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Evaluation of land productivity, competition and insect diversity in different intercropping patterns of sunflower (*Helianthus annuus* L.) and soybean (*Glycine max* L.) under low-input condition

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ABSTRACT- Intercropping is a sustainable practice to achieve higher production with the aim to limit external inputs. A field experiment was conducted at the research farm of the Faculty of Agriculture, University of Maragheh, Maragheh, Iran, during 2016 growing seasons with ten treatments to evaluate the yield, analyze the competition and insect's assemblages in sunflower (as main plant)/soybean (as companion plant) intercropping. Treatments included sunflower sole cropping, soybean sole cropping, replacing intercropping sunflower with soybean (50:50, 34:66, 66:34, 40:60, 60:40, 25:75) and additive intercropping of two plants (100:50 and 100:100%). Results showed that the highest sunflower grain yield (275 g m^{-2}) was obtained in sunflower monoculture that was not significantly different with intercropping ratios of 25:75 and 60:40. Also, the highest and lowest grain yield of soybean was achieved in soybean monoculture (130.1 g m^{-2}) and ratio of 100:50 (48.5 g m^{-2}), respectively. The highest land equivalent ratio, monetary advantage index and intercropping advantage value was obtained in intercropping ratio of 25:75. Moreover, in all cropping patterns the aggressivity (A) and crowding ratio (CR) values of sunflower were higher than soybean, indicating that sunflower was the dominant species. Also, the highest density for herbivores was recorded in soybean monoculture and the families of Thripidae (37.60- 43.87%) and Cicadellidae (34.01-37.71%) had the most relative density. Furthermore, intercropping of sunflower with soybean increased pollinators and natural enemies' abundance compared with monocultures. Overall, based on the ecological, agronomical and economical indices intercropping sunflower with soybean with ratio of 25:75 is a feasible alternative method to achieve similar production with respect to monocropping.

INTRODUCTION

Conventional agricultural systems are based on cultivation and productivity using monoculture systems (De La Fuente et al., 2014). Most of these systems are vulnerable due to using genetically similar plants and reducing biodiversity (Malézieux et al., 2009). In addition, excessive application of chemical inputs (e.g. fertilizers, insecticides and pesticides) in these systems causes serious problems such as chemical pollutions, intensifying soil erosion, destruction of natural resources, disruption of the natural enemies, increasing weeds and pest's damages and economic yield instability (Kassam and Brammer, 2013; Gomiero et al., 2011).

Intercropping system is one of the sustainable agricultural methods defined as growing two or more plants simultaneously, which provides interconnections between plants and leads to using more resources efficiently of nutrient, water and land, improving plant production and decreasing damages of weeds, pests and plant diseases (Amani Machiani et al., 2018b; Monti et al., 2016). This cropping system assists in enhancing the crop productivity of land, provides good land cover to protect soil from water and wind erosion, improves soil organic matter and soil fertility through nitrogen fixation and increases employment opportunities (Hauggaard-Nielsen et al., 2009; Chapagain and Riseman, 2014). Most of the intercropping systems produce higher yield compared with their monoculture components due to more resource efficiency of nutrients, water and land (Nassiri Mahallati et al., 2015:

Singh et al., 2015). Results of some studies demonstrated that intercropping systems suppress weed growth and decrease pest and insect populations compared with monocultures due to the increasing diversity of natural enemies (Jones et al., 2005; Parolin et al., 2012; Hurej et al., 2013). Among different intercropping systems, intercropping legumes with other plants species has shown a significant potential for higher performance, explained by higher use efficiency of solar radiation, nutrients, water, and improved nitrogen transfer from legume to companion crops (Amani Machiani et al., 2018b).

Soybean (*Glycine max* L. Merrill) is an annual legume crop which belongs to Leguminosae family. Soybean has the maximum global production among the oilseed crops sharing 53% followed by rapeseed mustard (*Brassica napus* L.) sharing 15% and cotton seed (*Gossypium hisutum* L.) sharing 10% of oilseed production (Pratap, 2012). It is one of the most important sources of protein production (25-45%) and is a staple crop in the diets of people and animals in numerous parts of the world (Pratap, 2012). On average, the amount of nitrogen fixation by soybean is estimated to be 65-115 kg/ha during the growing season (Herridge et al., 1990) and is therefore less dependent on synthetic nitrogen fertilizers.

Sunflower (*Helianthus annuus* L.) is an annual oil-yielding crop belonging to Asteraceae (Compositae) family. Sunflower world production was 44.7 million tons and oil production of this amount reached 21 million tons in 2014 (FAO, 2014). Sunflower seed oil is the fifth in production among edible vegetable oils in the world. The productivity of sunflower seeds is not only controlled by many genes but also affected highly by environmental conditions (Vega et al, 2001). Results of studies exhibited that intercropping sunflower with nitrogen fixation legumes could improve crop productivity (De La Fuente et al., 2014). De La Fuente et al. (2014) concluded that intercropping sunflower with soybean produced more grain yield per unit area compared with plants monoculture and land equivalent ratio (LER) value in all intercropping patterns. Additionally, sunflower is known as insectary plant that attracts and maintains natural enemies and beneficial insects such as pollinators and parasitoids (with its nectar and pollen resources) which contribute to biological control of pests (Parolin et al., 2012; Brennan, 2013). Thus, using insectary plants such as sunflower, alfalfa (*Medicago sativa* L.), white clover (*Trifolium repens* L.) and etc. in intercropping systems is one of the best ways to control the pests in sustainable agricultural systems.

