Intercropping of fenugreek as living mulch at different densities for weed suppression in coriander

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Living mulch planted between rows might limit weed growth. The objective of this study was to determine the weed-suppressing effect of fenugreek intercropped with coriander, with the aim to select a suitable density of fenugreek for intercropping in coriander production. Five fenugreek densities and three weed control levels were evaluated in a factorial arrangement of treatments. Results indicated that increasing density of fenugreek living mulch suppressed weed growth and increased seed yield compared to weed infested conditions. Maximum weed biomass was recorded in sole coriander with no control (329 and 274 g m⁻² in 2012 and 2013, respectively), while minimum weed biomass was recorded in plots which fenugreek intercropped at the density of 50 plants m⁻² and one hand weeding was applied. Increasing fenugreek density decreased the LAI of coriander with similar gentle slopes for both years. The seed yields obtained from weed free, one hand weeding, and no control plots were 1618, 973, and 457 kg ha⁻¹, respectively. With increase in weed control level fenugreek density caused a decrease with greater impact on the coriander seed yield. Essential oil content from dried fruit ranged from 0.52 to 1.14% and 0.52 to 1.10% in 2012 and 2013, respectively. Our findings confirm that fenugreek can be used as living mulch in organic coriander production to reduce the biomass of weeds. However, the use of fenugreek did not provide reliable weed control throughout the season and so must be combined with additional weed management options to achieve acceptable control.

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1. Introduction

Coriander (Coriandrum sativum L.) is a culinary and medicinal plant from the Umbelliferae family. This plant is of economic importance since it has been used as flavoring agent in food products, perfumes and cosmetics. As a medicinal plant coriander has been credited with a long list of medicinal uses (Emamghoreishi and Heidari-Hamedani, 2006). In Iran more than 3200 ha are under coriander with an average production of 2 t ha⁻¹. However, coriander is not a good competitive crop against weeds. Its early growth is slow and in typical planting pattern weeds cause significant decrease in coriander yields.

In modern agriculture, chemicals have become the most frequently used weed control strategy. However, environmental and economic costs, as well as increased weed resistance to herbicides have led to a desire for less herbicide use on farms (Yousefi and Rahimi, 2014). One environmentally sound way to decrease herbicide use is living mulch as a cultural weed control method. Such systems consist of a species pre-sown or intercropped with a main crop in order to serve as a soil cover, which contributes towards weed control. Living mulches have the potential to reduce soil erosion, increase soil organic matter and nitrogen, improve water filtration, lower weed pressure (Hartwig and Ammon, 2002), and reduce weed seed bank (Gibson et al., 2011). However, living mulches 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). This yield reduction is very likely caused by the competition for light, water and nutrients between the living mulch and main crop (Thorsted et al., 2006). Plant density has been shown to be a main factor which changes the outcome of competition in plant community (Yousefi et al., 2012). In some cases, increased plant density leads to quicker canopy closure, increased crop interference and greater weed suppression, resulting in increased yields (Kolb et al., 2012; Jamshidi et al., 2013). However, high density of living mulch plants can lead to increases in competition for resource between living mulch plants and main...
crop. Hence, determining optimal plant density (the density which led to high weed suppression and low competition to main crop) of living mulch crops is crucial for efficient intercropping.

One of the most promising vegetable species appeared to be appropriate for this purpose is fenugreek (Trigonella foenum-graecum L.), because of the low height (0.3–0.6 m), quickly seedlings emergence and excellent soil surface coverage at a short time after emergence. Additionally, fenugreek produces numerous secondary metabolites, and some of them show allelopathic activity. For instance, Omezzi et al. (2014) showed that the aqueous and organic extracts of fenugreek significantly delayed germination and seedling growth in lettuce (Lactuca sativa). Extracts from the shoots were most active and showed selective activity on several weeds (Haouala et al., 2008).

There is only limited information available on herbicide-free weed management practices that provide adequate weed suppression while maintaining acceptable yields. Despite reports on the effect of fenugreek as living mulch on weed suppression, to the best of our knowledge no study has investigated the fenugreek density effect to optimize living mulch efficiency. Therefore, the objective of this study was to determine the weed-suppressing effect of fenugreek intercropped with coriander, with the aim to select a suitable density of fenugreek for intercropping in coriander production.

