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RESEARCH ARTICLE



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

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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.

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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 (Horriggan 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).

Zafarani (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

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 bitter 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 m² for the four respective patterns and 10 and 15 m² 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. Bitter vetch planting dates were 12 May 2013 and 13 May 2014.

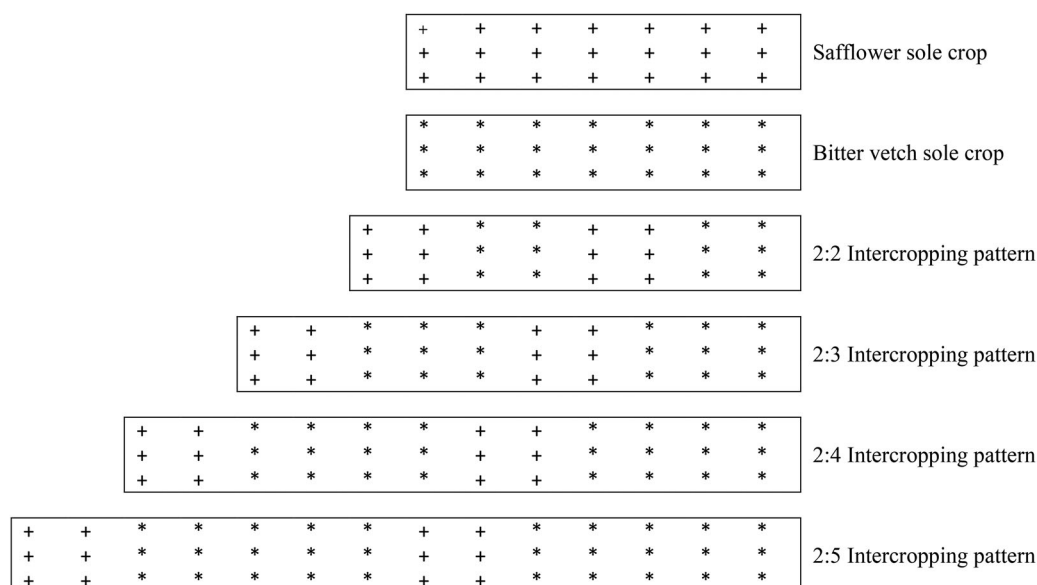


Figure 1. Schematic diagram of different intercropping patterns between safflower (+) and bitter vetch (*).

Table 2. Inputs for farming systems.

| Inputs | Farming systems | |
|---|------------------|---------|
| | 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 (<i>A. lipoferum</i> and <i>A. chroococcum</i>) (L/ha) | – | 1 |
| Biophosphat (<i>B. lentus</i> and <i>P. putida</i>) (kg/ha) | – | 1 |
| Metasystox as pesticides (L/ha) | 2–2 ^a | – |
| Gallant Super as herbicide (L/ha) | 3–2 ^a | Weeding |

^aThe 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):

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

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):

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

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.

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

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 |

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.

| Source of variation | df | Bitter vetch | | | | | Safflower | | | | | | |
|----------------------------|----|----------------------|-------------------------|--------------------|------------|---------------|---------------------|-----------------------|--------------------------|------------------|------------|---------------|---------------|
| | | 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).

^aPatterns 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.

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; Huñady & Hochman 2014; Zafarani 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; Zafarani 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 inter-specific 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 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.

^aPatterns mean bitter vetch and safflower row ratios (bitter vetch:safflower).

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

| Year | Farming system | Intercropping patterns ^a | Bitter vetch | | | Safflower | | | | Total seed yield (t/ha) | Total biomass yield (t/ha) |
|------|----------------|-------------------------------------|-------------------------|-------------------|----------------------|----------------------|-------------------|----------------------|-------------------|-------------------------|----------------------------|
| | | | 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 (%) | | |
| 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.

^aPatterns 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).

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

| Year | Intercropping patterns (bitter vetch:safflower) | | | |
|--------------------|---|------|------|------|
| | 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 |

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

| Year | Intercropping patterns (bitter vetch:safflower) | | | |
|--------------------|---|--------|--------|--------|
| | 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

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.

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).

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.

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