The growth and productivity of plants in intercropping were affected by competition between plants (Lithourgidis et al., 2011). Higher performance in intercropping systems was achieved when interspecific competition between intercropping components was lower than intraspecific competition (Willey, 1990). For this purpose, some ecological indices including land equivalent ratio and standard equivalent ratio (Ofori and Stern, 1987), competitive indices including aggressivity, relative crowding coefficient, competitive ratio and actual yield loss (Willey, 1979; Dhima et al., 2007) and economic indices including monetary advantage, relative value total, intercropping advantage and system productivity index (Ghosh, 2004) have been developed to describe advantages or disadvantages of intercropping compared with sole cropping systems.

The objectives of this study were: (i) evaluation of the grain yield of sunflower (as the main plant) and soybean (as the companion plant) in different intercropping patterns compared with monocultures, (ii) evaluation of ecological and monetary indices in these cropping patterns, (iii) evaluation of insect assemblages and their diversities in intercropping systems compared with monocultures.

MATERIALS AND METHODS

Site Description

A field experiment was conducted at the research farm of the Faculty of Agriculture, University of Maragheh, Maragheh, Iran (longitude 46°16' E, latitude 37°23' N, altitude 1485 m) in 2016 growing seasons (June–September). The soil texture of the experimental site was a silty clay with pH of 7.51. The soil contained 0.63% organic carbon, 0.09% total N, 21.4 mg kg^{-1} available P, 503 mg kg^{-1} available K and 5.43 mg kg^{-1} available Fe (depth of 0-30 cm). Meteorological data of experimental area including monthly average temperature and monthly total rainfall during long term averages (10 years) are shown in Fig. 1.

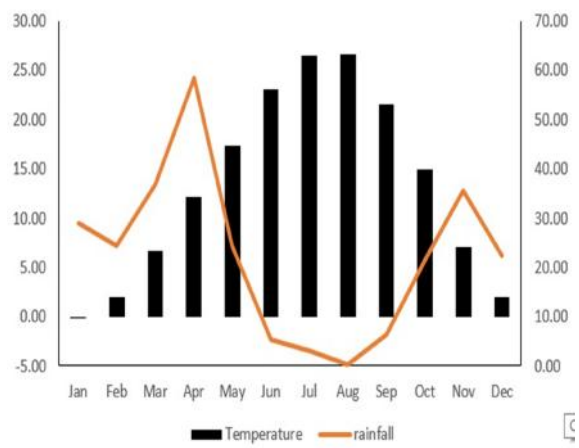

Fig. 1. Long term averages (10 years) of monthly precipitation and temperature in Maragheh, Iran.

Treatments

The experiment was conducted based on a randomized complete block design (RCBD) with ten treatments and three replications. Treatments included soybean monoculture (G_s), sunflower monoculture (H_s), different ratios of replacement intercropping (50:50, 34:66, 66:34, 40:60, 60:40 and 25:75%) (sunflower: soybean) and different ratios of additive intercropping (100:50 and 100:100).

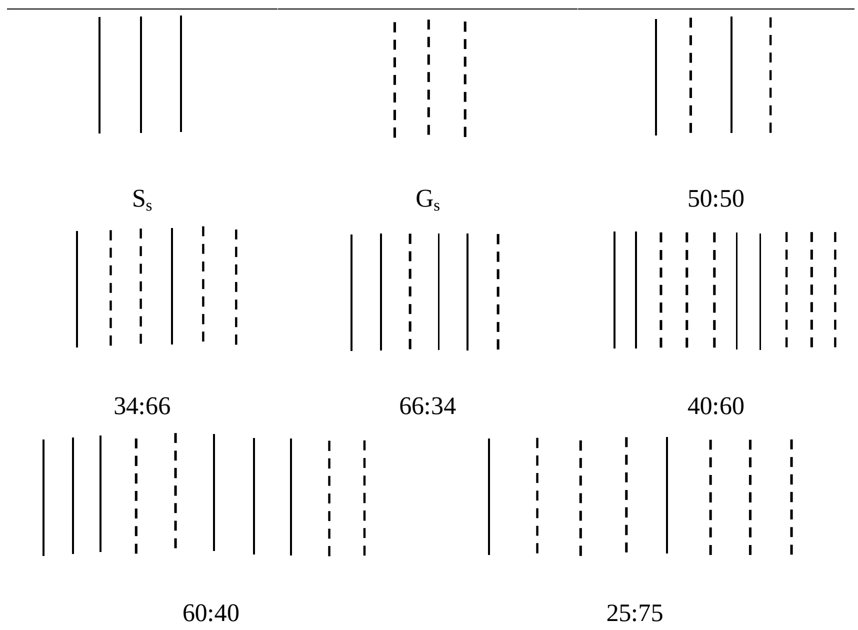

Fig. 2. Layout of sunflower/soybean intercropped patterns.
G_S (Soybean monoculture); S_S (sunflower monoculture); Ratios (Sunflower: soybean); ---------------- showing Sunflower rows and ……..…… Showing soybean rows.

