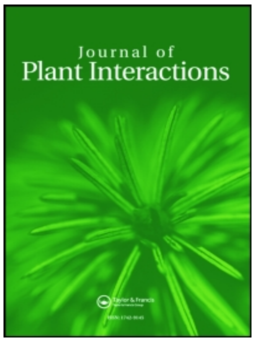

Journal of Plant Interactions

ISSN: 1742-9145 (Print) 1742-9153 (Online) Journal homepage: https://www.tandfonline.com/loi/tjpi20

Intercropping patterns and different farming systems affect the yield and yield components of safflower and bitter vetch

Jalal Jalilian, Azin Najafabadi & Mohammad Reza Zardashti

To cite this article: Jalal Jalilian, Azin Najafabadi & Mohammad Reza Zardashti (2017) Intercropping patterns and different farming systems affect the yield and yield components of safflower and bitter vetch, Journal of Plant Interactions, 12:1, 92-99, DOI: 10.1080/17429145.2017.1294712

To link to this article: https://doi.org/10.1080/17429145.2017.1294712

JOURNAL OF PLANT INTERACTIONS, 2017
VOL. 12, NO. 1, 92–99
https://doi.org/10.1080/17429145.2017.1294712

Taylor & Francis
Taylor & Francis Group

RESEARCH ARTICLE

OPEN ACCESS Check for updates

Intercropping patterns and different farming systems affect the yield and yield components of safflower and bitter vetch

Jalal Jalilian, Azin Najafabadi and Mohammad Reza Zardashti

Department of Agronomy, Faculty of Agriculture, Urmia University, Urmia, Iran

ABSTRACT

This factorial field experiment was done based on a randomized complete block design in Urmia University, Iran, in 2013 and was repeated in 2014. Treatments included two farming systems (high input and organic) and different intercropping patterns that alternated bitter vetch (*Vicia ervilia* L.) and safflower (*Carthamus tinctorius* L.) with row ratios of 2:2, 3:2, 4:2 and 5:2. Sole cropping of bitter vetch and safflower was used as the control. In both years, the 2:2 intercropping pattern had biomass yield advantages compared to sole cropping and the other intercropping ratios, based on greater land equivalent ratio values. Safflower had higher relative crowding coefficients, competitive ratio (CR) and aggressivity (A) values than bitter vetch. High-input farming was more effective than the organic system in both years. Safflower was the superior competitor when grown with bitter vetch, and its productivity dominated the total biomass yields. Thus, intercropping of safflower with bitter vetch has the potential to improve performance with high land-use efficiency.

ARTICLE HISTORY
Received 18 March 2016
Accepted 9 February 2017

KEYWORDS
Competitiveness indices; high input; land equivalent ratio; mono-crop; organic system

1. Introduction

Intercropping refers to cultivation of two or more crops planted simultaneously in the same land (Sarkar et al. 2000) that provides the possibility of yield benefit in accordance with sole cropping (Bhatti et al. 2006). A major benefit of intercropping is increase in production per unit area compared to sole cropping through the effective use of resources, including water, nutrients and solar energy (Nasri et al. 2014). Intercropping is preferred to sole cropping as a result of superior yield due to better absorption of resources, and this is especially realized when legumes are planted with the other crops (Sachan & Uttam 1992), that improves soil fertility due to increased nitrogen fixation (Manna et al. 2003). Intercropping of Fabaceae and Asteraceae families' results in increased crop yield, maximized resource consumption and enhanced productivity of cultivation system (Singh Rajesh et al. 2010). Interspecific interaction between species in the rhizosphere can also affect the nutrient availability and uptake in intercropping (Li et al. 2010). Light, water and nutrients may be more completely absorbed and converted to crop biomass by intercropping, which is the simultaneous growing of two or more crop species in the same field. This is a result of differences in the competitive ability for growth factors between intercrop components (Amini et al. 2013).

Besides functional agrobiodiversity, intercropping is based on the ecological principles of competition, complementarity and facilitation. If interspecific competition for growth factors is lower than intraspecific competition, species share only a part of the same niche and reduced competition or the competitive production principle is in action (Vandermeer 2011).

Bitter vetch (*Vicia ervilia* L.), a member of Fabaceae family, is an ancient legume of the Mediterranean region that has been used for grain and hay production. It has a number of favorable characteristics, such as high yield, resistance to drought and insects and good energy and protein content that make it a potentially and economically useful source for animal diets (Sadeghi et al. 2009).

Safflower (*Carthamus tinctorius* L.) is an annual, broadleaf oilseed crop of the family Asteraceae that originated in southern Asia (Kohnaward et al. 2012) and adapted chiefly to dry land or irrigated cropping systems (Rohini & Sankara 2000).

Conventional farming, known as high-input system, has played an important role in improving food production; it has been largely dependent on intensive inputs of synthetic fertilizers, pesticides and herbicides (Horrigan et al. 2002). Alternative farming systems, including organic farming system, are being explored to improve the overall soil health, agricultural sustainability and environmental quality (Wienhold & Halvorson 1999).

Organic farming systems use lower levels of nutrient and pesticide inputs than chemical farming systems and are characterized by improved biological activity and biodiversity (Hole et al. 2005). This involves using methods to get good crop yields without damaging the natural environment or the people who live and work in it (Rigby & Cáceres 2001).

Recent meta-analyses have revealed that the 'yield gap' of organic agriculture to conventional agriculture is 19–25% (Seufert et al. 2012). However, yield differences are highly contextual, depending on the cropping system and site characteristics, and range from 5% lower yields in organic agriculture (rain-fed legumes and perennials) to 34% lower yields (Seufert et al. 2012).

Zafaranieh (2015) reported that yield and yield components and land equivalent ratio (LER) of safflower intercropped with chickpea were significantly influenced by various combinations of culture. Also, Kazemeini and

CONTACT Jalal Jalilian j.jalilian@urmia.ac.ir

Sadeghi (2012) reported that intercropping of safflower with green bean, improved yield, yield component and biological yield. Intercropping of safflower/potato (Rahimi Darabad et al. 2011) and bitter vetch/corn (Javanmard et al. 2009) showed a clear advantage over sole cropping in terms of biomass and other traits.

