EJFA Emirates Journal of Food and Agriculture

Emirates Journal of Food and Agriculture 36: 1–14
doi: 10.3897/ejfa.2024.120581

RESEARCH PAPER

Assessing light and quality indicators of fodder at different levels of nitrogen fertilizer based on additive intercropping of barley (*Hordeum vulgare*) and vetch (*Vicilia ervilia*) under dryland farming

Hossein Neyestan[1], Hamid Abbasdokht[1], Ahmad Gholami[1]

1 *Faculty of Agriculture, Shahrood University of Technology, Shahrood, Iran*

Corresponding author: Hamid Abbasdokht (Habbasdokht@yahoo.com)

Academic editor: Abdul Jaleel ♦ **Received** 8 February 2024 ♦ **Accepted** 28 February 2024 ♦ **Published** 14 March 2024

Abstract

The intercropping system leads to increasing radiation use efficiency and quality indicators and improving the stability in the production of fodder plants. Intercropping and reducing the use of chemical fertilizers are the most effective methods to achieve sustainable agriculture goals. To investigate light and quality indicators of fodder obtained from barley and vetch additive intercropping at different levels of nitrogen fertilizer, a split plot experiment was performed with a randomized complete block design (RCBD) and 4 replications in two experimental fields in Sisab and Shirvan, North Khorasan Province, Iran, during 2017–2018. The factor included nitrogen fertilizer at three levels (zero, 50 and 100 Kg.ha^{-1} (N_0, N_1 and N_2)) and the subfactor included the combination of crops at four levels (barley pure cropping (I_1), 15% vetch +100% barley (I_2), 30% vetch +100% barley (I_3) and 45% vetch + 100% barley (I_4) additive intercropping). The results showed the highest fodder dry weight, absorbed radiation, radiation use efficiency, light extinction coefficient, ground cover percentage and leaf area index (LAI) in I_3 and N_2 in Sisab, and the lowest in I_1 and N_0 in Shirvan. Also, the highest crude protein (CP) was obtained from I_4 and N_2 in Shirvan, and the lowest crude protein was obtained from I_1 and N_0 in Sisab, which was inconsistent with neutral detergent fiber (NDF). The study results showed that increasing the percentage of vetch by 30% in intercropping and using nitrogen fertilizer led to increases in the indicators measured in the experiment.

Keywords

Additive intercropping, Barley, Nitrogen, Light indicator

Introduction

Taking advantage of all factors is very important in the process of agricultural production and productivity and comprehensive planning for efficient use of sources, environmental management and food security. It is necessary to use modern methods for agriculture, economy and efficiency of production to achieve sustainable agriculture. Improving fertility and controlling soil erosion, reducing damage caused by pests, diseases and weeds, stabilizing yield under undesired conditions and increasing yield under desired environmental conditions, increasing the efficiency of using environmental sources, and creating diversity and stability in the agricultural ecosystem are among the main objectives of sustainable agriculture (Yang et al. 2014). Therefore, researchers attempt to ensure food security by designing and implementing stable systems. One of the important points in sustainable agricultural systems is the increase in the production of agricultural products, where environmental factors are exploited in a better way (Stoltz and Nadeau 2014).

Given that different species in the mix have varied needs, intercropping can be an effective and significant component of sustainable agriculture. It also reduces competition. Studies have shown that biological superiority of intercropping is obtained from the full use of growth sources. The use of efficient crops for exploiting sources, especially water and solar radiation, is one of the most important solutions (Yang et al. 2014; Kaci et al. 2018; Gilani et al. 2021). In addition to maintaining the ecological balance and stability, this system pursues goals such as maximum utilization of environmental sources such as light, water, soil, food, quantitative and qualitative increase in yield and finally improvement of economic and nutritional conditions (Latati et al. 2017). An affordable way to increase output while lowering the need for outside inputs and lessen environmental issues is by intercropping (Monti et al. 2016). The selection of legumes and non-legumes is one of the most common mix patterns. In addition to nitrogen fixation, leguminous plants help to reduce nitrogen use. In addition, the selection of plants with different physiological and morphological properties reduces the competition for attracting sources, and each plant uses environmental sources more efficiently. As a result, the yield of intercropping is increased compared to pure cropping (Kermah et al. 2017). The presence of nearby plants has an effect on the availability and access to nutrients required by different species. In fact, the result of intraspecific and extraspecific competition of plants determines the amount of food in agricultural ecosystems. Therefore, the way of planting adjacent species in an ecosystem is very important in the quantity and quality of different plants (Asadi Sanam et al. 2019). Nitrogen, as the most important nutrient in soil fertility, forms the axis of chemical fertilizers. Nitrogen is present in the structure of protein, nucleic acid, chlorophyll, enzymes, phosphatides and most vitamins and other organic molecules that play an effective role in the exchange of plant substances (Behera et al. 2014). The amount and method of fixing light energy in plants is one of the most important physiological indicators that determine growth and yield, which changes in agricultural ecosystems due to various management methods. Photosynthesis and production of dry matter is a function of absorbed light, which depends on the structural properties of the canopy as well as the photosynthetic properties (absorbed radiation use efficiency) by plant species. More light absorption depends on the structure of the canopy, i.e. LAI and its vertical distribution in the canopy, the rate of leaf development and durability, the angle of the leaves and morphological properties such as the height of the plant and the arrangement of the side branches (Ahmadi et al. 2011).

In this regard, this study was conducted to evaluate the yield and investigate the light extinction coefficient, the radiation absorbed percentage, the LAI and the ground cover percentage in barely and vetch and additive interacropping of these two species. Given the role and importance of rainfed interacropping systems with low rainfall, especially in Iran, in order to achieve sufficient and high-quality fodder yield, the present study pursues the following objectives:

1. Evaluating the quantity and quality of fodder produced in rainfed intercropping of barley and vetch
2. Investigating light extinction coefficient, radiation absorbed percentage, LAI and green cover percentage in rainfed interacropping of barley and vetch.

Materials and methods

This study was conducted as half-split in the crop year of 2017–2018 in a research field at rainfed agriculture research stations of Sisab (latitude 37°45' longitude 57°65' altitude 1050 m above sea level) and Shirvan (latitude 37°49' longitude 57°92' altitude 1097 m above sea level), North Khorasan Province, Iran with RCBD and 4 replications. The factor included three levels of nitrogen fertilizer from the source of urea fertilizer (zero, 50 and 100 Kg. ha^{-1}) and the subfactor was the combination of crops at four levels, including barley pure cropping, 15% vetch + 100% barley, 30% vetch + 100% barley, 45% vetch + 100% barley additive intercropping.

Planting was done in the first half of November. Each plot consisted of 6 rows, the distance between the rows was 25 cm, and the length of each row was 5 m. The density was 375 barley plants per m². Barley cultivar Abidar and vetch (*Vicilia ervilia*) were used for intercropping. To reduce the marginal effect, the side lines and two meters at the beginning and end of the middle lines of cultivation were removed, and then sampling was done and three replications were taken from each treatment and five samples were taken from each replication. Harvest was on 6/10/2019. The traits measured in this experiment included grain yield, fodder dry weight, radiation absorbed percentage at spiking stage and after spiking, radiation use efficiency, light extinction coefficient before spiking, at spiking stage, and after spiking, ground cover percentage, leaf area index (LAI), neutral detergent fiber (NDF) by the method of Van Soest et al. (1991) and crude protein (CP) by the method of Bradford (1976). For sampling, a square of 0.25 m^2 was used, which was randomly placed in each plot, and the plants inside the square were taken and transported

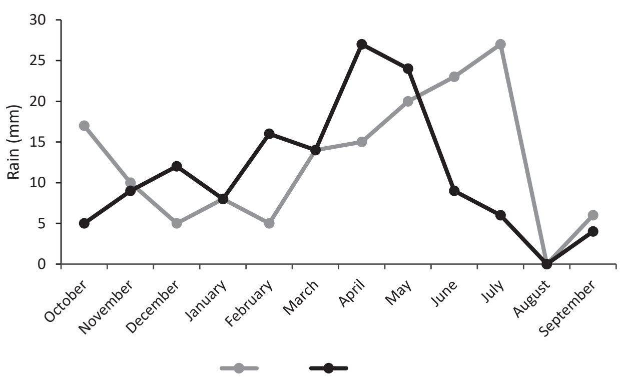

Figure 1. Rainfall in the crop year 2017-2018 in two research fields.

