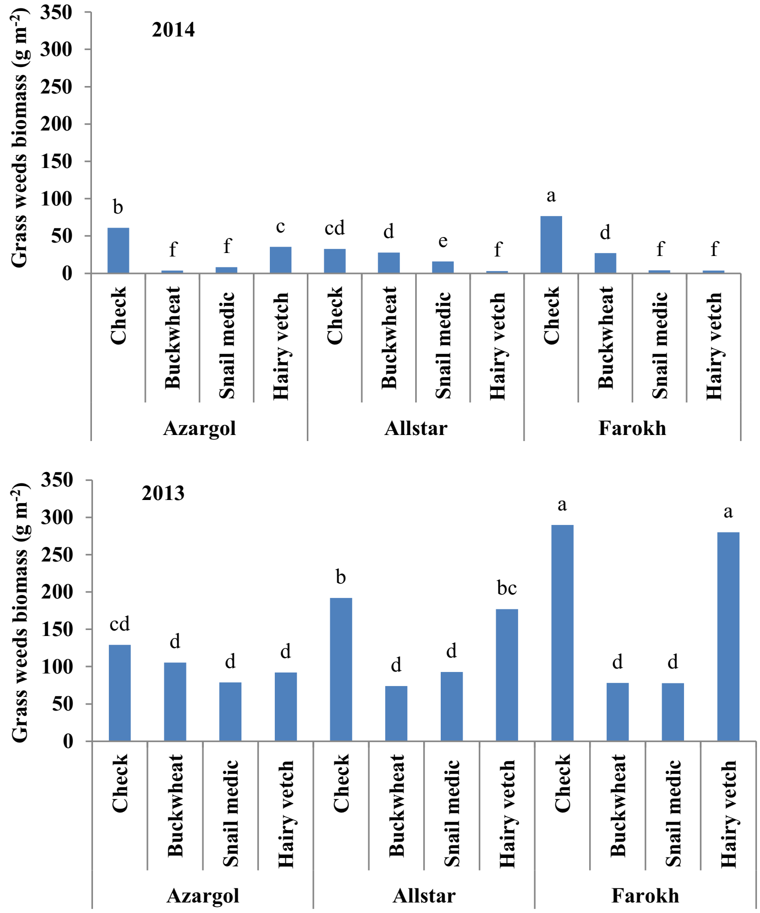
Effect of treatments on dominant broadleaf weeds

The treatment effect on broadleaf weeds was not consistent between years ($P \leq 0.05$), and as a result, 2 years are presented separately. The main effects of sunflower cultivars on density and aboveground biomass of broadleaf weeds were sparse; aboveground biomass was affected only in 2013, and density was affected only in 2014 (Table 2). In 2013, maximum aboveground biomass (353 g m^{-2}) was recorded in Allstar and the minimum (210 g m^{-2}) in Azargol. Density of broadleaf weeds differed with cultivars and was highest (83 plants m^{-2}) in Azargol and lowest (52 plants m^{-2}) in Allstar (Table 3).

Significant effects of living mulch on the density and aboveground biomass of broadleaf weed species were observed in both years (Table 2). Intercropping of buckwheat, hairy vetch, and snail medic reduced aboveground biomass of broadleaf weeds (by 28, 10, and 6 % in 2013 and 75, 51, and 61 % in 2014, respectively) and weed density (by 64, 23, and 29 % in 2013 and 72, 62, and 64 % in 2014, respectively) compared to weedy check (Table 3).

There was interaction between living mulch and cultivar on density and aboveground biomass of broadleaf weeds in both seasons (Table 2). Intercropping of buckwheat as living mulch with Farokh (in 2013) and Azargol (in 2014), respectively, reduced aboveground weed biomass by 42 and 94 % compared to check plots (Fig. 1). Similarly, lower broadleaf weed density was observed when buckwheat was intercropped with Farokh (45 plants m^{-2}) and Azargol (8 plants m^{-2}) in 2013 and 2014, respectively (Fig. 2).