There are few published reports on effects of intercropping patterns on safflower and bitter vetch under different farming systems. Therefore, the main objective of this study was to investigate changes in yield and yield components in safflower and bitter vetch intercropping under high-input and organic farming systems.

2. Material and methods

This field experiment was conducted at the research field of Urmia University (37° 39′ N and 44° 58′ E, altitude 1365 m, West Azarbaijan Province, Urmia-Iran) during 2013 and 2014. Weather conditions of the experimental site including the monthly precipitation and mean air temperature are compared in Table 1 with long-term averages (1985–2014). Land preparation was done in early spring of 2013 and 2014 by disk and cultivator. The land had been deeply plowed in the previous fall.

The experiment was arranged in a factorial based on Randomized Complete Block Design with three replications. Treatments were two farming systems (high input and organic) and six intercropping patterns including different safflower (*C. tinctorius* L.) and bitter vetch (*V. ervilia* L.) row ratios: 2 rows (50 cm wide) of bitter vetch alternated with 2 rows (100 cm wide) of safflower; 3 rows (75 cm wide) of bitter vetch alternated with 2 rows of safflower; 4 rows (100 cm wide) of bitter vetch alternated with 2 rows of safflower; 5 rows (125 cm wide) of bitter vetch alternated with 2 rows of safflower; safflower and biter vetch sole cropping as the control (Figure 1). The inter-row spacing was 25 cm for bitter vetch and 50 cm for safflower. There was a 30 cm gap between bitter vetch and safflower strips. The intercropping area ratios occupied by bitter vetch and safflower were 33%:67%, 43%:57%, 50%:50% and 55%:45%, respectively, for the four respective patterns. The intercropping plots area was 15.75, 17.5, 19.25 and 21 m^2 for the four respective patterns and 10 and 15 m^2 for sole vetch and safflower, respectively. In both years, vetch was sown by hand at the end of April and safflower was sown by hand in middle of May.

Agronomic practices (tillage operations, field leveling, nitrogen and phosphorus fertilizers, organic manure, weed and pest management) for each farming system were applied according to the mentioned treatments (Table 2). All plants were irrigated uniformly as locally recommended (once irrigation per nine days). The high-input system involved the use of chemical control of pest (*Acanthiophilus helianthi* Rossi) and weeds with the use of Metasystox and Galant. Hand weeding was done in organic farming system (Table 2). Some of the physicochemical characteristics of

Table 1. The mean monthly temperature and rainfall in both 2013 and 2014 are compared with those of a longer period (1985–2014).

Months	January	February	March	April	May	June	July	August	September	October	November	December	Avg. or Tot.
2013													
M.A.T. (°C)	−0.4	3.8	7.4	12.2	15.4	20.9	24	22.8	19	11.2	7.3	−5.9	11.47
M.R. (mm)	43.9	9.2	19.3	32.9	55.1	6	0	0.1	0	9.2	62	41.8	279.5
2014													
M.A.T. (°C)	−2.5	0.8	8	12.6	17.3	21.8	24.8	25	20.1	11.3	4.4	2.2	12.15
M.R. (mm)	32	1.6	48.2	21.8	50.4	2.2	0	0.3	3.2	147.5	28.6	11.5	347.3
1985–2014													
M.A.T. (°C)	−2.1	0.2	5.22	11.26	15.81	20.84	23.86	23.32	18.9	12.6	5.77	0.35	11.33
M.R. (mm)	25.4	28.2	46.7	54.7	37.1	10	5.6	2.8	4.3	30.5	39.4	28.1	312.8

Notes: M.A.T. = mean air temperature; M.R. = mean rain; Avg. = average; Tot. = total. Safflower planting dates were 12 May 2013 and 13 May 2014. Biter vetch planting dates were 12 May 2013 and 13 May 2014.

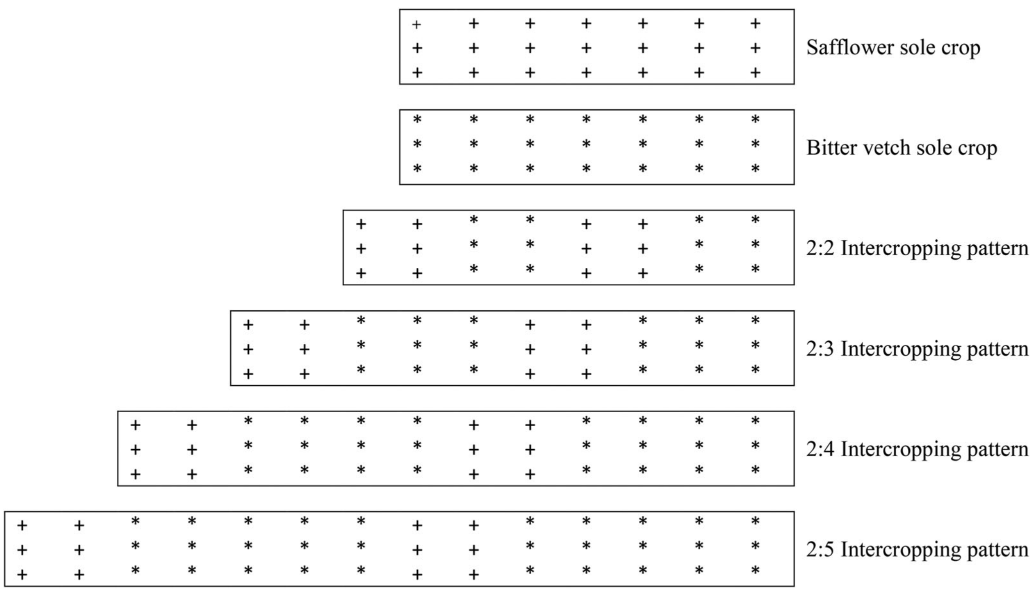

Figure 1. Schematic diagram of different intercropping patterns between safflower (+) and bitter vetch (*).

Table 2. Inputs for farming systems.

	Farming systems	
Inputs	High input	Organic
Tillage operations	Plow + shovel	Plow
Leveling	Rake	–
Urea (kg/ha)	120	–
Triple superphosphate (kg/ha)	90	–
Cow manure (t/ha)	–	40
Nitroxin (*A. lipoferum and A. chroococcum*) (L/ha)	–	1
Biophosphat (*B. lentus* and *P. putida*) (kg/ha)		1
Metasystox as pesticides (L/ha)	2–2[a]	–
Gallant Super as herbicide (L/ha)	3–2[a]	Weeding

[a]The first number represents number of times application was made; and the second number represents amount of chemical used.

the soil, based on farming system treatment, are given in Table 3.