Table 1. Selected properties at soil depths of 0–30 cm at the experimental location.

Location	N (%)	K (mg/Kg)	P (mg/Kg)	Ca (meq/Lit)	Fe (mg/Kg)	Mn (mg/Kg)	Zn (mg/Kg)	EC ($dS.m^{-1}$)	pH	Texture
Sisab	0.13	144	131	33	7.8	17.2	1.1	0.37	7.5	Clay-Loam
Shirvan	0.11	131	151	19	8.3	16.4	0.8	0.4	8	Clay-Loam

to the laboratory. According to the results of the soil test (Table 1), 50 Kg. ha^{-1} of phosphorus fertilizer of the triple superphosphate type was used. So that all the required phosphorus fertilizer was given in the form of basic fertilizer and used in the treatments at the ratio defined in the nitrogen fertilizer test from the source of urea at three stages: germination, stem elongation, and spiking of barley.

Measuring radiation absorbed

In order to investigate how the light is distributed in the plant community, radiation absorbed and used by the mix canopy was measured at three stages (before spiking, at spiking stage and after spiking of barley) using the Sun Scan Canopy Analysis ΔT. The method of measurement was that by using this tool, the amount of light on the top of the mixed crop canopy and finally light at the bottom of the canopy was measured. Given the difference between light at the top of the canopy and light at the bottom of the canopy, radiation absorbed by the mix canopy was obtained in micromole/m^2/second. Using the following equations, light extinction coefficient and the radiation absorbed percentage by vegetation were calculated (Awal et al. 2006).

$$K = LN\frac{I1}{I0}/LAI \quad (1)$$

K = Coefficient of light extinction
I_1 = Light intensity at the bottom of the canopy
I_0 = Light intensity at the top of the canopy
LAI = Leaf area index

At the same time as the light measurement, LAI was also measured using the Sun Scan tool. Combined analysis and mean comparison (at the probability level of 5% by least square difference (LSD)) were performed using SAS (9.4). Excel was also used to draw graphs.

Grain yield

The results of combined analysis showed that all the main effects and the interaction of nitrogen fertilizer × planting ratio at the level of 1% and the interaction of location × nitrogen fertilizer × planting ratio at the level of 5% were significant (Table 2).

Mean comparison showed that the highest grain yield (1675 Kg. ha^{-1}) was obtained from I_1 and N_2 in Sisab and the lowest grain yield (1129 Kg. ha^{-1}) was obtained from I_3 and N_1 in Shirvan. which had no significant difference with I_3 and I_4 and N_0 (Table 3). It seems that due to lower soil fertility of Shirvan compared to Sisab, the final yield is more affected by the use of nitrogen fertilizer. It seems that the absence of interspecies competition in pure cropping has led to better use of nutrients and other sources such as water by barley, and as a result, the final grain yield in single cropping is higher than intercropping. In intercropping, the less ecological, morphological and physiological similarity of the existing plants, environmental sources use such as light is maximized and radiation use efficiency increases. So that the distribution of photosynthetic materials to the pod more and as a result the yield increases (Gao et al. 2010). Kaci et al. (2018) in a study on beans and durum wheat stated that the highest grain yield of durum wheat in all three years of the experiment was obtained from intercropping treatment, which was significantly different from pure cropping, but the grain yield of beans was more in intercropping than single cropping, but no statistically significant difference was observed (Kaci et al. 2018).

Fodder dry weight

The results of the analysis of the experimental data show all the main effects and the interaction of nitrogen fertilizer ×

Table 2. Results of data analysis of yield, radiation absorbed percentage and radiation use efficiency affected by location, nitrogen fertilizer and planting ratio.

S.O.V	DF	Grain yield	Fodder dry weight	Radiation absorbed percentage at spiking stage	Radiation absorbed percentage after spiking	Radiation use efficiency
Location (L)	1	490347**	2038751**	958.24**	855.62**	0.33**
$Error_1$	6	1958	85562	0.23	1.13	0.02
Nitrogen	2	550011**	563710**	628.35**	669.33**	0.36**
L*N	2	1674**	410	2.49**	2.19**	0.03
$Error_2$	12	1928	5313	0.13	0.67	0.01
Intercropping (I)	3	160412**	6322425**	812.31**	903.49**	2.48**
N*I	6	22603**	25715**	25.79**	16.71**	0.05**
L*I	3	2273	19036**	4.81**	6.10**	0.08**
L*N*I	6	5025*	6388	0.40	1.78**	0.02
$Error_3$	54	2131	3381	0.43	0.39	0.01
C.V		3.35	2.08	1.07	0.98	5.38

* and ** are significant at the level of 5% and 1%, respectively.

Table 3. Mean comparison of the interaction of location × planting ratio × nitrogen fertilizer on grain yield, radiation absorbed percentage and light extinction coefficient.

Location	Nitrogen fertilizer	Cropping mix	Grain yield (Kg.ha^{-1})	Radiation absorbed percentage after spiking	Light extinction coefficient (before spiking)
Sisab	0 (Kg)	Sole barley	1415^{c}	54.05^{m}	0.287^{k}
		100 barley + 15 vetch	1324^{de}	59.35^{k}	0.373^{h}
		100 barley + 30 vetch	1219^{f}	68.55^{d}	0.520^{b}
		100 barley + 45 vetch	1317^{e}	63.25^{h}	0.421^{f}
	50 (Kg)	Sole barley	1537^{b}	57.12^{l}	0.315^{j}
		100 barley + 15 vetch	1376^{cde}	67.30^{ef}	0.382^{h}
		100 barley + 30 vetch	1320^{e}	72.12^{c}	0.488^{cd}
		100 barley + 45 vetch	1537^{b}	68^{de}	0.536^{a}
	100 (Kg)	Sole barley	1675^{a}	62.12^{i}	0.339^{i}
		100 barley + 15 vetch	1546^{b}	67.37^{ef}	0.406^{g}
		100 barley + 30 vetch	1500^{b}	79.62^{a}	0.539^{a}
		100 barley + 45 vetch	1653^{a}	74.75^{b}	0.543^{a}
Shirvan	0 (Kg)	Sole barley	1207^{f}	49.57^{o}	0.255^{l}
		100 barley + 15 vetch	1226^{f}	53.87^{m}	0.335^{i}
		100 barley + 30 vetch	1173^{fg}	62.55^{hi}	0.442^{e}
		100 barley + 45 vetch	1163^{fg}	57.50^{l}	0.385^{h}
	50 (Kg)	Sole barley	1388^{cd}	52^{n}	0.285^{k}
		100 barley + 15 vetch	1228^{f}	60.97^{j}	0.340^{i}
		100 barley + 30 vetch	1129^{g}	65.50^{g}	0.440^{e}
		100 barley + 45 vetch	1425^{c}	62^{i}	0.482^{cd}
	100 (Kg)	Sole barley	1515^{b}	57.37^{l}	0.320^{j}
		100 barley + 15 vetch	1387^{cd}	62.62^{hi}	0.377^{h}
		100 barley + 30 vetch	1337^{cde}	71.25^{c}	0.477^{d}
		100 barley + 45 vetch	1523^{b}	66.75^{f}	0.495^{b}

Averages with common letters indicates no significant difference at the probability level of 5% by the LSD.

planting ratio; and location × planting ratio were significant at the level of 1% (Table 2). Comparison of the interaction of mix × nitrogen fertilizer showed that the highest dry weight of forage (3288 Kg. ha^{-1}) was obtained from I_4 and N_2 and the lowest dry weight of forage (1930 Kg.ha^{-1}) was obtained from I_1 and N_0 (Fig. 2). It can be concluded that in this case, intraspecies and interspecies competition is reduced and the mix components have complementary competition in using the available sources. One of the advantages of intercropping is the increase in production per unit area compared to single cropping, due to the better use of environmental factors such as space, water and nutrients in the soil and better use of light due to the useful arrangement of the canopy (Ren et al. 2016). There are many reports on increased economic yield of plants in the intercropping system compared to single cropping (Yan et al. 2014).