2. Materials and methods

2.1. Field experiments

Two field experiments were conducted at the Research Farm of the University of Zanjan, Zanjan, Iran, in 2012 and 2013. This region is characterized by a semi-arid cool climate, with an annual mean temperature of 11 °C and mean precipitation of 293 mm for the past 30 years. Mean monthly temperature and rainfall data during the growing season, recorded near the experimental area, are given in Table 1. The soil type was a sandy loam, with a pH of 8.1 and 8.18, and soil organic matter of 1.1% and 1.3% in 2012 and 2013, respectively. The soil was ploughed using a mouldboard plough (20–25 cm) that was followed by two disks to prepare the seedbed. As the crops were grown under organic conditions, only animal manure (20 t ha⁻¹) was added prior to plowing, and then thoroughly incorporated in the soil.

Coriander (cv. Esfahan) and fenugreek (cv. Ardakani) were sown at a row spacing of 0.25 m on 10 May 2012 and 4 May 2013. The plots consisted of ten 5-m-long rows. Furrow (in 2012) and drip (in 2013) irrigation were used on all plots. Irrigation was carried out weekly until physiological maturity of the coriander. Weeds were manually removed in weed-free plots throughout the season; no chemicals (herbicide and pesticide) were applied to the plots in both seasons.

2.2. Experimental treatments

The study was arranged as factorial experiment based on randomized complete block design with three replications. Factors were five fenugreek densities (0, 10, 20, 30 and 50 plants m⁻²), which were intercropped with coriander in three levels of weed infestations (un-weeded control, weed free control, and one hand-weeding at 35 days after crop emergence). Fenugreek and coriander were over seeded to ensure uniform crop establishment, and were then thinned to the desired densities at 3–4 leaf stage. The density of 50 plants m⁻² for coriander was established.

2.3. Plant sampling

For assessing the effect of the treatments on coriander leaf area (LA), destructive sampling was carried at flowering in both years. All coriander plants from a 50-cm length of the two middle rows of each plot were harvested by cutting at the soil surface. The areas of green leaves were measured using a Delta-T leaf area meter (Delta-T Devices, Cambridge, England). Leaf area index (LAI) of coriander was calculated by the following equations:

\[
\text{LAI} = \frac{\text{LA}}{\text{GA}}
\]  

where LA is leaf area (cm²) of sampled area and GA is sampled area (cm²). At coriander maturity weeds were cut at ground level from a 1 m × 1 m area in each plot. Weeds were counted and dried at 75 °C for 72 h for biomass determination. For assessing the effect of the treatments on coriander yield, crops growing along a 2-m length of the centre two rows in each plot were hand clipped at maturity (on 8 September 2012 and 23 August 2013) and dried to a constant weight at 70 °C for 48 h.

2.4. Isolation of essential oil

Fruits were dried in oven at 40 °C until constant mass and crushed by grinder for isolation of essential oil. Crushed fruits were subjected to hydrodistillation in Clevenger-type apparatus. 40 g crushed fruit were watered with 400 ml distilled water (1:10). Distillation lasted for approximately 3 h at boiling point. The obtained oil was separated from water and dried over anhydrous sodium sulfate.

2.5. Statistical analysis

Data were tested for normality of distribution (Shapiro–Wilk test) and homogeneity of variance by SigmaPlot (11.0). For the weed density data, square root transformation was made before analysis; preliminary ANOVA was used using PROC GLM in SAS Software (Version 9.1, SAS Institute Inc., Cary, NC) to find out treatment effects and their interactions. Linear regression was used using SigmaPlot for describing the changes in measured indices against increasing density of fenugreek. To compare the treatment effects including experiment year, the estimated parameters were compared using t-test (with SAS) and the value of standard error of parameters.

3. Results

3.1. Weed species composition

The common weeds found during the experiments were prostrate pigweed (Amaranthus bitoides S. Wats.), redroot pigweed (Amaranthus retroflexus L.), Italian bugloss (Anchusa italic Reitz).
Lambsquarter (*Chenopodium album* L.), morninglory (*Convolvulus arvensis* L.), barnyard grass (*Echinochloa crus-galli* (L.) P. Beauv.), pinweed (*Erodium cicutarium* L.), liquorice (*Glycyrrhiza aspera* Pall.), *Goldbachia laevigata* (M. Bieb) DC., Common mallow (*Malva neglecta* wallr.), Russian thistle (*Salsola kali* L.), green foxtail (*Setaria viridis* (L.) P. Beauv.), black nightshade (*Solanum nigrum* L.), common sowthistle (*Sonchus oleraceus* L.), and common cocklebur (*Xanthium strumarium* L.)