In organic farming system, cattle manure was mixed with soil before planting and seed inoculation with nitroxin (*Azospirillum lipoferum* and *Azotobacter chroococcum*) and biophosphat (*Bacillus lentus*, *Pseudomonas putida*) bacterial suspensions at 10^9 CFU ml^{-1} for 30 min before planting (Ozturk et al. 2003). Both plants were harvested at physiological maturity by cutting 10 plants randomly from each plot and yield and yield component of each plant were measured.

2.1. Indices of competition

2.1.1. Land equivalent ratio (LER)

LER is an index of intercropping advantage that indicated the amount of interspecific competition or facilitation in an intercropping system (Fetene 2003):

$$\text{LER} = \frac{Y_{is}}{Y_{ss}} + \frac{Y_{iv}}{Y_{sv}},$$

where Y_{is} and Y_{ss} are the yields of intercrop and sole cropping of safflower, and Y_{iv} and Y_{sv} are the yields of intercrop and sole cropping of bitter vetch. A LER of 1.0 indicates that the two intercropped species make alike demands on the same limiting resources. A LER more than 1.0 reveals an intercropping advantage or a demonstration that interspecific facilitation is higher than interspecific competition so that intercropping results in greater land-use efficiency. A LER under 1.0 reveals mutual antagonism in the intercropping system. As a result, a LER less than 1.0 has no intercropping advantage and indicates that interspecific competition is more than interspecific facilitation in the intercropping system (Fetene 2003; Wahla et al. 2009).

2.1.2. Aggressivity

In order to measure yield changes of two component crops affected by interspecies competition in intercropping, McGilchrist (1965), introduces the aggressivity. This index compares the yields between intercropping and sole cropping, as well as their respective land occupancy (Wahla et al. 2009). Thus, we used the aggressivity concept to estimate the interspecies competitiveness of bitter vetch relative to safflower in the intercropping system:

$$A_{vs} = \frac{Y_{iv}}{Y_{sv} \times F_v} - \frac{Y_{is}}{Y_{ss} \times F_s},$$

where A_{vs} is the aggressivity of bitter vetch relative to safflower in the intercropping system, Y_{iv} and Y_{is} are yields of bitter vetch and safflower in intercropping, Y_{sv} and Y_{ss} are yields of bitter vetch and safflower in sole cropping and F_v and F_s are the proportions of the area occupied by vetch and safflower. If A_{vs} is over 0.0, the competitive ability of bitter vetch exceeds that of safflower in intercropping; in any other case, the safflower offers greater competitiveness.

2.1.3. The relative crowding coefficient (RCC)

The RCC introduced by De Wit (1960) was used as an indicator to consider and compare the competitive ability of one species to the other in the intercropping system. Based on this, Wahla et al. (2009) gave the following detailed definition:

$$K_v = \frac{Y_{iv} \times F_s}{(Y_{sv} - Y_{iv}) \times F_v} \; ; \; K_s = \frac{Y_{is} \times F_v}{(Y_{ss} - Y_{is}) \times F_s},$$

where K_v and K_s are the relative crowding coefficients of bitter vetch and safflower, and Y_{iv}, Y_{sv}, Y_{is} and Y_{ss} are the yields of intercropped and sole cropping of bitter vetch, and safflower, respectively; F_v and F_s are the proportional land occupancy of bitter vetch and safflower in the intercropping system. Each component crop has its own *K* value in an intercropping system (Bhatti et al. 2006). The higher the *K* value of one species is, the more competitive and dominant that species is in the intercropping system (Wahla et al. 2009).

2.1.4. Competitive ratio

The competitive ratio (CR) was used to evaluate which one crop competes with the other in an intercropping system (Willey & Rao 1980; Wahla et al. 2009), and can be calculated by following the formula (Bhatti et al. 2006):

$$\text{CR}_{vs} = \frac{Y_{iv}/(Y_{sv} \times F_v)}{Y_{is}/(Y_{ss} \times F_s)},$$

where CR_{vs} is the competitive ratio of bitter vetch relative to safflower, Y_{iv} and Y_{is} are the yields per unit area of vetch and safflower in intercropping, Y_{sv} and Y_{ss} are the yields per unit area of bitter vetch and safflower in sole cropping and F_v and F_s are the proportions of the area occupied by bitter vetch and safflower in the intercropping system. When CR_{vs} is greater than 1.0, the competitive ability of vetch is higher than safflower in the intercropping system (Zhang et al. 2011).

Analysis of variance was done on the two-year data by using the general linear model procedure in the statistical analysis system (SAS Institute 2003). Means were separated using Duncan test at the 95% level of probability.

Table 3. Physicochemical characteristics of soil based on cropping systems.

	High-input system	Organic system
EC (dS/m)	0.54	2.12
Soil texture	Clay loam	–
pH	7.21	7.06
O.C. (%)	0.94	1.22
N (%)	0.094	0.102
P (mg/kg)	7.6	8.6
K (mg/kg)	395	480
Clay (%)	32	32
Silt (%)	37	37
Sand (%)	31	31

3. Result and discussion

3.1. Yield and yield components

In the second year, the mean monthly rainfall was above normal, but in the first year, it was below normal. The mean monthly temperature was slightly above normal (long-term temperature) in both years (Table 1). During the growing season, the temperature in the second year was higher than in the first year; this could be a reason for the differences between years (Table 5).

Analysis of variance showed that there was a significant effect of treatments interaction on seed and biomass yield of bitter vetch, and 1000-seed weight, seed yield, biomass yield and harvest index of safflower in both years (Table 4). The main effects of farming systems and intercropping patterns on pod number, 1000-seed weight and harvest index of bitter vetch were significant in the two-year study (Table 4). In the bitter vetch, the number of seeds per pod only at the first year was affected by the interaction of treatments (Table 4). Safflower head number and the number of seeds per head were affected by interaction of treatments in 2014, but in 2013, the main effects of treatments had a significant impact on these traits (Table 4).