Mean comparison of the data showed that the highest fodder dry weight (3327 Kg. ha^{-1}) was obtained from I_4 in Sisab and the lowest fodder dry weight (1935 Kg. ha^{-1}) was obtained from I_1 in Shirvan (Fig. 3). It seems that the

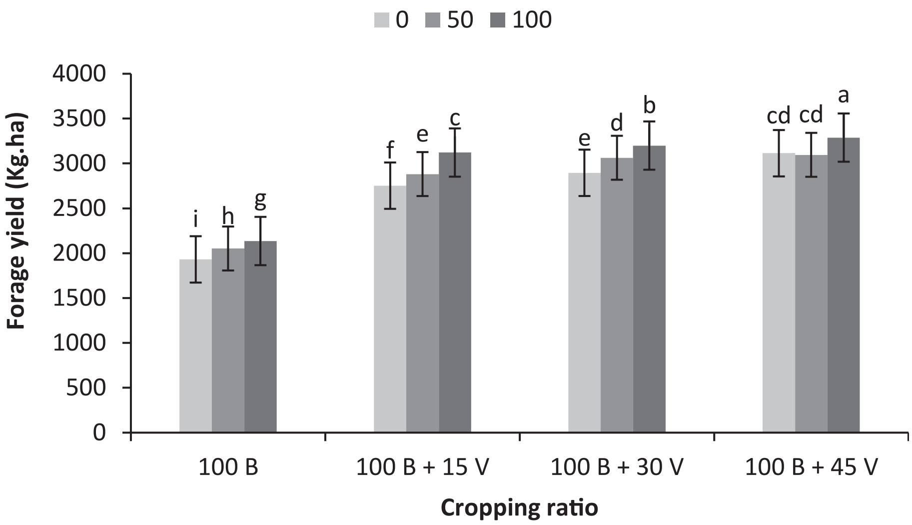

Figure 2. Interaction of planting ratio × nitrogen on fodder dry weight (Kg. ha^{-1}). Different letters indicate a significant difference at the probability level of 5% by the LSD.

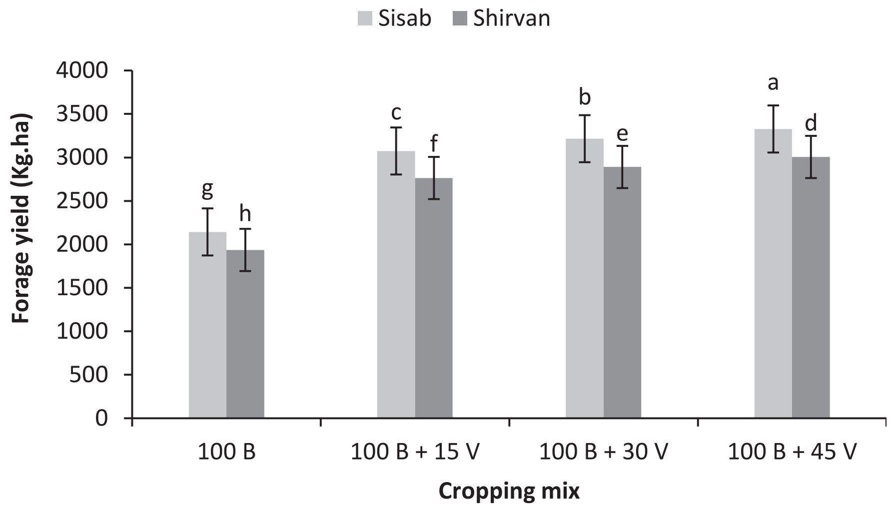

Figure 3. Interaction of planting ratio × location on fodder dry weight (Kg. ha^{-1}). Different letters indicate a significant difference at the probability level of 5% by the LSD.

reason for this is the plant's capability to absorb more radiation, increasing the availability of nitrogen through biological nitrogen fixation by vetch at this planting ratio. In this case, the allocation and distribution of sources between species is more efficient, which has led to the improvement of growth and photosynthesis and consequently the increase in fodder dry weight at this planting ratio (Rezai Chianeh 2015). Also, the significant difference between the amount of dry fodder produced in two different location is due to the higher fertility of Sisab and greater access to water sources.

Radiation absorbed (spiking stage)

All the main effects and the interaction of nitrogen × planting ratio; and location × planting ratio caused the radiation absorbed percentage to be significant at the level of 1% (Table 2). Mean comparison showed that the highest radiation absorbed percentage (68.96%) was obtained from N_2 in Sisab, and the lowest radiation absorbed percentage (53.61%) was obtained from N_0 in Shirvan (Fig. 4). Given that the experiment is rainfed and rainfall in Sisab was higher than in Shirvan, the better availability of moisture during the growing season increased the effect of nitrogen use in this region compared to Shirvan, which increased LAI and the radiation absorbed percentage in this treatment. Siadat and Derakhshan (2019) showed that radiation absorbed and RUE depend on LAI and its durability, and the use of nitrogen led to the improvement of RUE by increasing these two traits.

Mean comparison showed that the highest radiation absorbed percentage at spiking stage (73%) was observed in I_3 and N_2, and the lowest radiation absorbed percentage (50%) was observed in I_1 and N_0. The difference between these two treatment combinations was 31.5% (Fig. 5). Given that nitrogen fertilizer increases vegetative growth and photosynthesizing level. In all treatment combinations,

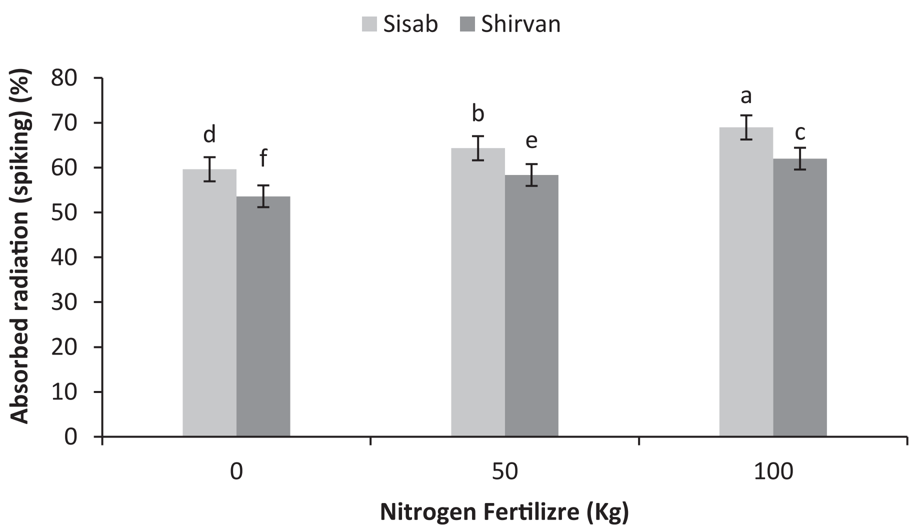

Figure 4. Interaction of location × nitrogen on the radiation absorbed percentage at spiking stage (%). Different letters indicate a significant difference at the probability level of 5% by the LSD.

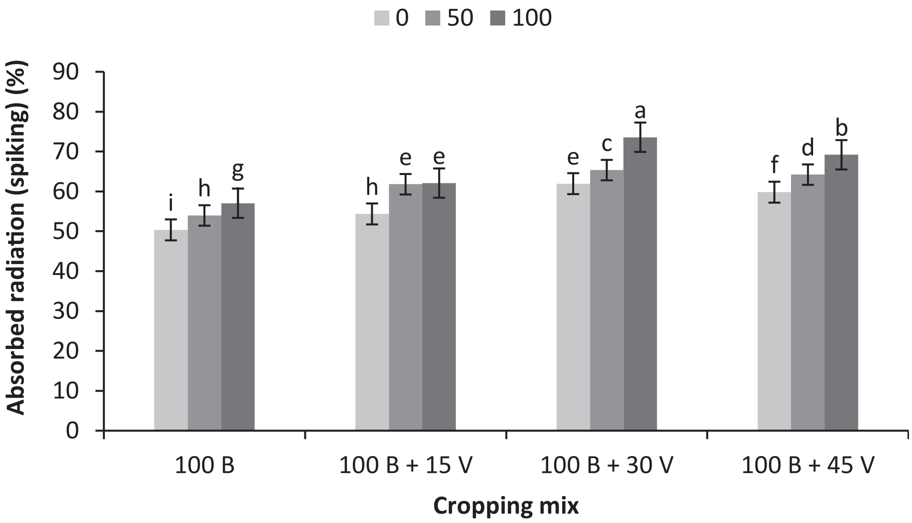

Figure 5. Interaction of planting ratio × nitrogen on radiation absorbed percentage at spiking stage (%). Different letters indicate a significant difference at the probability level of 5% by the LSD.

radiation absorbed percentage has a direct and upward relationship with increasing nitrogen use. Also, in intercropping, due to the optimal use of space and a more suitable spatial arrangement, light loss will be less and radiation absorbed percentage will be higher compared to single cropping. Also, this will happen until the competition between does not lead to competition for light sources.