Fig. 3 Grass weed biomass as affected by interaction of sunflower cultivar and type of living mulch in 2013 and 2014. *Means followed by the same letter* are not different based on Fisher's protected LSD test at $P \leq 0.05$



Effect of treatments on dominant grass weeds

The analysis of variance showed that the aboveground biomass of grass weed species was significantly influenced by the type of cultivar (Table 2). In general, Cv. Farokh showed a higher aboveground grass weed biomass and Azargol lower in 2013 (Table 3). The results also showed a significant effect of living mulch on aboveground biomass of grass weeds in both years (Table 2). The biomass varied from 83 g m^{-2} for snail medic and 203 g m^{-2} for weedy check in 2013 and 9 g m^{-2} for snail medic and 56 g m^{-2} for weedy check in 2014 (Table 3). The main effects of cultivars and interaction effects of cultivar × living mulch on density of grass weeds did not differ between the 2 years ($P \leq 0.05$). Averaged over 2 years, weed density was lower in buckwheat (77 plants m^{-2}) and higher in check (215 plants m^{-2}).

The interaction effect of cultivar × living mulch was significant on grass weed biomass (Table 2). In 2013, when both buckwheat and snail medic were used as living mulch, all three cultivars tended to produce less biomass (85 g m^{-2}). In this year, all three sunflower cultivars grown on plots covered by hairy vetch had weed infestation similar to the check. However, in 2014, planting hairy vetch between rows of Allstar and Farokh or planting buckwheat and snail medic between rows of Azargol produced lower grass weed. In this year, the highest grass weed biomass was observed in sole Farokh (Fig. 3).

Effect of treatments on total weeds

The results from analysis of variance showed that the type of cultivar used had significant effect on the total weed biomass in both years (Table 2). The comparison of the main effects of sunflower cultivars on the total

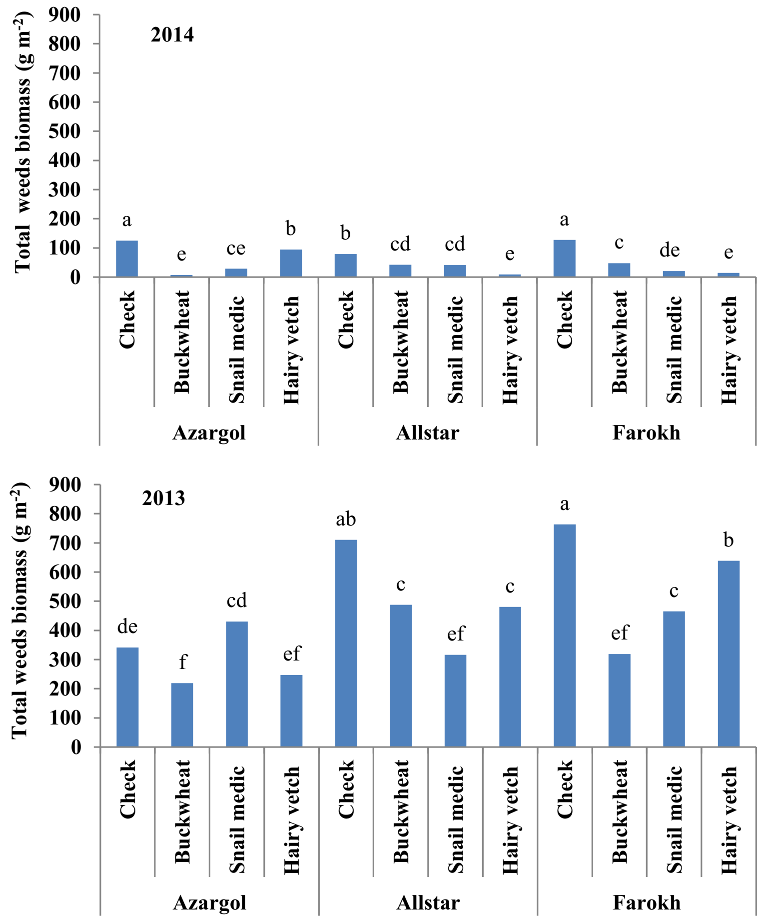


Fig. 4 Total weed biomass as affected by interaction of sunflower cultivar and type of living mulch in 2013 and 2014. *Means followed by the same letter* are not different based on Fisher's protected LSD test at $P \leq 0.05$

weed biomass revealed that Azargol and Allstar had minimum weed biomass in 2013 and 2014, respectively (Table 3). Total weed density was also significantly affected by cultivar type in 2013. Azargol with an average of 267 plants m^{-2} had the lowest weed density. However, the main effect of cultivar was not significant on total weed density in 2014.