In both years, the pod number per plant, 1000-seed weight, harvest index and the number of seeds per pod of bitter vetch that were located in high-input farming system were improved in comparison with organic system (Table 5). Also, in safflower, the most head number per plant and the number of seeds per head were obtained from high-input system (Table 5). In high-input system, more nutrient accessibility (N and P) (Table 2) led to improvement in the yield and yield component (Uhart & Andrade 1995). Phosphorus used in high-input system has different impacts such as cell division, fertilization and development of reproductive organs. It can improve root development and increase absorption of water and nutrients (Marschner 2002). Also, it has been found that the rice spike (Delmotte et al. 2011) and yield components of wheat (Hildermann et al. 2009) increased in high-input system.

Compared with the intercropping patterns, sole cropping of bitter vetch had the highest pod numbers, 1000-seed weight and harvest index in the first year, but in 2014, the highest mentioned traits were obtained in sole cropping and 5:2 intercropping pattern (Table 6). More light absorption and access to other inputs in sole cropping of bitter vetch may cause high performance of photosynthesis and ultimately increase some yield components (Tables 6 and 7). In safflower, 2:2 intercropping pattern was the most effective on head number per plant and the number of seeds per head in comparison with other intercropping patterns (Table 6).

According to the mean comparison, sole cropping of bitter vetch, in 2013, at high-input system had the maximum number of seeds per pod (Table 8). Safflower at the first year in 2:2 intercropping pattern under high-input system had the higher 1000-seed weight and harvest index (Table 8). Also in 2014, safflower plants at 2:2 intercropping pattern in high-input system had the most effect on head number per plant and harvest index in comparison with other treatments (Tables 7 and 8). For number of seeds per pod and 1000-seed weight of bitter vetch, 3:2 and 4:2 sowing patterns in high-input system were the optimum patterns (Table 8). Due to lack of competition between bitter vetch plants with safflower for light and other resources, as well as utilization of chemical fertilizers and pest and disease management, sole cropping of bitter vetch had the highest seed number per pod in high-input system. As compared with sole cropping, some component yield reduction at intercropping can be attributed to competition for moisture, nutrients

Table 4. Two-year analysis of variance (mean square) for yield and yield components of bitter vetch and safflower intercropping affected by different farming systems and intercropping patterns.

		Bitter vetch								Safflower			
Source of variation	df	Pod number per plant	Number of seeds per pod	1000-seed weight	Seed yield	Biomass yield	Harvest index	Head number per plant	Number of seeds per head	1000-seed weight	Seed yield	Biomass yield	Harvest index
2013													
Replications	2	0.15	0.0002	0.06	0.0003	0.0002	0.16	1.24	0.31	0.08	0.03	0.023	3.43
Farming systems (FS)	1	115.2**	0.81**	97.9**	0.6**	1.51**	156.54**	101.8**	160.7**	49.92**	5.15**	9.39**	296.2**
Intercropping pattern (IP)	4	14.14**	0.38**	9.52**	1.56**	6.52**	40.76**	11.25**	17.13**	5**	3.53**	27.97**	47.85**
FS × IP	4	0.25^{ns}	0.06**	0.9^{ns}	0.07**	0.17**	2.4^{ns}	0.12^{ns}	0.23^{ns}	0.36**	0.09**	0.22**	1.16*
Error	18	0.44	0.012	0.32	0.0007	0.0007	1.98	0.09	0.11	0.03	0.002	0.002	0.33
Coefficient of variant		2.06	3.97	1.33	3.53	1.53	3.38	1.49	0.81	0.48	2.12	0.81	1.56
2014													
Replications	2	0.01	0.004	0.13	0.0005	0.09	25.25	0.54	3.97	0.41	0.039	0.09	1.14
Farming systems (FS)	1	133.9**	0.46**	56.8**	0.69**	7.46**	274.2**	175.2**	79.38**	16.72**	6.93**	10.47**	394.3**
Intercropping pattern (IP)	4	22.17**	0.3**	19.46**	2.93**	7.64**	595.4**	24.52**	11.32**	1.14**	3.92**	10.3**	133.7**
FS × IP	4	0.1^{ns}	0.005^{ns}	0.28^{ns}	0.05**	0.28**	38.09^{ns}	2.67**	2.79**	7.56**	0.13**	0.23**	12.17**
Error	18	0.22	0.003	0.13	0.001	0.05	14.5	0.13	0.28	0.13	0.003	0.004	0.37
Coefficient of variant		1.41	1.87	0.82	2.8	8.94	8.81	2.13	1.11	1	2.11	1.15	1.33

Note: ns, not significant.
*Significant at .05 probability level.
**Significant at .01 probability level.

Table 5. Two-year mean comparison for some yield components of bitter vetch and safflower affected by farming systems.

Year	Farming system	Bitter vetch				Safflower	
		Pod number per plant	Number of seeds per pod	1000-seed weight (g)	Harvest index (%)	Head number per plant	Number of seeds per head
2013	High input	34.11a	ns	44.82a	43.85a	22.36a	44.26a
	Organic	30.19b	ns	41.2b	39.28b	18.67b	39.63b
2014	High input	35.64a	3.37a	45.83a	46.33a	ns	ns
	Organic	31.42b	3.13b	43.08b	40.28b	ns	ns

Notes: The same letters in each column within each year show non-significant difference at $P \leq .05$ by Duncan test. ns: not significant based on variance analysis (Table 4).

Table 6. Two-year mean comparison for some yield components of bitter vetch and safflower affected by intercropping patterns.

Year	Intercropping pattern[a]	Bitter vetch				Safflower	
		Pod number per plant	Number of seeds per pod	1000-seed weight (g)	Harvest index (%)	Head number per plant	Number of seeds per head
2013	Sole	34.35a	ns	44.76a	46a	19.15e	40.13e
	2:2	30.68d	ns	41.45d	32.98bc	22.68a	44.44a
	3:2	30.78d	ns	42.36c	39.62c	20.29c	41.71c
	4:2	32.05c	ns	42.85c	41.75b	20.82b	42.65b
	5:2	32.9b	ns	43.63b	40.49bc	19.63d	40.78d
2014	Sole	35.4a	3.51a	46.35a	51.43a	ns	ns
	2:2	31.13d	2.98e	41.88e	28.72c	ns	ns
	3:2	32.05c	3.07d	43.58d	37.45b	ns	ns
	4:2	33.73b	3.29c	44.6c	47.46a	ns	ns
	5:2	35.35a	3.41b	45.86b	51.46a	ns	ns

Notes: The same letters in each column within each year show non-significant difference at $P \leq .05$ by Duncan test. ns: not significant based on variance analysis (Table 4).
[a]Patterns mean bitter vetch and safflower row ratios (bitter vetch:safflower).

and solar radiation associated with intercropping mixtures (Belel et al. 2014).