The highest radiation absorbed percentage (70.61%) was observed inI_3 in Sisab and the lowest radiation absorbed percentage (51.22%) was observed in I_1 in Shirvan. The difference between these two treatments is 27.4% (Fig. 5). Given that rainfall in Sisab is higher than in Shirvan, which leads to the production of more dry matter and the increase in leaf area in rainfed agriculture, radiation absorbed percentage in this region at all planting ratios is higher. Also, due to the limitation in increasing the density in intercropping and the increase in interspecies competition, the best planting ratio in the mix to increase radiation absorbed percentage is $I_{3.}$ According to the results, it can be noted that by increasing the percentage of vetch more than 30% in intercropping, the competition for light has increased and shading has reduced radiation absorbed percentage (Fig. 6).

Radiation absorbed (after spiking)

All the main effects of planting ratio, nitrogen, location and interactions caused radiation absorbed to be significant at the level of 1% (Table 2). Mean comparison of the interaction location × planting ratio × nitrogen fertilizer showed after spiking, I_3 and N_2 in Sisab had the highest radiation absorbed percentage (79.62%), and the lowest radiation absorbed percentage (49.57%) was obtained from I_1 and N_0 in Shirvan (49.57%). The difference between these two treatment combinations was 37.74% (Table 3).

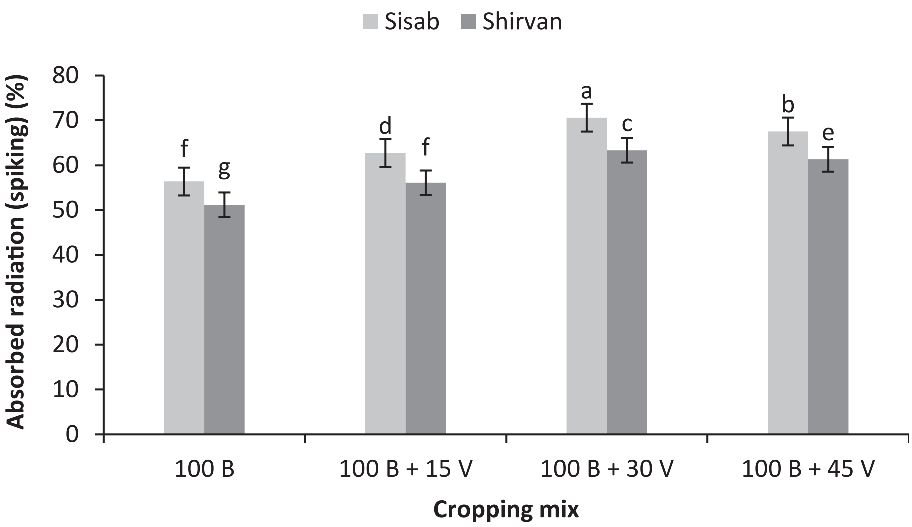

Figure 6. Interaction of planting ratio × location on radiation absorbed percentage at spiking stage (%). Different letters indicate a significant difference at the probability level of 5% by the LSD.

Intercropping can increase radiation absorbed by combining species that cover the soil and use radiation in the growing season. The difference between barley and vetch in LAI has the potential to increase the productivity of the system (Zhu et al. 2016). This can be due to the proper distribution of light in intercropping and the greater compatibility of the canopy with this amount of light, which will finally lead to better absorption of light and the production of dry matter in proportion to the radiation. It seems that the reason for the improvement of the maximum radiation absorbed by the wheat canopy is the improvement of LAI, following the increase in the number and rate of the expansion of leaves, along with the increase in the use of nitrogen fertilizer. Also, nitrogen improves radiation absorption by affecting leaf life span and increasing leaf surface index durability. Kaur et al. (2016) also reported that the application of nitrogen fertilizer improved radiation absorption by increasing the leaf area index. The increase in fertilizer consumption through the increase in the leaf area and photosynthetic tissues leads to an increase in radiation absorbed, so that the highest radiation absorbed in wheat was obtained from the highest level of fertilizer (Bozorgi Hossein Abad et al. 2019). The content of moisture and nitrogen available to the plant by increasing the growth rate of the plant, reducing the rate of leaf aging, changing the color of the canopy and preventing the tubularization of the plant leaves, increases radiation absorbed by the plant (Ullah et al. 2019). Due to different moisture content in rainfed agriculture, and radiation in the two test regions, the difference in radiation absorbed in the two test regions can be justified.

Radiation use efficiency

The results of combined analysis showed that the main effects of location, nitrogen and planting ratio and the interaction of planting ratio × nitrogen, and location × planting ratio were significant at the level of 1% on radiation use efficiency (Table 2). Mean comparison showed that the highest radiation use efficiency (2.37 g/MJ) was obtained from I_3 and N_2, which showed no significant difference from I_4, N_1 and N_2. Also, the lowest radiation use efficiency (1.73 g/MJ) was obtained from pure barley cropping and N_0, which was in a statistically significant group similar to other levels of nitrogen use in pure cropping (Fig. 7). Various studies have reported an increase or reduction in radiation use efficiency of plant components in intercropping. Some studies have considered the effect of intercropping on radiation use efficiency to be insignificant, but in any case, what is very important is the improvement of production efficiency in intercropping systems, in relation to light (Ahmadi et al. 2011). Intercropping alone has many ecological advantages. One of the reasons for increasing radiation use efficiency in intercropping treatments can be the reduction in intraspecies competition and the positive effects of other intercropping species. A linear relationship between the increase in plant nitrogen concentration and radiation use efficiency has also been reported by other researchers (Fletcher et al. 2008; Jafari Kohini et al. 2020). It has been stated in various reports that the limitation of nitrogen access causes the reduction in radiation use efficiency by 40% (Massignam et al. 2012; Teixeira et al. 2014).

As shown in Fig. 8, the highest radiation use efficiency (2.29 g/MJ) was observed in I_3 in Sisab, and no significant difference was observed with I_4 in Sisab and Shirvan. The lowest radiation use efficiency (1.54 g/MJ) was observed in pure barely cropping in Shirvan (Fig. 8). According to the results, it can be said that intercropping has improved radiation use efficiency compared to pure cropping. Probably, the increase in radiation use efficiency is achieved through the complementary and synergistic effects of intercropping, in such a way that the availability of nitrogen through biological nitrogen fixation of vetch also leads to the improvement of photosynthesis and as a result the accumulation of dry matter. This led to an increase in radiation use efficiency in intercropping. Increasing radiation

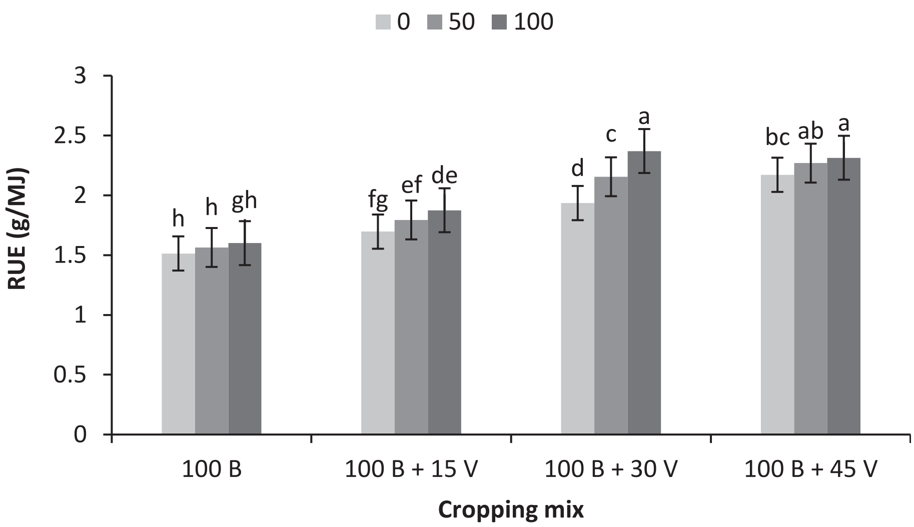

Figure 7. Interaction of planting ratio × nitrogen on radiation use efficiency at spiking stage (g/MJ). Different letters indicate a significant difference at the probability level of 5% by the LSD.