Significant effects of living mulch on the total weed density and biomass were observed in both years (Table 2). When the distance between the rows was covered with buckwheat and snail medic, weed density decreased significantly from 423 in weedy plots to 183 plants m^{-2} in 2013 and from 365 to 104 plants m^{-2} in 2014, respectively. Compared to weedy plots, buckwheat and snail medic reduced total weed biomass by 43 % in 2013 and 72 % in 2014, respectively (Table 3).

The interaction effect of cultivar × living mulch was significant on total weed biomass (Table 2). In 2013, intercropping of buckwheat with Cv. Azargol resulted in the lowest total weed biomass (219 g m^{-2}), while Cv. Farokh at weedy condition produced the highest weed biomass (763 g m^{-2}). In 2014, except for hairy vetch-Azargol, all treatments had weed biomass lower than weedy check. In this year, intercropping of buckwheat with Cv. Azargol had minimum (7 g m^{-2}) weed biomass (Fig. 4).

The comparison of the interaction effects of cultivar × living mulch on the total weed density revealed that sole Allstar with an average of 505 plants m^{-2} had the maximum and Farokh grown on plots covered by buckwheat had the minimum weed density (133 plants m^{-2}) in 2013 (Fig. 5). The interaction effect was also significant in 2014; however, combination of all three living

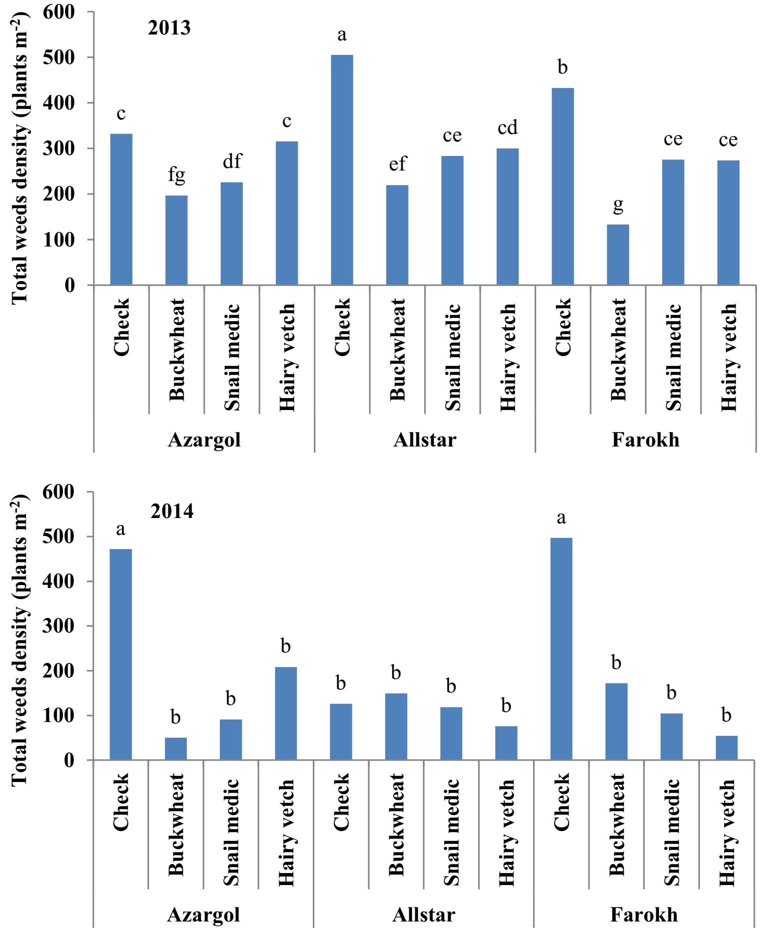


Fig. 5 Total weed density as affected by interaction of sunflower cultivar and type of living mulch in 2013 and 2014. *Means followed by the same letter* are not different based on Fisher's protected LSD test at $P \leq 0.05$

mulches and cultivars had statistically similar weed density. This could be due to (i) differences in the weedy check treatment among cultivars and (ii) although the differences in the total weed density among treatments were considerable (e.g., 50 plants m^{-2} in the buckwheat-Azargol plots and 208 plants m^{-2} in the hairy vetch-