The number of rows for Gs, Hs, 50:50, 34:66, 66:34, 40:60, 60:40, 25:75, 100:50 and 100:100 cropping patterns were 4, 4, 5, 6, 6, 10, 10, 8, 4 and 4, respectively. The length of each row was 4 m and the distance between rows was considered 50 cm. The plots were separated from each other with a distance of 50 cm width. Treatment planting patterns are presented in Fig. 2. The optimum density of soybean and sunflower was considered to be 38.5 and 7.4 plants m^{-2}, respectively. In addition, 20 kg ha^{-1} Urea (46% N) was added to the soil as a starter fertilizer in planting times. Also, before sowing 100 kg ha^{-1} triple superphosphate (TSP) was applied to soil. To conduct the trial at low-input conditions and to display the impact of intercropping patterns, no additive chemical input (chemical fertilizer, pesticides and herbicides) was applied to the treatments during field preparation and growth period. Soybean seeds were planted immediately after inoculation with commercial rhizobia (*Rhizobium japonicum*) on the15th of May in 2016.

Measurements

Grain yield of soybean and sunflower in different intercropping patterns and monocultures were measured at crop maturity. Sunflower and soybean were harvested on the 5th and 27th of October, respectively. Grain yield of soybean and sunflower was measured at 12% ±1 and 10% ±1 moisture content respectively, and expressed in g m^{-2} unit (Abbasi Surki et al., 2012).

In order to evaluate the effect of interaction between intercropping species, agronomical indices (including LER, LER_s and EY_i) were used. To determine the land use efficiency in intercropping systems compared to monoculture, the land equivalent ratio (LER) and standard land equivalent ratio (LER_s) indices were applied using the following equations adapted from Ofori and Stern (1987):

$$LER = LER_g + LER_h$$

$$LER_g = \frac{Y_{gi}}{Y_{gm}} \quad (1)$$

$$LER_h = \frac{Y_{hi}}{Y_{hm}}$$

where LER_g and LER_h were land equivalent ratio of soybean and sunflower in different intercropping patterns, respectively; Y_{gm} and Y_{hm} were the yields of soybean and sunflower (per unit of area) in monoculture and Y_{gi} and Y_{hi} were the yields of soybean and sunflower in intercropping patterns, respectively.

$$LERS = LERS_g + LERS_h$$

$$LERS_g = \frac{Y_{gi}}{Y_{gm\,max.}} \quad (2)$$

$$LERS_h = \frac{Y_{hi}}{Y_{hm\,max.}}$$

In this index, the yields of plants in intercropping patterns were divided to maximum yield in monoculture. $LERS_g$ and $LERS_h$ were standard land equivalent ratio of soybean and sunflower, respectively, and $Y_{gm\ max}$ and $Y_{hm\ max}$ were the maximum yields achieved in soybean and sunflower monoculture, respectively.

In this study, sunflower was considered as the main plant and soybean as an intercrop component. Then, the yield of soybean from each treatment was converted to sunflower equivalent yield in intercropped patterns as follows (Agegnehu et al., 2006):

$$EY_{gi} = Y_{gi} \times \frac{P_1}{P_2}$$

$$EY_i = Y_{hi} + EY_{gi} \qquad (3)$$

where EY_{gi} was sunflower equivalent yield of soybean (g m^{-2}), Y_{gi} was the yield of soybean in intercropping patterns, P_1 was the price of soybean (US$ 0.45 kg^{-1}), P_2 was the price of sunflower (US$ 0.37 kg^{-1}), Y_{hi} was sunflower grain yield (g m^{-2}) and EY_i was sunflower equivalent yield in different intercropped patterns.

To evaluate competitive indices, the aggressivity (A) and crowding coefficient (K) values, suggested by Willey, (1979), were used as:

$$K = K_g + K_h$$

$$K_g = \frac{Y_{gi} \times Z_{hi}}{(Y_{gm} - Y_{gi}) \times Z_{gi}} \qquad (4)$$

$$K_h = \frac{Y_{hi} \times Zgi}{(Y_{hm} - Y_{hi}) \times Z_{hi}}$$

$$A_g = \left(\frac{Y_{gi}}{Y_{gm} \times Z_{gi}}\right) - \left(\frac{Y_{hi}}{Y_{hm} \times Z_{hi}}\right)$$

$$A_h = \left(\frac{Y_{hi}}{Y_{hm} \times Z_{hi}}\right) - \left(\frac{Y_{gi}}{Y_{gm} \times Z_{gi}}\right) \qquad (5)$$

where K_g was crowding coefficient of soybean, K_h was crowding coefficient of sunflower, A_g was aggressivity of soybean, A_h was aggressivity of sunflower, Z_{gi} was the sown proportion of soybean in intercropping patterns and Z_{hi} was the sown proportion of sunflower in different intercropped patterns.