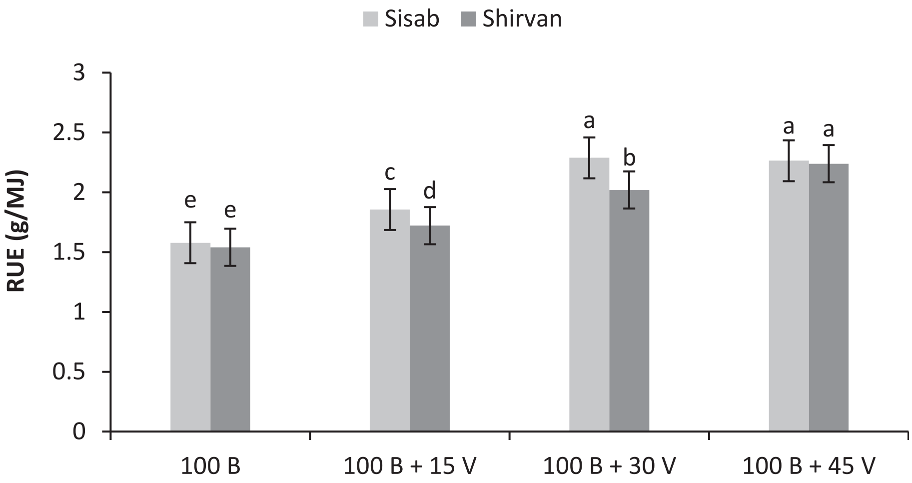

Figure 8. Interaction of planting ratio × location on radiation use efficiency at spiking stage (g/MJ). Different letters indicate a significant difference at the probability level of 5% by the LSD.

use efficiency in intercropping has been reported by many researchers (Rezvani Moghaddam et al. 2020). They stated that the use of intercropping systems is an essential ecological strategy to improve the efficiency of absorption and use of sources for the sustainable development of crop production. Yildirim and Bahar (2017) stated that radiation use efficiency was significantly dependent on the plant water use. Archontoulis (2011) reported that the value of K under water shortage was always lower than values under other conditions. Suitable moisture content at the disposal of plants during the vegetative stage can increase the leaf area, absorb light and accelerate photosynthesis, and consequently improve radiation use efficiency (Comas et al. 2019). Due to the higher rainfall in Sisab and more moisture that is available to the plants during the vegetative stage, radiation use efficiency is higher than in Shirvan.

Light extinction coefficient

As shown in Table 4, all the main effects and the interaction of nitrogen × planting ratio were measured at all three stages. Light extinction coefficient and the interaction of location × planting ratio before spiking was significant at the level of 1% and the interaction of location × nitrogen fertilizer × planting ratio before spiking was significant at the level of 5% (Table 4).

Mean comparison of traits showed that the highest light extinction coefficient during the growing season was observed in Sisab and the lowest light extinction coefficient was observed in Shirvan (Fig. 9). Tabarzad et al. (2016) reported that daily and hourly values of k in the atmosphere were affected by moisture content. Given that the experiment was conducted under rainfed conditions, and rainfall and moisture content are different in the two regions, the difference in light extinction coefficient can be justified.

Mean comparison showed that light extinction coefficient was affected by nitrogen use. The highest light extinction coefficient was obtained from N_2 treatment and the lowest value of this index was obtained from N_0 treatment (Fig. 10). Since the leaves of the plants in our mixture are very different in terms of shape, arrangement and angle, by increasing nitrogen fertilizer use and the change

Table 4. Analysis results of light extinction coefficient, ground cover percentage and LAI affected by location, nitrogen and planting ratio**.**

S.O.V	DF	Light extinction coefficient (before spiking)	Light extinction coefficient (spiking stage)	Light extinction coefficient (after spiking)	Ground cover percentage (spiking stage)	LAI (spiking stage)
Location (L)	1	0.04**	0.048**	0.06**	604**	3.64**
$Error_1$	6	0.0001	0.0004	0.001	1.85	0.005
Nitrogen	2	0.03**	0.052**	0.014**	2394**	12.4**
L*N	2	0.00009	0.0002	0.00009	5.75**	0.0007
$Error_2$	12	0.00009	0.0004	0.001	0.41	0.01
Intercropping (I)	3	0.19**	0.37**	0.28**	999**	11.66**
N*I	6	0.006**	0.01**	0.032**	17.84**	0.18**
L*I	3	0.001**	0.0009	0.002	0.94*	0.002
L*N*I	6	0.0002*	0.0003	0.002	1.55**	0.002
$Error_3$	54	0.00009	0.0004	0.001	0.31	0.006
C.V		2.27	4.08	5.51	1	1.60

* and ** are significant at the level of 5% and 1%, respectively.

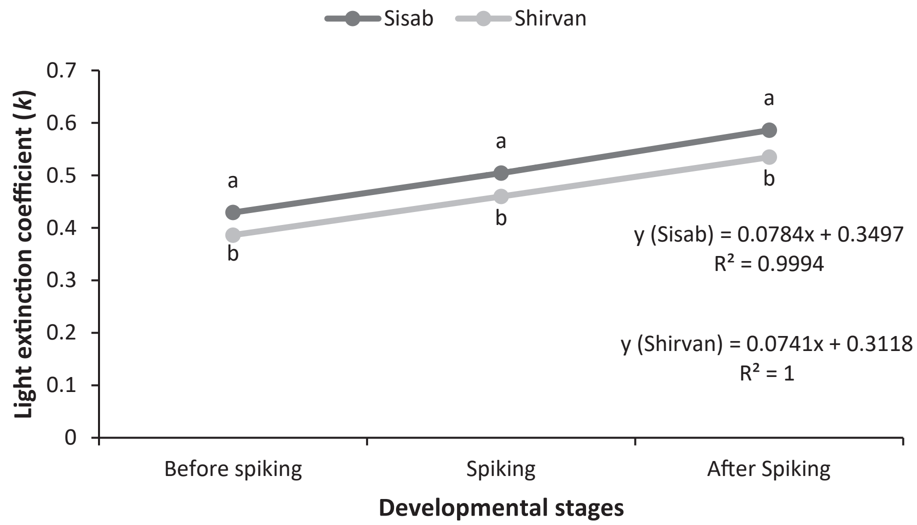

Figure 9. Effect of location on light extinction coefficient before spiking, at spiking stage and after spiking. Different letters indicate a significant difference at the probability level of 5% by the LSD.

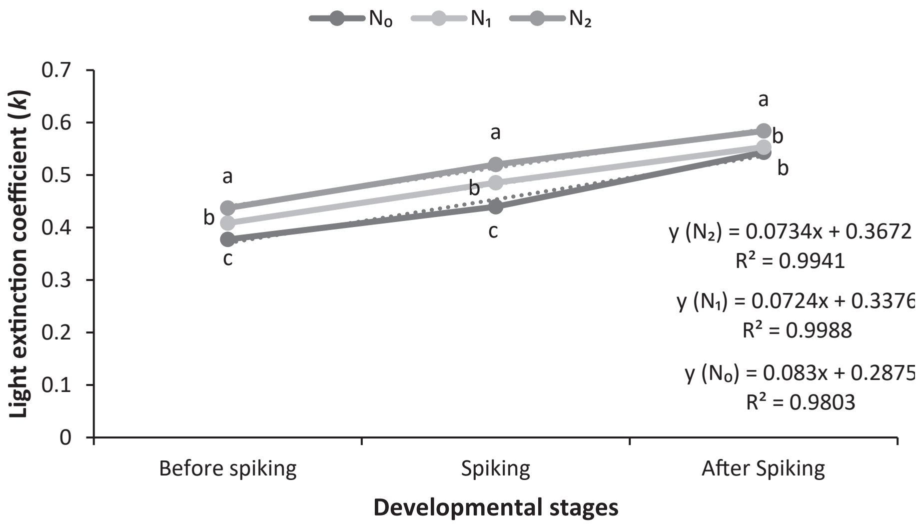

Figure 10. Effect of nitrogen on light extinction coefficient before spiking, at spiking stage and after spiking. Different letters indicate a significant difference at the probability level of 5% by the LSD.

in the number, size and distribution of the leaves, light extinction coefficient increased in intercropping.