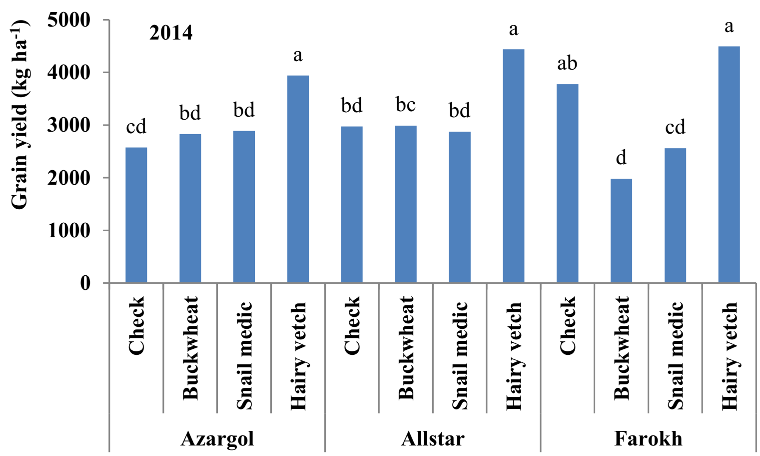


Fig. 6 Sunflower grain yield as affected by interaction of sunflower cultivar and type of living mulch in 2014. *Means followed by the same letter* are not different based on Fisher's protected LSD test at $P \leq 0.05$

Azargo plots), they were not statistically different likely due to high coefficient of variation (68 %).

Sunflower grain yield

The treatment effect on grain yield was not consistent between years ($P \leq 0.05$), and as a result, it was analyzed separately for each year. In 2013, grain yields of Allstar, Azargol, and Farokh Cvs in the weed-free plots were 7353, 8665, and 7822 kg ha^{-1}, respectively. Compared to weed-free plots, sunflower cultivar yields in the weedy plots were decreased by 5730, 7052, and 5209 kg ha^{-1}, respectively. In 2013, the main effect of cultivar and living mulch was significant on grain yield, while interaction of two factors was not significant (Table 2). The highest grain yield (7126 kg ha^{-1}) was obtained in Cv. Azargol. Among the living mulch treatments, the highest (6649 kg ha^{-1}) and lowest (5675 kg ha^{-1}) grain yields were obtained in the presence of snail medic and hairy vetch, respectively (Table 3).

The main effect of cultivars was not significant on grain yield in 2014, while the main effect of living mulch was significant. Significant interaction between sunflower cultivars and living mulch was also observed for grain yield (Table 2). In 2014, the highest grain yield (4494 kg ha^{-1}) was obtained from interaction of hairy vetch and Cv. Farokh. Presence of hairy vetch between rows of sunflower increased grain yield of Farokh, Azargol, and Allstar by 15, 34, and 33 %, respectively, when compared to weedy plots (Fig. 6).

Discussion

There was no consistent effect of the weeds on sunflower yield over 2 years. The total weed biomass in 2013 was greater than in 2014. However, sunflower yield in 2013 was doubled compared to yield in 2014. The air temperatures in the two experimental years were similar, so it is unlikely that temperature contributed to the differences in crop yield and weed pressure between the 2 years. The following reasons could be responsible for these results: (1) the experimental field site had lain fallow in the year preceding the start of the study in 2013, while for study in 2014 was cropped with barley. A few studies have shown that previous crop residues can sometimes inhibit plant growth. For example, soil incorporation of crop residues decreased seed germination of *Trianthema portulacastrum* to 58 % and caused 71 % seedling mortality. (2) The soil organic matter in the experimental sites in 2014 was lower than in 2013. Water supply was similar in both years. The lower organic matter content of the soil in 2014 may, however, have resulted in some soil moisture deficit. Ample soil moisture conditions in 2013 could have been conducive to rapid germination and development of both crop and weeds.