The total seed yield of safflower grown in sole cropping and all intercropping patterns increased in 2014 relative to 2013. But the biomass yield decreased in 2014 in some intercropping patterns. The total biomass of safflower at sole cropping in high-input system in 2013 was more than that of other intercropping patterns and organic system in both years (Table 8).

Compared to the organic system, the high-input system increased the total yield of both plants, because of more input usage (Tables 2 and 8). The sole cropping of safflower for both systems in 2013 yielded higher than all the bitter vetch:safflower combinations. But in 2014, the 2:2 pattern without any significant difference with 3:2 pattern had the most total biomass yield (Table 8). The total seed and biomass yield of bitter vetch was always lower than that of safflower grown in sole cropping and all intercropping patterns during the two experimental years (Table 8). The facilitative effect of bitter vetch can uptake part of its nitrogen requirements through symbiotic biological nitrogen fixation which, in turn, reduces the over burden pressure on soil nitrogen supply. Through this process, safflower will have more available soil nitrogen to utilize.

Table 7. Head number per plant and number of seeds per head of safflower affected by farming systems and different intercropping patterns.

Year	Farming systems	Intercropping patterns[a]	Head number per plant	Number of seeds per head
2014	High input	SS	16.71d	47.73d
		2:2	22.61a	50.33b
		3:2	21.4b	51.5a
		4:2	20.66c	50.33b
		5:2	17.1d	48.2cd
	Organic	SS	13.44f	44.93f
		2:2	16.98d	48.73c
		3:2	15.3e	46.76e
		4:2	15e	45.73f
		5:2	13.6f	45.66f

Notes: The same letters in each column within each year show non-significant difference at $P \leq .05$ by Duncan test.
[a]Patterns mean bitter vetch and safflower row ratios (bitter vetch:safflower).

In the first year of experiment, the total biomass yield of safflower in the high-input system was markedly higher than that of mono-cultured bitter vetch and all intercropping patterns. In 2014, the biomass yield of 2:2 and 3:2 intercropping pattern in high-input system was higher than other patterns and organic system (Table 8). However, the performance of legume and other crops intercropping varied by intercropping pattern, and many previous studies have reported that intercropping with legumes can achieve an enhance biomass and yield over corresponding monoculture (Zhang et al. 2011; Arshad & Ranamukhaarachchi 2012; Huňady & Hochman 2014; Zafaranieh 2015).

Sole cropping of bitter vetch in both years had the least biomass yield. Therefore, in our study, the 2:2 pattern was the optimal intercropping pattern. Some recent studies also demonstrated the potential for increased biomass yields through intercropping of annual legumes with safflower (Kazemini & Sadeghi 2012; Sadeghi & Sasanfar 2012; Zafaranieh 2015), and our findings are consistent with those results.

The biomass yield of an intercropping system is positively associated with the competitiveness of the component crops (Piano & Annicchiarico 1995; Li et al. 2001). The interspecific competition, including above- and below-ground competition, is defined as the interaction between the two species that reduces the fitness of one or both of them (Li et al. 2001) and obviously plays an important role in determining the species yields in an intercropping system (Li et al. 2001; Zhang et al. 2007). The species with the stronger competitiveness is generally termed the dominant species or superior competitor, and has a greater capacity to acquire resources and to occupy the superior ecological niche (Grace 1990).

Table 8. Yield and some yield components of bitter vetch and safflower intercropping affected by farming systems and different intercropping patterns.

			Bitter vetch			Safflower					
Year	Farming system	Intercropping patterns[a]	Number of seeds per pod	Seed yield (t/ha)	Biomass yield (t/ha)	1000-seed weight (g)	Seed yield (t/ha)	Biomass yield (t/ha)	Harvest index (%)	Total seed yield (t/ha)	Total biomass yield (t/ha)
2013	High input	SS	–	–	–	37.16d	4.05a	10.87a	37.28d	4.05a	10.87a
		2:2	2.71cd	0.42g	1.01g	38.96a	3.55b	8.17c	43.54a	3.98a	9.18b
		3:2	2.58def	0.55f	1.35e	38b	2.56d	6.44e	39.79b	3.11b	7.79c
		4:2	2.83c	0.74d	1.69d	38.26b	2.35e	5.79f	40.65b	3.09b	7.49e
		5:2	3.1b	0.94c	2.17c	37.66c	1.89f	4.94h	38.13cd	2.83d	7.12f
		VS	3.46a	1.99a	4.09a	–	–	–	–	1.99f	4.09i
	Organic	SS	–	–	–	34.13h	2.82c	9.22b	30.63g	2.82d	9.22b
		2:2	2.5ef	0.31h	0.82h	37.2d	2.63d	6.78d	38.77c	2.94c	7.6d
		3:2	2.4f	0.42g	1.09f	35.26f	1. 8f	5.5g	32.82f	2.22e	6.59g
		4:2	2.66cde	0.55f	1.38e	35.76e	1.68g	4.9h	34.34e	2.23e	6.28h
		5:2	2.65cde	0.64e	1.7d	34.8g	1.32h	4.22i	31.39g	1.96f	5.92h
		VS	2.83c	1.32b	3.06b	–	–	–	–	1.32g	3.06j
2014	High input	SS	–	–	–	37.36b	4.22a	8.51a	49.61c	4.22b	8.51b
		2:2	ns	0.59f	2.08e	34.5d	3.79b	7.08b	53.47a	4.39a	9.16a
		3:2	ns	0.84e	2.4de	38.06a	3.44c	6.57d	52.29b	4.28b	8.97a
		4:2	ns	1.11d	2.74cd	37.66ab	2.81f	5.68f	49.47c	3.92c	8.43b
		5:2	ns	1.39c	2.88c	37.36b	1.92h	4.62h	41.61e	3.31d	7.5c
		VS	ns	2.62a	5.4a	–	–	–	–	2.62i	5.4f
	Organic	SS	–	–	–	35.03d	3.1d	6.87c	45.21d	3.1e	6.87d
		2:2	ns	0.44g	1.56f	37.03b	2.96e	6.09e	48.62c	3.4d	7.65c
		3:2	ns	0.63f	1.62f	35.76c	2.15g	5.11g	42.02e	2.78f	6.74d
		4:2	ns	0.88e	1.62f	35.06d	1.76i	4.5i	39.24f	2.64g	6.12e
		5:2	ns	1.08d	1.98ef	34.6d	1.4j	3.99j	35.12g	2.48h	5.98e
		VS	ns	2b	3.75b	–	–	–	–	2j	3.75g