In different treatments, the trend of increasing light extinction coefficient increased linearly (Fig. 11). The highest light extinction coefficient was observed in I_3 at all stages and the lowest light extinction coefficient was observed in I_1 (Fig. 11). The results showed that intercropping had higher light extinction coefficient than pure cropping and performed better than pure cropping in utilizing radiation absorbed. When barley and vetch are grown in additive intercropping system, the light environment created is such that light loss is minimized. The results have also been stated by Ahmadi et al. (2011) that intercropping of barley and vetch is superior to pure cropping and these two species in terms of yield. When the sunlight penetrates into a plant community, it is affected by LAI and the arrangement of the leaves. Light extinction coefficient indicates the arrangement of the leaves, and in other words, it is the rate of light reduction in the plant community. The arrangement of the leaves is determined by the angle and accumulation of the leaves within the plant community.

Ground cover percentage (spiking stage)

The results of combined analysis showed that all the main effects and interactions at the level of 1% and the interaction of location × planting ratio at the level of 5% were significant on ground cover percentage (Table 4). Mean comparison of the interaction of nitrogen fertilizer × planting ratio × location showed that the highest ground cover percentage (76%) was observed in I_4 and N_2 in Sisab and the lowest ground cover percentage (38%) was observed in I_1 and N_0, and a 50% difference was observed between these two treatments (Table 5). Bybee-Finley and Ryan (2018) attributed the increase in ground cover percentage in intercropping to the increase in density, the increase in the number of plants per unit area, and the increase in

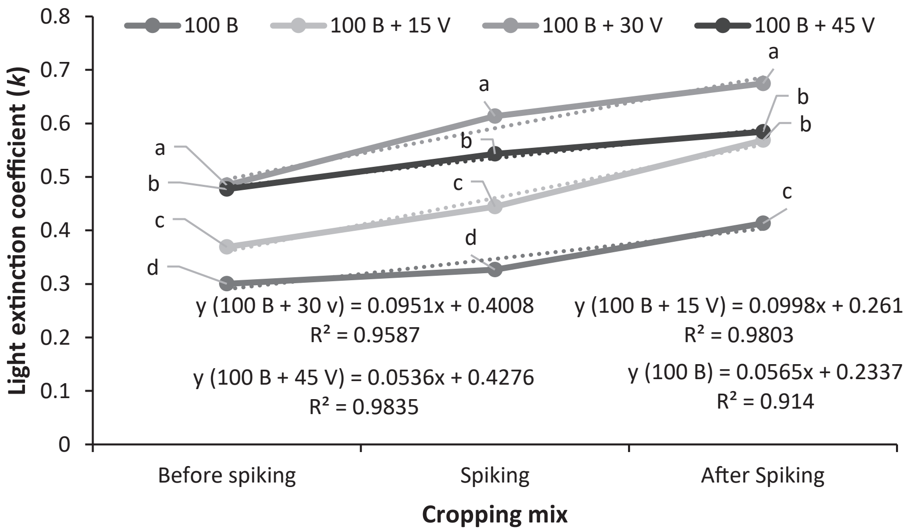

Figure 11. Effect of planting ratio on light extinction coefficient before spiking, at spiking stage and after spiking. Different letters indicate a significant difference at the probability level of 5% by the LSD.

leaf area. Also, due to the increase in LAI followed by the increase in vegetation cover, more light was absorbed in intercropping than in pure cropping of both crops. In addition, in intercropping, due to the difference in the root structure and the activity of absorption of nutrients from different depths of the agricultural soil, the possibility of absorption of elements is provided more appropriately. It seems that better absorption of light and increase in vegetation and on the other hand, better absorption of elements, especially nitrogen, in intercropping can provide faster growth of vegetation canopy and increase biomass. Due to the morphology of the broad leaves of vetch compared to Mustard seed, it is possible to close the canopy faster. The high efficiency of intercropping can be attributed to the high ground cover percentage and the efficiency of using environmental sources, especially light. In this way, the plants in intercropping make the most of the amount of light entering the canopy by filling the empty space and produce more products (Fallah et al. 2017). Ghafarian et al. (2021) reported that intercropping of Kochia, Sesbania and Cyamopsis tetragonoloba has higher ground cover percentage than single cropping. Higher ground cover percentage in the field makes plants use environmental sources (light, water, nutrients, etc.) better, which will have a positive effect on the yield. The reason for the increase in ground cover percentage in intercropping of maize and beans is the increase in the leaf area of the plants and the relationship between ground cover percentage, radiation use efficiency and yield, as well as the use of more light sources and as a result, the increase in the efficiency of photosynthesis (Rezaei et al. 2010). In this study, the closure of the canopy increases ground cover percentage and prevents the light from passing through the canopy. Nasrolahzadeh et al. (2016) reported that the use of biological and chemical fertilizers increases ground cover percentage of aize plants. Providing nutrients needed by the plant and further developing the root system of the plant to absorb nutrients as well as improving the soil fertility in nitrogen fertilizer application treatments have increased lAI and as a result ground cover percentage at the highest levels of nitrogen use higher than other levels (Raei et al. 2020).

Leaf area index (LAI)

The results of combined analysis showed that the main effects of location, planting ratio, nitrogen and the interaction of nitrogen × planting ratio ($P \leq 0.01$) on LAI were significant (Table 4). Fig. 12 shows that the highest LAI (5.03) was obtained from Sisab, which was different 7.75% from Shirvan (4.64) (Fig. 12).

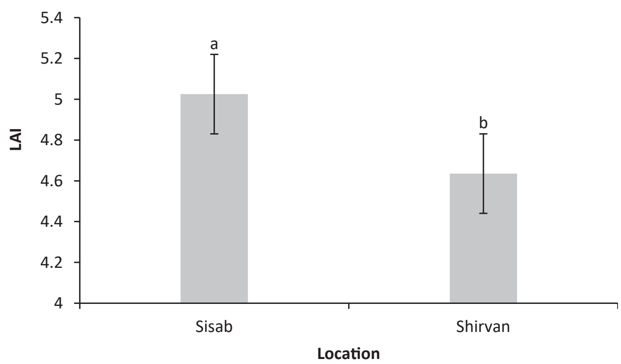

Figure 12. Effect of location on LAI at spiking stage. Different letters indicate a significant difference at the probability level of 5% by the LSD.

Mean comparison showed that the highest LAI (6.19) was obtained from I_4 and N_2 and the lowest LAI (3.29) was obtained from I_1 and N_0 (Fig. 13). Feng et al. (2020) in a study on soybean and maize intercropping showed that LAI and dry matter accumulation in all three years of the experiment caused an increase in intercropping compared to single cropping (Feng et al., 2020). Hu et al. (2020) stated that the highest amount of leaf area index, dry matter accumulation and plant growth rate was obtained from the soybean and maize intercropping treatment, which

Table 5. Mean comparison of the interaction of location × planting ratio × nitrogen fertilizer on ground cover percentage, NDF and CP.

Location	Nitrogen fertilizer	Cropping mix	Ground cover percentage (spiking stage)	NDF	CP
Sisab	0 (Kg)	Sole barley	42^{q}	418.75^{a}	351.25^{n}
		100 barley + 15 vetch	47.62^{o}	306.25^{i}	369.25^{m}
		100 barley + 30 vetch	50.87^{mn}	300.50^{j}	517.50^{h}
		100 barley + 45 vetch	56^{ij}	326.25^{g}	569.50^{g}
	50 (Kg)	Sole barley	50.25^{n}	413.75^{b}	366.50^{mn}
		100 barley + 15 vetch	55.45^{jk}	303.75^{ij}	398.75^{kl}
		100 barley + 30 vetch	60.75^{g}	305.50^{i}	586^{ef}
		100 barley + 45 vetch	63.12^{f}	314^{h}	581.75^{fg}
	100 (Kg)	Sole barley	56.50^{i}	398.25^{c}	404.25^{kl}
		100 barley + 15 vetch	65.87^{d}	294.50^{k}	461^{i}
		100 barley + 30 vetch	70.62^{b}	286^{l}	621.25^{d}
		100 barley + 45 vetch	76^{a}	299.50^{j}	600^{e}
Shirvan	0 (Kg)	Sole barley	38^{r}	379	388.50^{l}
		100 barley + 15 vetch	42.75^{q}	275.25^{mn}	409^{k}
		100 barley + 30 vetch	46.87^{o}	271no	568.50^{g}
		100 barley + 45 vetch	52^{l}	299.75^{j}	636.25^{cd}
	50 (Kg)	Sole barley	45.50^{p}	371^{e}	402.25^{kl}
		100 barley + 15 vetch	51.50^{lm}	277^{m}	358.50^{mn}
		100 barley + 30 vetch	54.75^{k}	271.25^{no}	639^{c}
		100 barley + 45 vetch	58.12^{h}	283^{l}	640^{c}
	100 (Kg)	Sole barley	50.75^{mn}	355.75^{f}	442.50^{j}
		100 barley + 15 vetch	61^{g}	275.75^{mn}	509^{h}
		100 barley + 30 vetch	65^{e}	253^{p}	684.25^{a}
		100 barley + 45 vetch	68.62^{c}	269^{o}	664.25^{b}

Means with common letters indicate no significant difference at the probability level of 5% by the LSD.