Weed biomass and density were greatly affected by living mulch. Lack of available uncovered, interrow spaces for weed establishment caused severe reduction in the weed infestation both in density and aboveground biomass. Many studies reported lower dry weights of weeds in systems that use living mulches because of covering the spaces between two rows (Jamshidi et al. 2013; Pouryousef et al. 2015). Sharma and Banik (2013) reported that intercropping systems of pea or chickpea with baby corn can suppress weed effectively. Additionally, reduction of weed growth in the crop-living mulch system could be explained by competition for water and nutrients, shading, and unfavorable conditions for weed germination under crop plant canopy (Brust et al. 2014). Shading causes reduction in photosynthetically active radiation and the ratio of red/far-red (R/FR) light perceived by the weeds beneath the canopy (Norsworthy 2004; Thompson and Grime 1983). Norsworthy (2004) reported that common cocklebur and sicklepod emergence was diminished after soybean canopy closure due to decrease in daily diurnal soil temperature fluctuations and increase in light interception by the canopy. Another possible explanation for weed density reduction could be the release of allelochemicals by living mulches that inhibit weed seed germination and growth (Brust et al. 2014).

Although all three living mulch crops in this study contributed to decreased weed infestation compared to weedy plots, there were highly significant differences among living mulch species in their ability to suppress weed growth. In general, buckwheat had a greater impact on weeds than hairy vetch or snail medic. This may be partly because of its quick-emerging (seedlings emerge 3–5 days after sowing), fast-growing (flowering occurs about 30 days after sowing), and erect growth habit (with height up to 150 cm) (Valenzuela and Smith 2002). All above mentioned traits play a major role in determining competitive ability of plants in community. Aside from this, buckwheat has an inhibitory effect on growth of other plants. For example, it has been reported that some flavonoids found in buckwheat such as catechin, quercetin, and isoquercitrin have inhibitory effects on growth of several weeds (Kalinova and Vrchotova 2009).

The sunflower cultivars greatly differed in their competitive ability against the weeds. The Cv. Azargol has a superior competitive ability than Allstar and Farokh, on the basis of the crop grain yield and weed infestation level. Crop plants could suppress the growth of the weeds through the release of allelochemicals (Bhadoria 2011). Therefore, the differences among sunflower cultivars could be partly due to difference in their allelopathic activity. Nikneshan et al. (2011) found that the allelopathic activity of some sunflower cultivars can affect noxious weed species such as *Hordeum spontaneum*, *Lolium rigidum*, and *A. retroflexus*. Moreover, Azargol had greater leaf area index (LAI) values (data not shown) than the two other cultivars. Since most of arable weeds are reported to be sensitive to shading (see Yirefu et al. 2012), high LAI results in rapid canopy closure, and consequently, weed seedlings experienced a higher and more rapid shading effect during the season. Thus, weeds are expected to emerge in the Azargol plots in a shorter time period compared with plots with Allstar or Farokh. Chikoye et al. (2008) reported a negative correlation between weed biomass and leaf area of corn. Uchino et al. (2009) also reported that degree of weed suppression depends significantly on vegetation cover ratio (and LAI) by main crops and/or cover crops.

Intercropping of buckwheat as living mulch resulted in grain yield similar or lower than weedy check in both years. The intercropped species may compete for the growth resources, and consequently, the main crop yield loss can occur in some situations (Gibson et al. 2011; Pouryousef et al. 2015). However, from a long-term perspective, decreasing trend in weed seed bank due to buckwheat mulch alleviates weed problems after few years and decreases the cost of control, which can be achieved with lower densities of living mulch in sunflower.

Conclusions

Weed control is a key factor for the successful organic production of sunflower. It is clear that the living mulch alone cannot provide efficient weed suppressing and combination with other complementary management strategies such as selection of competitive crop cultivars with high weed suppression ability is essential. Our findings confirmed that incomplete weed control performed with living mulch could be considerably improved by choosing highly competitive sunflower cultivars. Overall, selection of Azargol as a competitive cultivar and buckwheat as living mulch which provided 96 % control was the best combination method for broadleaf weed control, while Farokh-buckwheat which provided 77 % control was more effective combination for grass weed control. Our findings suggest that combining highly competitive sunflower cultivars with proper living mulch species is a feasible weed management strategy; however, selection of both crop cultivar and living mulch species should be adapted based on dominant weed spectrum.

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