Crowding ratio (CR) represented competitive ability of intercropping components and indicated the ratio of individual LER of intercrop component in which they were initially sown proportion. The CR index was calculated by the following equation (Dhima et al., 2007):

$$CR_g = \left(\frac{LER_g}{LER_h}\right) \times \left(\frac{Z_{hi}}{Z_{gi}}\right)$$

$$CR_h = \left(\frac{LER_h}{LER_g}\right) \times \left(\frac{Z_{gi}}{Z_{hi}}\right) \qquad (6)$$

Where CR_g was the crowding ratio of soybean and CR_h was the crowding ratio of sunflower.
The AYL index was calculated as:

$$AYL = AYL_g + AYL_h$$

$$AYL_g = \left[\frac{Y_{gi} / Z_{gi}}{Y_{gm} / Z_{gm}}\right] - 1 \qquad (7)$$

$$AYL_h = \left[\frac{Y_{hi} / Z_{hi}}{Y_{hm} / Z_{hm}}\right] - 1$$

where AYL_g, and AYL_h were the soybean and sunflower actual yield loss, respectively. Z_{gm} and Z_{hi} were the sown proportion of soybean and sunflower, respectively. The positive or negative values of AYL indicated an advantage or disadvantage of intercropping patterns when the main purpose was to compare yield on a per plant basis.

The economic indices such as monetary advantages index (MAI) and intercropping advantages (IA) were calculated according to the following formula (Ghosh, 2004): In order to economically evaluate different cropping patterns, relative value total (RVT), monetary advantages index (MAI) and also intercropping advantages (IA) were used which were calculated by the following formula (Ghosh 2004):

$$MAI = \left[(Y_{gi} \times P_g) + (Y_{hi} \times P_h)\right] \times \left[\frac{LER - 1}{LER}\right] \qquad (8)$$

$$IA = IA_g + IA_h$$

$$IA_g = AYL_g \times P_g \qquad (9)$$

$$IA_h = AYL_h \times P_h$$

$$RVT = \frac{(Y_{gi} \times P_g) + (Y_{hi} \times P_h)}{Y_h P_h} \qquad (10)$$

if $Y_h P_h > Y_g P_g$

where IA_g and IA_h were intercropping advantage of soybean and sunflower, respectively. P_g and P_h were the commercial value of soybean and sunflower, respectively.

The system productivity index (SPI) presented by Odo (1991), standardized the productivity of companion crop in terms of the primary crop which was calculated by the following formula:

$$SPI = \left(\frac{Y_{hm}}{Y_{gm}} \right) Y_{gi} + Y_{hi} \qquad (11)$$

Insect Assemblages

In order to analyze insect's assemblages in different cropping patterns, 6 yellow sticky cards were used at the first flowering stage of sunflower and soybean in three different heights (40, 80 and 120 cm). The cards had a grid system to make counting easier. After two months, the cards were transferred to the laboratory of plant protection in the University of Maragheh in order to identify the insect's family, species and calculate their relative. Each insect species was classified into herbivores and non-herbivores based on anatomical characteristics and bibliography (De La Fuente et al., 2014). The Shannon index was used to determine insect diversity in different cropping patterns as follows (Gliessman and Engles, 1999):

$$H = -\Sigma ni/N \times Lnni/N \qquad (12)$$

where ni was the number of species, N was the total numbers of insect populations in each cropping pattern and H was the Shannon index value.

Statistical Analysis

All data obtained were subjected to ANOVA using SAS software (version 9.1) and significant differences were compared with the LSD test at $P < 0.05$.

RESULTS AND DISCUSSION

Grain Yield

Grain yield of sunflower and soybean are presented in Table 1. Results demonstrated that, grain yields of sunflower and soybean were affected significantly by different cropping patterns. In sunflower, the highest (275 g m^{-2}) grain yield was obtained in sunflower monoculture (H_s) which was not significantly different with ratios of 25:75 and 60:40, while the lowest grain yield was observed in ratios of 100:100, 100:50, 50:50 and 34:66, respectively (Table 1). In addition, the highest (130.1 g m^{-2}) and lowest (48.57 g m^{-2}) soybean grain yields were achieved in soybean monoculture and intercropping pattern with ratio of 100:50, respectively.

Table 1. Means of sunflower and soybean grain yield in different cropping patterns

Treatments	Sunflower grain yield (g m^{-2})	Soybean grain yield (g m^{-2})
Sunflower monoculture (H_s)	275.0^{a}	-
Soybean monoculture (G_s)	-	130.1^{a}
100:50	209.7^{cd}	48.57^{e}
100:100	203.7^{d}	56.80^{d}
50:50	212.3^{cd}	57.10^{d}
34:66	214.5^{cd}	69.63^{c}
66:34	232.7^{bc}	54.10^{de}
25:75	259.6^{ab}	94.57^{b}
40:60	243.1^{b}	75.27^{c}
60:40	248.4^{ab}	75.87^{c}
SEM(±)	18.95	0.32
$LSD_{0.05}$	28.50	8.207

Different letters indicate significant differences at $P \leq 0.05$ values between treatments. 100:50, 100:100, 50:50, 34:66, 66:34, 40:60, 60:40 and 25:75 indicate the ratios of sunflower and soybean in cropping patterns.

Land Equivalent Ratio (LER), Standard Land Equivalent Ratio (LER_S), Total Land Output (TLO) and Sunflower Equivalent Yield (Ey_i)

In all intercropping patterns, the calculated LER and standard LER values were more than one. The highest LER and TLO values were recorded in ratios of 25:75, 60:40 and 40:60 cropping patterns, respectively (Table 2). Also, the lowest LER and TLO values were achieved in 100:50 and 100:100 additive intercropping patterns. According to Table 2, the highest and lowest sunflower equivalent yields (EY_i) were obtained in ratios of 25:75 and 100:50, respectively.