Notes: The same letters in each column show non-significant difference at $P \leq .05$ by Duncan test. ns: not significant based on variance analysis (Table 4). SS and VS means safflower and bitter vetch sole cropping, respectively.
[a]Patterns mean bitter vetch and safflower row ratios (bitter vetch:safflower).

3.2. LER of the intercropping system

Data on LER of different intercropping patterns are presented in Table 9. In first year, only the 2:2 sowing pattern had yield advantages, values greater than 1.00. In contrast, LER values of other intercropping patterns were all less than 1. In the second year, LER values of all intercropping pattern were more than 1.00. Only the two years mean of 5:2 pattern was less than one. Likewise, of the corresponding safflower LER values, only that of 2014 was above 1 and in 2013, only the 2:2 pattern had a LER value of more than one. In 2014, the 2:2 pattern had the most LER value, indicating that the 2:2 pattern had the most yield advantage compared to other patterns and had stable productivity (Table 9).

3.3. Aggressivity

The component crops did not exhibit equal competitive intensity based on aggressivity. In both sowing years, the aggressivity index of safflower relative to bitter vetch A (sv) was positive in all intercropping patterns. Furthermore, the average A (sv) values of two years were significantly greater than zero ($P \leq .05$), indicating that safflower was the dominant species and had much greater competitiveness in the intercropping system of safflower with bitter vetch (Table 10). The reduction in bitter vetch yield under intercropping with safflower could be attributed to the interspecific competition between the intercrop components for water, light, air and nutrients and also the aggressive effects of safflower on bitter vetch (Matusso et al. 2014). The shading of the bitter vetch by the taller safflower plants may also have contributed to the reduction in the yields of the intercropped bitter vetch (Belel et al. 2014; Karanja et al. 2014).

The productivity of the dominant species directly influences the apparent performance of the intercropping communities (Connell 1990; Li et al. 2001). Thus, the interspecific competitive behavior is essential for the structural stability of the intercropping agro ecosystem. Furthermore, knowledge of competitiveness can predict yields in an intercrop system. The competitive abilities of component crops can be defined in terms of aggressivity, relative crowding coefficient (K) and competitive ratio (Bhatti et al. 2006; Wahla et al. 2009). In general, non-legume crop is considered a suppressing crop in annual legume/non-legume intercrop system (Haynes 1980; Wahla et al. 2009), for example, soybean/wheat (Li et al. 2001), peanut/maize (Inal et al. 2007) and faba bean/barley (Strydhorst et al. 2008).

Table 9. LER values of different intercropping patterns of bitter vetch and safflower affected by farming system.

	Intercropping patterns (bitter vetch:safflower)			
Year	2:2	3:2	4:2	5:2
2013	1.06	0.93	0.97	0.97
2014	1.21	1.14	1.09	1.02
Two years' average	1.13	1.03	1.03	0.99

3.4. Relative crowding coefficient (RCC)

The interspecific competitive abilities were determined by the relative crowding coefficient (K). Referring to the k values of all intercropping patterns, in 2013, 2:2, 2:3 and 2:4 intercropping patterns, K_s was always greater than K_v. But in the 5:2

Table 10. Aggressivity of safflower relative to bitter vetch (A_{sv}) for the different intercropping patterns for two years.

	Intercropping patterns (bitter vetch:safflower)			
Year	2:2	3:2	4:2	5:2
2013	0.51*	0.332*	0.295*	0.13*
2014	0.407*	0.425*	0.387*	0.175*
Two years' average	0.458*	0.392*	0.341*	0.152*

*Significantly different from 0 at $P \leq .05$.

Table 11. RCC of safflower (k_s) and bitter vetch (k_v) based on different intercropping patterns.

Year	K value	Intercropping patterns (bitter vetch: safflower) 2:2	3:2	4:2	5:2
2013	K_s	1.47	0.39	0.32	0.21
	K_v	0.071	0.115	0.18	0.26
2014	K_s	2.45	0.82	0.45	0.24
	K_v	0.107	0.15	0.207	0.28
Two years' average	K_s	1.96	0.6	0.38	0.23
	K_v	0.088	0.13	0.19	0.27

Note: K_s: *k* value of safflower, K_v: *k* value of bitter vetch.

sowing pattern, K_v was greater than K_s, thus bitter vetch was more competitive than safflower in the intercropping community (Table 11).

However, similar results were observed in our study, as indicated by the competitive indicators of aggressivity (A_{sv}), the crowding coefficient (K_s and K_v) and the competitive ratio (CR_{sv}). The average A_{sv} value over two years for each sowing pattern was positive, suggesting that safflower was the dominant species and had much great competitiveness in safflower/bitter vetch intercropping. Thus, safflower was able to acquire more resource than bitter vetch, and its yield influenced the total biomass of the intercropping system. Safflower with its superior ability to uptake nitrogen and with a more vigorous rooting system was able to make a more efficient use of the available resources which caused it to become the dominant crop in intercropping treatments.

Regardless of the first year and intercropping patterns, the RCC of safflower (k_s) was always higher than the corresponding k_v value of bitter vetch, except in the 5:2 pattern in both years that k_v was more than k_s. Thus, safflower had stronger competitive ability and acquired the growth resources more competitively than bitter vetch in the intercropping system. Safflower dominated and occupied a superior ecological niche in the intercropping system. The competitive ratio (CR) is considered a better measure of competitive ability of the crops compared with the RCC and aggressivity (Willey & Rao 1980; Wahla et al. 2009). Higher bitter vetch CR values in our study indicated that in different intercropping patterns, safflower was more competitive than bitter vetch.