### 3.2. Total weed density and biomass production

Results of analysis of variance showed that the density of fenugreek as living mulch had significant effect on the total weed density in 2012 and 2013; however the interactions were not significant. Parameter estimates of the linear regression also showed no significant difference between the slopes indicating no interactions between fenugreek density and weed control level on weed density. The total weed density was higher in 2013 than 2012 (intercept values of lines in Fig. 1). The slope value (0.016 and 0.018 for 2012 and 2013, respectively) showed that with every plant increase in fenugreek density about a 2% (1.6–1.8%) decrease was caused in total weed densities.

Effects of treatments were also significant on total biomass of weeds. For 2012, the interaction between fenugreek densities and control levels was also found significant. For both years either in one hand weeding or no control, the slopes of decrease in weed biomass were identical; therefore weed biomass was similarly affected by fenugreek density (Fig. 2). Maximum weed biomass (329 (24) and 274 (18) g m\(^{-2}\) in 2012 and 2013, respectively, Fig. 2) was recorded in sole coriander with no control, while minimum weed biomass was recorded in plots which fenugreek intercropped at the density of 50 plants m\(^{-2}\) and one hand weeding was also applied. Control levels also affected the total weed biomass. When one hand-weeding was used, weed biomass decreased by 41 and 35% (compared to weed infested treatment) for 2012 and 2013, respectively.

In 2013, the interaction between treatments was not significant. However, the weed infestation level was higher in weed infested plots; the effect of fenugreek densities showed no dependency on control level and the slope of decrease in weed biomass was similar. In contrast for 2012, the control effect of fenugreek intercropping on weed biomass was correlated with the level of weed infestations, as when one hand weeding was applied on weed population, increasing density of fenugreek caused greater decrease in total weed biomass (Fig. 2). In weed infested plots, the weed biomass was estimated at 330 g m\(^{-2}\) that decreased with a slope of 2.73 (0.17) against increasing density of fenugreek, while in plots with one hand weeding the total weed biomass (in sole coriander cropping) was estimated at 252 g m\(^{-2}\) that decreased with a rate of 4.48 (0.2) against increasing density of fenugreek.

### 3.3. Coriander LAI

In both years of study, coriander LAI was affected by both fenugreek density and weed control level, while interaction effects were not significant. Increasing fenugreek density decreased the LAI of coriander with similar gentle slopes for both years (Fig. 3). However, the amount of coriander LAI was significantly depended on applied weed control levels. In weed free plots, the amount of LAI had greater value compared to one hand weeding or weed infested plots. On other hand, the increase in fenugreek density caused a higher decrease in LAI of coriander in weed free plots.

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**Fig. 1.** Relationships between weed density and increasing fenugreek density as living mulch at different levels of weed control. The equations of fitted lines are shown. Values in the brackets are standard error of parameters.

**Fig. 2.** Relationships between weed biomass and increasing fenugreek density as living mulch at different levels of weed control. The equations of fitted lines are shown. Values in the brackets are standard error of parameters.
Therefore, the greater amount of LAI in weed free was more affected by the presence of fenugreek as a companion crop.

### 3.4. Coriander seed yield

Both the fenugreek density and weed control level significantly affected the seed yield, however, the interaction was found significant only in 2012. For the respective year, as indicated by intercept values (Fig. 4), the seed yields obtained from weed free, one hand weeding, and no control plots were 1618 (24), 973 (19), and 457 (21) kg ha\(^{-1}\), respectively. When no control was applied on weeds, fenugreek density had lower effect on seed yield and the slope of line showed lower value, while with increase in weed control level fenugreek density caused a decrease with greater impact on the coriander seed yield (Fig. 4). In 2013, the seed yields obtained from weed free, one hand weeding, and no control plots were 1343 (41), 755 (28), and 457 (17) kg ha\(^{-1}\), respectively. The slope of decrease in seed yield with increasing fenugreek density was greater in weed free, while one hand weeding and no control plots had similar values and was identically affected by fenugreek density.

### 3.5. Coriander seed essential oil (%)

Essential oil content from dried fruit ranged from 0.52 to 1.14% and 0.52 to 1.10% in 2012 and 2013, respectively. In 2012, essential oil content of coriander was significantly affected by fenugreek density (\(p = 0.03\)) and weed control (\(p < 0.01\)). However, the interaction effect of fenugreek density \(\times\) weed control was not significant. Also there was no linear trend between seeds essential oil content and fenugreek density as the ones were found in other traits. Essential oil content increased from 0.74% to 0.88% with increasing fenugreek density from 0 to 10 plant m\(^{-2}\), while another 10 plants increase in fenugreek density decreased the seed oil content to 0.80%. Again with increasing fenugreek density to 30, 40 and 50 plants m\(^{-2}\) a slight increasing trend was observed in seed essential oil contents. This up and down in seed oil content was similarly found in 2013; however the total amount of seed oil was at lower level.