Competition Indices

In sunflower-soybean intercroppings, sunflower had positive A_h, indicating that sunflower was the dominant species (Table 3). Results of K values were converted to A values so that the highest and lowest K values were achieved in one row of sunflower and three rows of soybean planting pattern (25:75) and ratio of 100:50 intercropping patterns, respectively (Table 3). The CR values for sunflower was much higher than one in most treatments. Also, in all cropping patterns, the values of CR in sunflower (CR_h) were higher than soybean (CR_g). Furthermore, the highest and lowest CR values in sunflower were recorded in ratios of 25:75 (CR= 3.9) and 66:34 and 60:40 (CR= 1), respectively.

Also, the intercropping ratios of 66:34 and 25:75 had the highest and lowest CR soybean values, respectively.In addition, sunflower AYL values (AYL_h) were positive (with the exception of 100:50 and 100:100 treatments) and also higher than those of the soybean. Moreover, the highest (2.54) and lowest (-0.92) AYL was recorded in ratios of 25:75 and 100:100 intercropping patterns, respectively (Table 3).

Monetary Indices

According to Table 4, total IA values in all cropping patterns except for the ratios of 100:50 and 100:100 were positive. The highest values of IA were achieved in ratios of 25:75, 40:60 and 34:66, with IA values of 0.92, 0.35 and 0.34, respectively (Table 4). Also, the highest (55.65) and lowest (11.86) MAI values were observed in one row of sunflower with three rows of soybean (25:75) and additive intercropping patterns with ratio of 100:500 (Table 4). In addition, the highest and lowest system productivity index (SPI) and relative value total (RVT) values were recorded in ratios of 25:75 and 100:50, respectively (Table 4).

Effect on Insect Assemblages

According to Table 5, 13 insect species were identified in different cropping patterns. In all treatments, the herbivores population density was the highest in soybean monoculture while the density of non-herbivores was the highest in cropping patterns with ratios of 100:50 and 100:100 (Table 5). Among herbivore insect species, the insets of Thripidae (37.60-43.87%) and Cicadellidae (34.01- 37.71 %) families were the most abundant. According to the Shannon index values presented in Fig. 3, the highest and lowest Shannon index values were recorded in ratios of 100:100 (H= 1.53) and 50:50 (H= 1.33), respectively (Fig. 3).

Table 2. Mean of land equivalent ratio (LER), standard LER (LERs), Total land output (TLO) and sunflower equivalent yield (EYi).

Treatment combinations	LER_h	LER_g	LER total	$LERS_h$	$LERS_g$	LER_S total	TLO	EY_i
100:50	0.76	0.37	1.13	0.72	0.36	1.08	258.3	268.7
100:100	0.74	0.44	1.18	0.70	0.42	1.12	260.5	272.8
50:50	0.77	0.44	1.21	0.73	0.42	1.15	269.4	281.7
34:66	0.78	0.54	1.32	0.74	0.51	1.25	284.1	299.1
66:34	0.85	0.42	1.27	0.80	0.40	1.20	286.8	298.4
25:75	0.94	0.73	1.67	0.89	0.69	1.58	354.2	374.6
40:60	0.88	0.58	1.46	0.84	0.55	1.39	318.4	334.6
60:40	0.90	0.58	1.48	0.85	0.56	1.41	324.3	340.7
Average	0.83	0.51	1.34	0.78	0.49	1.27	294.5	308.8

100:50, 100:100, 50:50, 34:66, 66:34, 40:60, 60:40 and 25:75 indicate the ratios of sunflower and soybean in cropping patterns

Table 3. The competition indices (A, CR, K and AYL) values in different intercropping patterns

Planting ratio	Aggressivity		Crowding ratio		Crowding coefficient			Actual yield loss		
	A_h	A_g	Ca_{ry}	CR_g	K_h	K_g	K_{total}	AYL_h	AYL_g	AYL_{total}
100:50	0.02	-0.02	1.02	0.97	1.61	1.19	1.91	-0.24	-0.42	-0.65
100:100	0.30	-0.30	1.7	0.59	2.86	0.78	2.22	-0.26	-0.66	-0.92
50:50	0.67	-0.67	1.8	0.57	3.39	0.78	2.65	0.54	-0.31	0.23
34:66	1.55	-1.55	2.9	0.34	7.09	0.58	4.08	1.37	-0.36	1.01
66:34	0.02	-0.02	1	0.98	2.75	1.42	3.91	0.28	-0.01	0.27
25:75	2.91	-2.91	3.9	0.26	50.57	0.89	44.85	2.78	-0.24	2.54
40:60	1.35	-1.35	2.3	0.44	11.43	0.92	10.46	1.21	-0.24	0.97
60:40	0.21	-0.21	1	0.97	6.22	2.10	13.06	0.51	0.14	0.65
Average	0.9	-0.9	2	0.6	10.7	1.1	10.4	0.8	-0.3	0.5

100:50, 100:100, 50:50, 34:66, 66:34, 40:60, 60:40 and 25:75 indicate the ratios of sunflower and soybean in cropping patterns

Table 4. Intercropping advantage (IA), Monetary advantages index (MAI), Relative value total (RVT) and system productivity index (SPI) values in different intercropping patterns.