3.5. Competitive ratio (CR) of safflower and bitter vetch intercropping

The competitive ratio of safflower (CR_{sv}) in different safflower/bitter vetch intercropping patterns always exceeded 1.0 in both years and thus were higher than the competitive ratios of bitter vetch relative to safflower during two years' period (CR_{vs} is the reciprocal of CR_{sv}, the value of CR_{vs} were not listed) (Table 12). Meanwhile, the average CR_{sv} value over two years was also higher than 1.0 for each intercropping configuration. In contrast, the average CR_{vs} values were less than 1, suggesting that safflower had greater competitive intensity relative to bitter vetch in safflower/bitter vetch combination (Table 12).

Our results suggest that safflower is the dominant crop in safflower/bitter vetch combination, at least under the current experimental settings, as indicated by the higher RCCs, competitive ratios and positive aggressivity. This reveals that safflower intercropped with bitter vetch utilized the resources more aggressively, and its production was the major factor that determined the overall yields. Other reports examining forage production also indicated that intercropping improves the stability of agricultural production and provides greater crop security as a whole (Skelton & Barrett 2005). Moreover, intercropping is a desirable land-use system to compensate the deficiency in currently available arable land (Abdel Magid et al. 1991).

Table 12. Competitive ratio of safflower (CR) and bitter vetch intercropping.

Year	CR value	Intercropping patterns (bitter vetch: safflower) 2:2	3:2	4:2	5:2
2013	CR_{sv}	1.71	1.46	1.36	1.15
2014	CR_{sv}	1.55	1.55	1.43	1.19
Two years' average	CR_{sv}	1.63	1.51	1.4	1.17

Note: CR_{sv}: Competitive ratio of safflower relative to bitter vetch.

4. Conclusion

In the first year (2013), only the 2:2 intercropping pattern had a biomass yield advantage based on the LER value above 1.0. In the subsequent year (2014), all safflower/bitter vetch intercropping patterns displayed yield advantages and higher land-use efficiency based on higher LER values. The biomass yields of mono-cultured safflower and all intercropping patterns increased in the second year. Safflower was the dominant crop and a superior competitor in the safflower/bitter vetch combination, and had higher aggressivity, RCCs and competitive ratios compared to bitter vetch. Thus, the higher annual increase in safflower yield resulted in the higher total biomass of safflower/bitter vetch associations compared to that of safflower and bitter vetch sole cropping. The average annual biomass yields of safflower decrease with the increasing land proportion occupied by bitter vetch in the intercropping system. Generally, in both years, the 2:2 intercropping pattern presented the most stable yield advantage.

Disclosure statement

No potential conflict of interest was reported by the authors.

ORCID

Azin Najafabadi http://orcid.org/0000-0003-3170-7458
Mohammad Reza Zardashti http://orcid.org/0000-0002-5947-5831

References

Abdel Magid HM, Ghoneim MF, Rabie RK, Sabrah RE. 1991. Productivity of wheat and alfalfa under intercropping. Exp Agric. 27:391–395.

Amini R, Shamayeli M, Dabbagh Mohammadi Nasab A. 2013. Assessment of yield and yield components of corn (*Zea mays* L.) under two and three strip intercropping systems. Int J Biosci. 3:65–69.

Arshad M, Ranamukhaarachchi SL. 2012. Effects of legume type, planting pattern and time of establishment on growth and yield of sweet sorghum-legume intercropping. Aus J Crop Sci. 6:1265–1274.

Belel MD, Halim RA, Rafii MY, Saud HM. 2014. Intercropping of corn with some selected legumes for improved forage production: a review. J Agri Sci. 6:48–62.

Bhatti IH, Ahmad R, Jabbar A, Nazir MS, Mahmood T. 2006. Competitive behavior of component crops in different sesame-legume intercropping systems. Int J Agric Biol. 8:165–167.

Connell JH. 1990. Apparent versus real competition in plants. In: Grace JB, Tilman D, editors. Perspectives on plant competition. London: Academic Press; p. 9–26.

Delmotte S, Tittonell P, Mouret JC, Hammonda R, Lopez-Ridauraa S. 2011. On farm assessment of rice yield variability and productivity