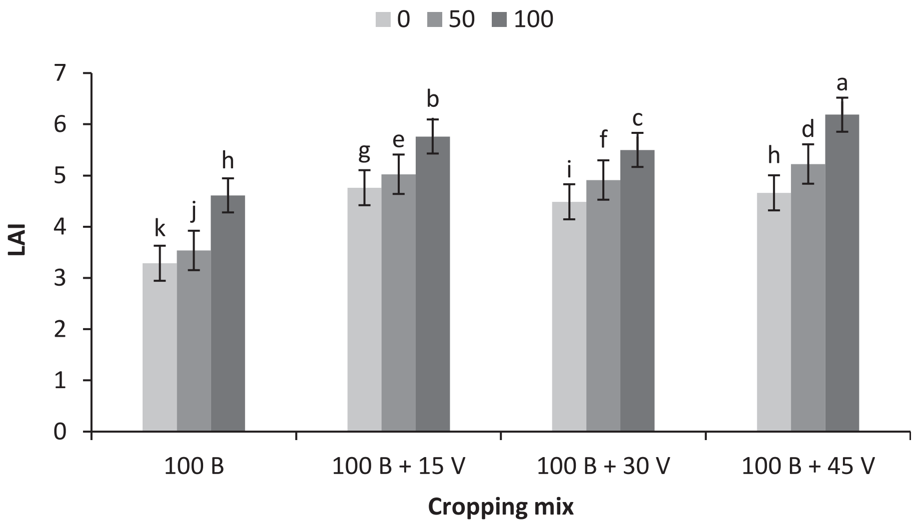

Figure 13. Interaction of planting ratio × nitrogen on LAI at spiking stage. Different letters indicate a significant difference at the probability level of 5% by the LSD.

had a significant difference compared to the single cropping. In general, intercropping of two species with different leaf arrangement and height absorb more light in terms of quantity and quality. In fact, in single cropping, some photosynthetic radiation is always lost due to the presence of empty space in the canopy, but the loss in intercropping is reduced due to the greater coverage of the soil surface, as a result, radiation absorbed is lower than that of single cropping. This alone can cause an increase in the leaf area and the accumulation of dry matter (Awal et al. 2006). By increasing the availability of nutrients, the development of the leaf area also increased. This allowed more photosynthesis, which finally increased grain yield. LAI is a major physiological component of the production, yield and growth rate of crops, which itself has complex properties, and its main components are the number and the size of the leaves. Studies have shown that nitrogen fertilizer has a direct effect on increasing the leaf area by increasing the longitudinal growth of the stem, improving the growth of leaves, and increasing the durability of the leaves (Ghanbari et al. 2021). The study results of the effect of nitrogen on properties of wheat also showed the significance of the effect of increasing nitrogen use on the increase in wheat leaf area (Dier et al. 2018). The results of another study showed that increasing nitrogen from 60 to 180 Kg. ha^{-1} increased the wheat leaf area by about 50% (Bag et al. 2020).

Neutral detergent fiber (NDF)

The effect of planting ratio, nitrogen, location, the interaction of planting ratio × nitrogen, the interaction of location × planting ratio, and the interaction of location × planting ratio × nitrogen were significant at the level of 1% on NDF (Table 6). Mean comparison of the interaction of nitrogen fertilizer × planting ratio × location showed that the highest NDF (418.75 g/kg) was observed in I_1 and N_0in Sisab and the lowest NDF (253 g/kg) was was observed in I_3 and N_2 treatment in Shirvan (Table 5). The content of fiber is one of the parameters of fodder quality, which is widely used for measuring fodder quality. For this purpose, the important chemical composition including NDF is evaluated (Dehghanian et al. 2020). Nejad et al. (2018) by evaluating fodder quality indicators in intercropping of maize and Vigna unguiculata stated that the treatment of maize pure cropping had the highest NDF, and the increase in the percentage of Vigna unguiculata at planting ratios, the concentration of this index balanced. In this regard, it can be concluded that in intercropping systems of cereals with one or more legumes, due to morphological differences of intercropping components, more shading and less penetration of light into the canopy, the leguminous plant allocates more photosynthetic materials to the vegetative organs, especially the leaves, and the leaf-to-stem ratio increases, as a result, NDF of the fodder reduces (Javanmard et al. 2020).

Table 6. Analysis results of NDF and CP affected by location, nitrogen and planting ratio.

S.O.V	DF	NDF	CP
Location (L)	1	24864**	44204**
$Error_1$	6	0.71	78
Nitrogen	2	2832**	44199**
L*N	2	14	1624**
$Error_2$	12	17.51	150.03
Intercropping (I)	3	61097**	335939**
N*I	6	248.61**	5301**
L*I	3	285.46**	2673**
L*N*I	6	31.07*	1083**
$Error_3$	54	11.81	130.85
C.V		1.09	2.26

* and ** are significant at the level of 5% and 1%, respectively.

Crude protein (CP)

Combined analysis showed that all main effects, and interactions on CP ($P \leq 0.01$) were significant (Table 6). Mean comparison of the interaction of nitrogen fertilizer × planting ratio × location showed that the highest NDF (684.25 Kg. ha^{-1}) was observed in I_3 and N_2 treatment in Shirvan and the lowest NDF (351.25 Kg. ha^{-1}) was observed in I_0 and N_0 (Table 5). The amount of CP is one of the most important quality properties of forage plants, and has been used in most studies to evaluate the quality of forage at the time of harvest (Yolcu et al. 2009). Legumes have a high level of protein compared to cereals, and therefore, CP of fodder is improved in intercropping of legumes and cereals (Sadeghpour et al. 2013). As shown, in all intercropping treatments, the amount of CP increases by increasing the percentage of vetch. This can be due to the capability of vetch to fix nitrogen and reduce the competition in nitrogen absorption by the components of the intercropping system (Nejad et al. 2018). Given that cereals and legumes in intercropping systems complement each other in nitrogen usr, it can be concluded that considering the use of nitrogen fertilizer and biological nitrogen fixation by vetch and the lack of competition for this element, the content of nitrogen of the barley increased and led to an increase in the protein content of the total fodder in intercropping.

Conclusion

In general, the study results showed that increasing the percentage of vetch by 30% in intercropping led to increases in the indicators measured in the experiment. One of the advantages of intercropping is the increase in production per unit area compared to single cropping, due to the better use of environmental factors such as water and nutrients in the soil and better use of light due to the useful arrangement of the canopy (Ren et al., 2016). Also, the increase in the use of nitrogen fertilizer in intercropping due to the presence of leguminous plants in this mixture, with biological nitrogen fixation, reduced the interspecies competition for this element, and increased the final dry fodder production, which is the final product. It is better to be more careful in the use of nitrogen fertilizer in each region according to the type of cropping and soil testing, because excess use of fertilizer leads to the imposition of significant economic costs and environmental pollution, which is against the principles of sustainable agriculture.

Acknowledgements

I would like to express my sincere gratitude to Dr. Alireza Gilani, who have been involved in this research.

Conflict of Interest

Hossein Neyestani, Hamid Abbasdokht, and Ahmad Gholami declare they have no competing interests.

Author Contribution

Hossein Neyestani contributed to data analysis and practical experimental work, Hamid Abbasdokht wrote the manuscript and interpretation of the data, and Ahmad Gholami participated in the conception and design of the experiment.

References

Ahmadi A, Dabbagh Mohammdi Nasab A, Zehtab Salmasi S, Amini R, Janmohammadi H (2009) Evaluation of yield and advantage indices in barley and vetch intercropping. Journal of Agricultural Science and Sustainable Production 20: 77–87.

Ahmadi A, Dabbagh Mohammdi Nasab A, Zehtab Salmasi S, Amini R, Janmohammadi H, Nami F (2011) Investigation of light status in sole cropping and intercropping of barley and vetch and its relationship with forage yield. Journal of Agricultural Science and Sustainable Production 21: 53–65.