Treatment combinations	Intercropping advantage					
	IA_h	IA_g	IA_{total}	MAI	SPI	RVT
100:50	-0.09	-0.19	-0.27	11.86	312.2	0.94
100:100	-0.10	-0.30	-0.39	15.22	323.8	0.96
50:50	0.20	-0.14	0.06	18.16	332.9	0.99
34:66	0.50	-0.16	0.34	26.53	361.7	1.05
66:34	0.10	-0.01	0.10	22.92	346.9	1.05
25:75	1.03	-0.11	0.92	55.65	459.4	1.31
40:60	0.46	-0.11	0.35	39.16	402.2	1.17
60:40	0.19	0.06	0.25	41.26	408.8	1.20
Average	0.29	-0.12	0.17	28.85	368.5	1.08

100:50, 100:100, 50:50, 34:66, 66:34, 40:60, 60:40 and 25:75 indicate the ratios of sunflower and soybean in cropping patterns

Table 5. Density of Arthropoda collected in different cropping patterns

Number of species	Family	Cropping patterns									
		Sunflower monoculture	Soybean monoculture	100:50	100:100	50:50	34:66	66:34	25:75	40:60	60:40
	Herbivores										
1	Thripidae	42.34	43.87	40.47	37.60	40.03	40.38	38.81	40.13	38.08	37.62
1	Phlaeothripidae	2.21	2.46	1.84	1.48	1.76	1.70	1.72	1.85	1.69	1.76
1	Aleyrodidae	12.25	12.62	12.50	12.99	12.28	11.89	11.88	11.75	11.77	12.42
1	Aphidoidae	0.92	1.25	0.90	0.34	0.86	0.81	1.20	0.94	1.18	1.09
3	Cicadellidae	38.74	42.56	34.87	36.51	39.39	39.04	39.38	39.01	41.19	40.97
	Non-herbivores										
1	Aeolothripidae	2.28	1.90	4.94	5.37	2.86	2.71	3.18	3.16	2.47	2.45
1	Araneae	0.26	0.00	0.54	1.29	0.06	0.05	0.06	0.14	0.41	0.04
4	Hymenoptera	1.66	0.14	4.95	5.52	3.40	3.76	4.16	3.74	3.36	1.01

100:50, 100:100, 50:50, 34:66, 66:34, 40:60, 60:40 and 25:75 indicate the ratios of sunflower and soybean in cropping patterns

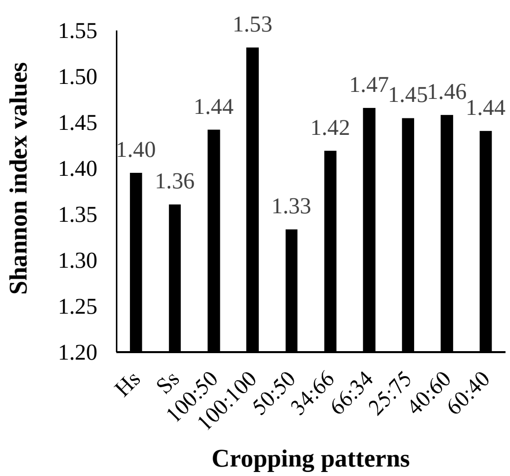

Fig. 3. Shannon index values in different cropping patterns. 100:50, 100:100, 50:50, 34:66, 66:34, 40:60, 60:40 and 25:75 indicate the ratios of sunflower and soybean in cropping patterns.

Grain Yield

Based on the results of this research, the highest grain yield in sunflower and soybean was obtained in monoculture of each tested plant. However, in sunflower, there were no significant differences between sunflower monoculture and ratios of 25:75 and 60:40. Higher production in monoculture of sunflower and soybean may be due to the homogeneous environment under sole crop systems (Amani Machiani et al., 2018b; Xu et al., 2008). These results are in agreement with those previously reported by Neugschwandtner and Kaul, (2015). They reported that the grain yields of pea (*Pisum sativum* L.) intercropping with oat (*Avena sativa* L.) declined 90% in a 50:50 replacement cropping pattern compared with oat monoculture. In contrast, De La Fuente et al. (2014) concluded that intercropping sunflower and soybean produced more grain yield per unit area compared with each plant monoculture due to resource use complementarity in time and space between different plants in intercropping systems. Furthermore, it was shown in this study that the average of soybean grain yield (66.48 g m^{-2}) in intercropping patterns reduced by 48.9% compared with soybean monoculture. Decline in soybean grain yield in intercropping patterns may be due to sunflower height and shading on soybean and restricting the amount of resources available (De La Fuente et al., 2014).

Land Equivalent Ratio (LER), Standard LER, Equivalent Yield (Ey_i) and Total Land Output (TLO)

Plant yield advantages in intercropping systems compared with monoculture systems were estimated by land equivalent ratio (LER) index that compares the yields obtained in intercropping plants with the same crop yields in sole crop (Chapagain and Riseman, 2014; Lithourgidis et al., 2011). LER index represents the efficiency of intercropping systems in using the environmental resources compared with monoculture systems (Nassiri Mahallati et al., 2015). When the LER value is higher than one, it indicates the advantage of intercropping compared with monocropping (Dhima et al., 2007; Agegnehu et al., 2006). The average LER (1.34) and LER_S (1.27) represent that 34 and 27% more area would be required in sole cropping to achieve equal productivity in intercropping (Midya et al., 2005). The results of equivalent yield (EY_i) and total land output (TLO) were conformed to those LER. Alike, the highest and lowest EY_i and TLO was achieved in 25:75 and 100:50 cropping patterns, respectively. The higher LER and TLO values in intercropping patterns may be due to using more resources efficiency such as nutrients, water, land, solar radiation and atmospheric CO_2, decreased weeds, pests and diseases damage (Kassam and Brammer, 2013; Nassiri Mahallati et al., 2015). Duchene et al. (2017) concluded that yield improvement in intercropping cereal with legume was achieved by increasing temporal, spatial and chemical complementary. Likewise, Chapgain and Riseman, (2014) concluded that the LER and TLO values in barley and pea intercropping were more than sole cropping due to increasing nitrogen availability in intercropping systems and improving the physical, chemical and biological soil properties.