gaps between organic and conventional cropping systems under Mediterranean climate. Eur J Agron. 35:223–236.
De Wit CT. 1960. On competition. Verslagen Van Landbouwkundige Onderzoekingen. 66:1–82.
Fetene M. 2003. Intra-and inter-specific competition between seedlings of *Acacia etbaica* and a perennial grass (*Hyparrhenia hirta*). J Arid Environ. 55:441–451.
Grace JB. 1990. On the relationship between plant traits and competitive ability. In: Grace JB, Tilman D, editors. Perspective on plant competition. London: Academic Press; p. 51–65.
Haynes RJ. 1980. Competitive aspects of the grass-legume association. Adv Agron. 33:227–261.
Hildermann I, Thommen A, Dubois D, Boller T, Wiemken A, Mader P. 2009. Yield and baking quality of winter wheat cultivars in different farming systems of the DOK long-term trial. J Sci Food Agric. 89:2477–2491.
Hole DG, Perkins AJ, Wilson JD, Alexander IH, Grice PV, Evans AD. 2005. Does organic farming benefit biodiversity? Biol Cons. 122:113–130.
Horrigan L, Lawrence RS, Walker P. 2002. How sustainable agriculture can address the environmental and human health harms of industrial agriculture. Environ Health Perspect. 110:445–456.
Huňady I, Hochman M. 2014. Potential of legume-cereal intercropping for increasing yields and yield stability for self-sufficiency with animal fodder in organic farming. Czech J Genet Plant Breed. 50:185–194.
Inal A, Gunes A, Zhang F, Cakmak I. 2007. Peanut/maize intercropping induced changes in rhizosphere and nutrient concentrations in shoots. Plant Physiol Biochem. 45:350–356.
Javanmard A, Dabbagh Mohammadi Nasab A, Javanshir A, Moghaddam M, Janmohammadi H. 2009. Forage yield and quality in intercropping of maize with different legumes as double-cropped. J Food Agric Environ. 7:163–166.
Karanja SM, Kibe AM, Karogo PN, Mwangi M. 2014. Effects of intercrop population density and row orientation on growth and yields of sorghum-cowpea cropping systems in semi-arid Rongai, Kenya. J Agric Sci. 6:34–43.
Kazemeini A, Sadeghi H. 2012. Reaction of the green bean-safflower intercropping patterns to different nitrogen fertilizer levels. Iran Agric Res. 31:13–22.
Kohnaward P, Jalilian J, Pirzad A. 2012. Effect of foliar application of micro-nutrients on yield and yield components of safflower under conventional and ecological cropping systems. Int Res J Appl Basic Sci. 3:1460–1469.
Li H, Shen J, Zhang F, Marschner P, Cawthray G, Rengel Z. 2010. Phosphorus uptake and rhizosphere properties of intercropped and monocropped maize, faba bean, and white lupine in acidic soil. Biol Fertil Soils. 46:79–91.
Li L, Sun J, Zhang F, Li X, Yang S, Rengel Z. 2001. Wheat/maize or wheat/soybean strip intercropping: I. Yield advantage and interspecific interactions on nutrients. Field Crops Res. 71:123–137.
Manna MC, Ghosh PK, Acharya CL. 2003. Sustainable crop production through management of soil organic carbon in semiarid and tropical India. J Sustain Agric. 21:85–114.
Marschner H. 2002. Relationships between mineral nutrition and plant diseases and pests. In: Marschner H, editor. Mineral nutrition of higher plants. New York (NY): Elsevier Science; p. 436–460.
Matusso JMM, Mugwe JN, Mucheru-Muna M. 2014. Effects of different maize (*Zea mays* L.) – soybean (*Glycine max* (L.) Merill) intercropping patterns on yields, light interception and leaf area index in Embu West and Tigania East sub counties, Kenya. Academic Res J Agric Sci and Res. 2:6–21.
Mcgilchrist CA. 1965. Analysis of competition experiments. Biometrics. 21:975–985.
Nasri R, Kashani A, Barary M, Paknejad F, Vazan S. 2014. Nitrogen uptake and utilization efficiency and the productivity of wheat in double cropping system under different rates of nitrogen. Int J Biosci. 4:184–193.
Ozturk A, Caglar O, Sahin F. 2003. Yield response of wheat and barley to inoculation of plant growth promoting rhizobacteria at various levels of nitrogen fertilization. J Plant Nutr Soil Sci. 166:262–266.
Piano E, Annicchiarico P. 1995. Interference effects in grass varieties grown as pure stand, complex mixture and binary mixture with white clover. J Agron Crop Sci. 174:301–308.
Rahimi Darabad G, Aghighi Shahverdi Kandi M, Barmaki M, Seyed Sharifi R, Hokmalipour S, Asadi S. 2011. Evaluation of yield and yield components in potato-safflower intercropping. J Appl Sci Res. 5:1423–1428.
Rigby D, Cáceres D. 2001. Organic farming and the sustainability of agricultural systems. Agric Sys. 68:21–40.
Rohini VK, Sankara KR. 2000. Embryo transformation, a practical approach for realizing transgenic plants of safflower (*Carthamus tinctorius* L.). Ann Bot. 86:1043–1049.
Sachan SS, Uttam SK. 1992. Intercropping of mustard with gram under different planting systems on eroded soils. Indian J Agron. 37:68–70.
Sadeghi GH, Mohammadi L, Ibrahim SA, Gruber KJ. 2009. Use of bitter vetch (*Vicia ervilia*) as a feed ingredient for poultry: a review. Worlds Poult Sci J. 65:51–64.
Sadeghi H, Sasanfar I. 2012. Effect of different safflower (*Carthamus tinctorius* L.)–bean (*Phaseolus vulgaris* L.) intercropping patterns on growth and yield under weedy and weed-free conditions. Arch Agron Soil Sci. 56:756–777.
Sarkar RK, Shit D, Maitra S. 2000. Competition function, productivity and economics of chickpea (*Cicer arietinum*)-based intercropping systems under rainfed conditions of Bihar plateau. Indian J Agron. 45:681–688.
SAS Institute. 2003. The SAS system for windows. Release 9.1. Cary (NC): SAS Inst.
Seufert V, Ramankutty N, Foley JA. 2012. Comparing the yields of organic and conventional agriculture. Nature. 485:229–232.
Singh Rajesh K, Kumar H, Singh Amitesh K. 2010. Brassica based intercropping systems – a review. Agri Review. 31:253–266.
Skelton LE, Barrett GW. 2005. A comparison of conventional and alternative agro ecosystems using alfalfa (*Medicago sativa*) and winter wheat (*Triticum aestivum*). Renew Agric Food Syst. 20:38–47.
Strydhorst SM, King JR, Lopetinsky KJ, Harker KN. 2008. Forage potential of intercropping barley with faba bean, lupin, or field pea. Agron J. 100:182–190.
Uhart SA, Andrade FH. 1995. Nitrogen deficiency in maize: II. Carbon nitrogen interaction effects on kernel number and grain yield. Crop Sci. 35:1384–1389.
Vandermeer JH. 2011. The ecology of agroecosystems. Burlington (MA): Jones and Bartlett Learning. 392 pp.
Wahla IH, Ahmad R, Ehsanullah A, Ahmad A, Jabbar A. 2009. Competitive functions of components crop in some barley based intercropping systems. Int J Agric Biol. 11:69–72.
Wienhold BJ, Halvorson AD. 1999. Nitrogen mineralization responses to cropping, tillage, and nitrogen rate in the northern great plains. Soil Sci Soc Am J. 63:192–196.
Willey RW, Rao MR. 1980. A competitive ratio for quantifying competition between intercrops. Exp Agric. 16:117–125.
Zafaranieh M. 2015. Effect of various combinations of safflower and chickpea intercropping on yield and yield components of safflower. Agric Sci Dev. 4:31–34.
Zhang G, Yang Z, Dong S. 2011. Interspecific competitiveness affects the total biomass yield in an alfalfa and corn intercropping system. Field Crops Res. 124:66–73.
Zhang L, Van Der Werf W, Zhang S, Li B, Spiertz JHJ. 2007. Growth, yield and quality of wheat and cotton in relay strip intercropping systems. Field Crops Res. 103:178–188.