At the weed free condition, essential oil content was 0.92%, while weed competition decreased it down to 0.76%. One hand-weeding produced essential oil content similar to weed infestation condition. In 2013, the effect of weed control was significant on essential oil content of coriander, while the effect of fenugreek density was not significant. Same to 2012, higher essential oil content (0.86%) was obtained at weed free condition and lower one (0.76%) obtained at weedy condition. Plots which received one hand-weeding produced 0.80% essential oil which was statistically similar to weed free condition.

### 4. Discussion

Total weed biomass was greatly affected by fenugreek living mulch. Lack of available uncovered, inter-row spaces for weed establishment resulted in a severe reduction in the biomass of weeds. Many studies reported lower dry weights of weeds in systems that use cover crops because of covering the inter-row spaces (Teasdale and Mohler, 1993; Jamshidi et al., 2013). In the present study, weed infestation was generally reduced, as the density of cover crop increased (Figs. 1 and 2). Previous research demonstrated that cover crop density influenced weed biomass (Jamshidi et al., 2013). Increasing crop densities lead to early closure of crop canopy and help to maximize crop competitiveness (Monaco et al.,...
2002). Rapid closure of the crop canopy over weeds decreases sunlight and limits weed growth (Monaco et al., 2002). The current study also showed quicker canopy closure with increase in mulch density which limited the available space for weeds. Also by covering the surface of the soil, living mulch decreases soil surface temperature (Borowy, 2012) leading to slow growth of weeds.

Our findings confirmed that fenugreek can be used as living mulch in organic coriander production to reduce the biomass of weeds. However, the use of fenugreek did not provide reliable weed control throughout the season and so must be combined with additional weed management options to achieve acceptable control.

Weed biomass was also significantly affected by one hand-weeding. Previous research has demonstrated that one hand-weeding can influence weed biomass (Yousefi and Rahimi, 2014). In our study, before hand-weeding mean temperature reached to about 19 °C in both years (Table 1), which was greater than base temperature of seed germination for most weed species in the experimental sites. Therefore, lower weed infestation resulted from one hand-weeding treatment could be in part due to higher weed emergence before weeding.

Seed yields of coriander in 2012 were higher than in 2013 in all the treatments. Crop emergence can be affected by soil temperature and soil moisture (see Chauhan, 2013) Mean temperature in 2012 was about 2 °C greater than 2013 at planting time (Table 1). The higher temperature could help the coriander plants to germinate and establish more quickly. Additionally, the precipitation during the growth season was higher in 2012 compared to 2013. The more favorable moisture and temperature in 2012 resulted in higher coriander yield than 2013.

Average over two years, coriander seed yield and LAI in the weedy plots were 73 and 40% lesser than in weed-free plots, respectively. Severe reductions in seed yield in the weedy plots in both years showed that coriander is highly sensitive to weed competition. Therefore, consistent weed control is necessary for successful coriander production.

Studies indicated that legume cover crop mulches have the ability to increase crop yield (Mennan et al., 2006; Isik et al., 2009; Bilalis et al., 2010). Gibson et al. (2011) reported that tomato yield was not reduced by growing buckwheat between rows. The intercropped species may compete for the same resources, resulting in a lower yield of the main crop (Kotota and Adamczewska-Sowińska et al., 2013). Based on the current study results, however, increasing density of fenugreek decreased the weed biomass; there was also reduction in coriander yield even in weed free plots compared to coriander monoculture. On the other hand, as fenugreek is used as vegetable or also green manure, the decrease in coriander yield is compensated with the respective benefits of fenugreek. Additionally, from a long term perspective of view, decreasing trend in weed seed bank due to fenugreek mulch alleviates weed problems after few years and decreases the cost of control, which can be achieved with lower densities of living mulch in coriander. Brainard and Bellinder (2004) suggested that the benefits of increased weed suppression must be balanced against yield reductions due to competition between species in intercropping.

It is concluded that the use of fenugreek as living mulch leads to a considerable reduction in weed biomass (about 53% at a density of 40 plants m⁻²). However, the weed control level was not entirely adequate. Therefore complementary management strategies such as seedbed preparation techniques (e.g. stale seedbed), more competitive cultivars and the use of cover crops with more allelopathic capability are important considerations for achieving complete weed control.

References


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