Competition Indices

In order to determine the competitive relationship between two crops in intercropping systems, aggressivity (A), Crowding ratio (CR), crowding coefficient (K) and actual yield loss (AYL) indices were used. Aggressivity was used to express how much the relative increase in one crop's yield is greater than that of the second crop (Agegnehu et al., 2006). Based on the results of this research, sunflower was the dominant in sunflower/soybean intercropping. Results of K values were conformed to A values so that in all treatments, soybean had a lower partial K than sunflower.

The CR values for sunflower was much higher than one in most treatments, indicating an absolute yield advantage of sunflower over the soybean in the intercropping patterns. The higher CR values in sunflower in comparison with soybean was due to higher A of sunflower relative to soybean in mixtures. The results of crowding ratio index were also in line with those of the aggressivity index.

In particular, sunflower AYL values (AYL_h) were positive and also higher than the soybean AYL values (AYL_g), which confirmed the results of A, K and CR values indicating that sunflower was more resistant to yield loss than soybean in intercropping patterns. Also, the total AYL value was more than one in ratios of 25:75 and 34:66 cropping patterns indicating an advantage of intercropping over monoculture. Similar results have been reported by Dhima et al. (2007) in common vetch-cereal intercropping.

Monetary Indices

The intercropping advantage (IA), monetary advantages index (MAI) and relative value total (RVT) represent the economic advantage values in intercropping systems. The positive and higher IA and MAI values seemed more profitable in the intercropping patterns compared with monocultures (Ghosh, 2004). Based on the results of this research, in most intercropping patterns (except for additive intercropping patterns) the IA values were positive, indicating that these patterns had an economic advantage over monocropping. In addition, the MAI values were positive in all treatments. The higher MAI values in different ratios of intercropping patterns was due to the LER and K values in these patterns. Similarly, Dhima et al. (2007) found that when LER and K were high, there was also significant economic benefit expressed with higher MAI values.

The relative value total (RVT) values were more than one in ratios of 34:66, 66:34, 25:75, 40:60 and 60:40 cropping patterns indicating the economic advantages of intercropping patterns compared with monocrops. Another index for assessing efficiency and productivity of intercropping system compared with monocultures is the system productivity index (SPI). In this study, the highest SPI value was obtained in the ratios of 25:75, 60:40 and 40:60 intercropped patterns, respectively. A similar trend to that of LER, A, K and CR was also obtained in SPI index.

Effect on Insect Assemblages

Increasing plant diversity in agricultural systems plays an important role in increasing insect diversification and improvement of pests biological control (Brown, 2012; Hurej et al., 2013; Dassou et al., 2015). According to the results of this study, most intercropping patterns had higher Shannon index values than those of plants monoculture. The highest shannon index was recorded in additive intercropping system with ratio of 100:100, indicating that this intercropping pattern had higher diversity of insects compared with the monoculture.

Additionally, the herbivores diversity and density were higher in soybean monoculture compared with sunflower monoculture and other intercropping patterns. Soybean is a good protein source for herbivore insects and, indirectly, for their associated non-herbivores (Lenardis et al., 2011). Results of this study indicated that the beneficial insect densities such as parasitoids and predators in all intercropping patterns were higher than sunflower and soybean monoculture which could be considered as a positive factor in biological control of pests (Fig. 4) (Hurej et al., 2013). Sunflower as an insectary plant could attract beneficial insects such as important pollinators (e.g., honey bees and other bee species) and parasitoids of agricultural insect pests and also can improve fecundity, longevity and survival of natural enemies to increase their effectiveness (Tylianakis et al., 2004; Berndt and Wratten, 2005). These results are in agreement with those previously reported by Wang et al. (2009). They reported that intercropping wheat and oil seed rape conserved more predators and parasitoids compared with wheat monoculture. Andow (1991) showed that the density of pest in intercropping system was lower in 52%, equal in 13% and variable in 20% of the studied cases in comparison with monoculture systems due to increasing diversity in intercropping patterns. Therefore, intercropping systems and increasing plant diversity could improve available spatial and temporal resources for natural enemies and thus increase beneficial insect diversity (Dassou et al., 2015; Brennan, 2016).

CONCLUSIONS

Our trials on sunflower and soybean intercropping arrangements demonstrated that there were no significant differences in sunflower grain yield between sunflower monoculture and intercropping patterns with ratios of 25:75 and 60:40. However, land equivalent ratio (LER) values in all intercropping patterns were more than one, indicating an advantage of intercropped patterns compared with plant monoculture. Results obtained from competition and economic indices indicated that intercropping one row of sunflower with three rows of soybean (ratio of 25:75) had a superior advantage because of better land equivalent ratio and better economics values than the other cropping patterns. Furthermore, increasing diversity and environmental resources by intercropping systems enhanced pollinators and natural enemies density compared with monoculture and the highest Shannon index value was recorded in 100:100 additive intercropping pattern. Overall, this study revealed that intercropping sunflower with soybean is an efficient strategy to achieve higher land productivity in low input conditions and increase natural enemies to biologically control pests. Generally, based on the ecological, agronomical and economical indices, replacing 25:75 intercropping pattern of sunflower with soybean suggested that farmers use it as a feasible alternative method to achieve similar production with respect to monocropping.

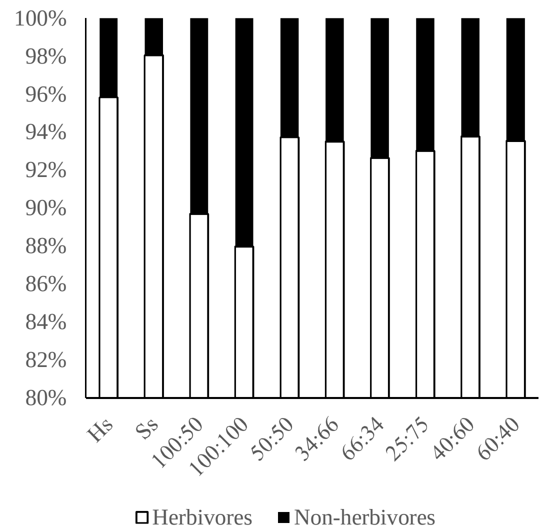

Fig. 4. The effect of intercropping patterns of sunflower with soybean on share of the total functional groups of insects.
100:50, 100:100, 50:50, 34:66, 66:34, 40:60, 60:40 and 25:75 indicate the ratios of sunflower and soybean in cropping patterns.
H_s: (sunflower monoculture); S_s (soybean monoculture)

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ارزیابی راندمان زمین، رقابت و تنوع حشرات در الگوهای مختلف کشت مخلوط آفتابگردان (*Helianthus annuus* L.) و سویا (*Glycine max* L.) در شرایط کم‌نهاده

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واژه های کلیدی:
حشرات علفخوار
کشت مخلوط
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شاخص شانون
نسبت برابری زمین

چکیده– کشت مخلوط به عنوان یک روش پایدار تولید با هدف استفاده حداقل از نهاده‌های خارجی محسوب می‌شود. در همین راستا یک آزمایش مزرعه‌ای با ده تیمار به منظور ارزیابی عملکرد، واکاوی رقابت و تنوع حشرات در کشت مخلوط سویا با آفتابگردان در فصل زراعی ۱۳۹۵ در مزرعه تحقیقاتی دانشکده کشاورزی دانشگاه مراغه اجرا شد. تیمارها شامل کشت خالص آفتابگردان (به عنوان گیاه اصلی)، کشت خالص سویا (به عنوان گیاه همراه) و نسبت‌های مختلف کشت مخلوط جایگزینی (۵۰:۵۰، ۳۴:۶۶، ۶۶:۳۴، ۴۰:۶۰، ۶۰:۴۰ و ۲۵:۷۵) و افزایشی (۱۰۰:۵۰ و ۱۰۰:۱۰۰) آفتابگردان-سویا بودند. نتایج نشان داد که بیشترین عملکرد دانه آفتابگردان (۲۷۵ گرم در متر مربع) در کشت خالص آن بدست آمد که با الگوی کشت ۲۵ درصد آفتابگردان+ ۷۵ درصد سویا و ۶۰ درصد آفتابگردان+ ۴۰ درصد سویا تفاوت معنی‌داری نداشت. همچنین بیشترین (۱۳۰/۱ گرم در متر مربع) و کمترین (۴۸/۵ گرم در متر مربع) عملکرد دانه سویا به‌ترتیب در کشت خالص سویا و الگوی ۱۰۰ درصد آفتابگردان+ ۵۰ درصد سویا حاصل شد. علاوه بر این، بالاترین نسبت برابری زمین، شاخص سودمندی مالی و سودمندی کشت مخلوط در الگوی ۲۵ درصد آفتابگردان+ ۷۵ درصد سویا بدست آمد. همچنین در همه الگوهای کشت، غالبیت جزیی و ضریب ازدحام نسبی آفتابگردان بیشتر از سویا بود که نشان دهنده توانایی رقابت بیشتر آفتابگردان نسبت به سویا است. در ضمن بالاترین تراکم حشرات علفخوار در کشت خالص سویا ثبت شد. خانواده‌های حشرات Thripidae و Cicadellidae دارای بیشترین تراکم نسبی بودند. علاوه بر این، کشت مخلوط آفتابگردان با سویا فراوانی حشرات گرده‌افشان و دشمنان طبیعی را نسبت به کشت‌های خالص افزایش داد. همچنین بیشترین شاخص شانون در الگوی کشت مخلوط افزایشی کامل حاصل شد. به طور کلی، بر اساس شاخص‌های زراعی، اکولوژیک و اقتصادی کشت مخلوط ۲۵ درصد آفتابگردان+ ۷۵ درصد سویا به عنوان یک روش جایگزین جهت حصول عملکردی مشابه کشت خالص آفتابگردان معرفی می‌گردد.