Archontoulis S, Vos J, Yin X, Bastiaans L, Danalatos N, Struik P (2011) Temporal dynamics of light and nitrogen vertical distributions in canopies of sunflower, kenaf and cynara. Field Crops Research 122: 186–198. https://doi.org/10.1016/j.fcr.2011.03.008

Asadi-Sanam S, Zavareh M, Pirdashti H, Sefidkon F, Nematzadeh G (2019) Evaluation of phytochemical properties of purple coneflower [*Echinacea purpurea* (L.) Moench] flowers in intercropping with green beans and different summer time planting dates. Iranian Journal of Horticultural Science 50: 61–76. https://doi.org/10.22059/ijhs.2018.246503.1353

Awal M, Koshi H, Ikeda T (2006) Radiation interception and use by maize/peanut intercrop canopy. Agricultural and Forest Meteorology 139: 74–83. https://doi.org/10.1016/j.agrformet.2006.06.001

Bag K, Bandyopadhyay K, Sehgal V, Sarangi A, Krishnan P (2020) Effect of tillage, residue and nitrogen management on radiation interception, radiation use efficiency and evapotranspiration partitioning. Journal of Agrometeorology 22: 285–294. https://doi.org/10.54386/jam.v22i3.190

Behera B, Singdevsachan SK, Mishra R, Dutta S, Thatoi H (2014) Diversity, mechanism and biotechnology of phosphate solubilising microorganism in mangrove—a review. Biocatalysis and Agricultural Biotechnology 3: 97–110. https://doi.org/10.1016/j.bcab.2013.09.008

Bradford MM (1976) A rapid and sensitive method for the quantitation of microgram quantities of protein utilizing the principle of protein-dye binding. Analytical Biochemistry 72: 248–254. https://doi.org/10.1016/0003-2697(76)90527-3

Bybee-Finley KA, Ryan MR (2018) Advancing intercropping research and practices in industrialized agricultural landscapes. Agriculture 8: 80. https://doi.org/10.3390/agriculture8060080

Comas LH, Trout TJ, DeJonge KC, Zhang H, Gleason SM (2019) Water productivity under strategic growth stage-based deficit irrigation in maize. Agricultural water management 212: 433–440. https://doi.org/10.1016/j.agwat.2018.07.015

de la Fuente EB, Suárez SA, Lenardis AE, Poggio SL (2014) Intercropping sunflower and soybean in intensive farming systems: Evaluating yield advantage and effect on weed and insect assemblages. NJAS-Wageningen Journal of Life Sciences 70: 47–52. https://doi.org/10.1016/j.njas.2014.05.002

Dehghanian H, Barmaki M, Dabbagh Mohamadi Nasab A, Seifdavati J (2020) Grass pea (*Lathyrus sativus* L.) -Cereal Intercropping: Evaluation of Productivity and Some Indices of Forage Quality. Journal of Agricultural Science and Sustainable Production 30: 61–76.

Dier M, Sickora J, Erbs M, Weigel H-J, Zörb C, Manderscheid R (2018) Decreased wheat grain yield stimulation by free air CO_2 enrichment under N deficiency is strongly related to decreased radiation use efficiency enhancement. European Journal of Agronomy 101: 38–48. https://doi.org/10.1016/j.eja.2018.08.007

Fallah S, Kakolvand R, Abbasi A (2017) Effect of Plant Competition on Water Use Efficiency of Intercropping Fenugreek and *Nigella* under Different Moisture Regimes. Journal of Water Research in Agriculture 31: 637–653. https://doi.org/10.22092/jwra.2018.115729

Feng L, Raza MA, Shi J, Ansar M, Titriku JK, Meraj TA, Shah GA, Ahmed Z, Saleem A, Liu W, Wang X, Yong T, Yuan S, Feng Y, Yang W (2020) Delayed maize leaf senescence increases the land equivalent ratio of maize soybean relay intercropping system. European Journal of Agronomy 118: 126092. https://doi.org/10.1016/j.eja.2020.126092

Fletcher AL, Moot DJ, Stone PJ (2008) Radiation use efficiency and leaf photosynthesis of sweet corn in response to phosphorus in a cool temperate environment. European Journal of Agronomy 29: 88–93. https://doi.org/10.1016/j.eja.2008.04.002

Gao Y, Duan A, Qiu X, Liu Z, Sun J, Zhang J, Wang H (2010) Distribution of roots and root length density in a maize/soybean strip intercropping system. Agricultural Water Management 98: 199–212. https://doi.org/10.1016/j.agwat.2010.08.021

Ghafarian MR, Yadavi AR, dabbagh Mohammadi Nasab A, Salehi M, Movahedi Dehnavi M (2021) Advantage of Forage Production in Kochia (*Kochia scoparia*), Sesbania (*Sesbania aculeata*) and Guar (*Cyamopsis tetragonoliba*) Intercropping under Irrigation Water Salinity. Journal of Agricultural Science and Sustainable Production 31: 71–86. https://doi.org/10.22034/saps.2021.12777

Ghanbari J, Khajoei-Nejad G (2021) Integrated nutrient management to improve some soil characteristics and biomass production of saffron. Industrial Crops and Products 166: 113447. https://doi.org/10.1016/j.indcrop.2021.113447

Gilani A, Abbasdokht H, Gholami A (2021) Effects of Thiobacillus and Different Levels of Sulfur Fertilizer on Growth and Physiological Indices in Intercropping of Sesame (*Sesamum indicum* L.) and Mung Bean (*Vigna radiata* L.). Gesunde Pflanzen 73: 317–333. https://doi.org/10.1007/s10343-021-00554-6

Hu F, Tan Y, Yu A, Zhao C, Fan Z, Yin W, Chai Q, Coulter JA, Cao W (2020) Optimizing the split of N fertilizer application over time increases grain yield of maize-pea intercropping in arid areas. European Journal of Agronomy 119: 126117. https://doi.org/10.1016/j.eja.2020.126117

Jafarikouhini N, Kazemeini SA, Sinclair TR (2020) Sweet corn nitrogen accumulation, leaf photosynthesis rate, and radiation use efficiency under variable nitrogen fertility and irrigation. Field Crops Research 257: 107913. https://doi.org/10.1016/j.fcr.2020.107913

Javanmard A, Sadre Karimi E, Amani Machiani M, Morshedloo MR, Ostadi A (2020) Effect of Symbiosis with Mychorrizal Fungus (*Funneliformis mosseae*) on Yield and Yield Component of Black Cumin (*Nigella sativa* L.) and Chickpea (*Cicer arietnium* L.) in Intercropping. Journal of Agricultural Science and Sustainable Production 30: 19–43. https://doi.org/10.22034/saps.2020.12290

Jeranyama P, Shrestha A, Neupane N (2020) Sustainable food systems: Diversity, scope and challenges. In: Rusinamhodzi L (Ed.) The Role of Ecosystem Services in Sustainable Food Systems. Elsevier, 1–16. https://doi.org/10.1016/C2018-0-00522-8

Kaci G, Blavet D, Benlahrech S, Kouakoua E, Couderc P, Deleporte P, Desclaux D, Latati M, Pansu MA, Drevon JJ (2018) The effect of intercropping on the efficiency of faba bean–rhizobial symbiosis and durum wheat soil-nitrogen acquisition in a Mediterranean agroecosystem. Plant, Soil and Environment 64: 136–146. https://doi.org/10.17221/9/2018-PSE

Kaur N, Bhullar MS, Gill G (2016) Weed management in sugar-cane-canola intercropping systems in northern India. Field Crops Research 188: 1–9. https://doi.org/10.1016/j.fcr.2016.01.009

Kermah M, Franke AC, Adjei-Nsiah S, Ahiabor BD, Abaidoo RC, Giller KE (2017) Maize-grain legume intercropping for enhanced resource use efficiency and crop productivity in the Guinea savanna of northern Ghana. Field Crops Research 213: 38–50. https://doi.org/10.1016/j.fcr.2017.07.008

Latati M, Aouiche A, Tellah S, Laribi A, Benlahrech S, Kaci G, Ouarem F, Ounane SM (2017) Intercropping maize and common bean enhances microbial carbon and nitrogen availability in low phosphorus soil under Mediterranean conditions. European Journal of Soil Biology 80: 9–18. https://doi.org/10.1016/j.ejsobi.2017.03.003

Massignam A, Chapman S, Hammer G, Fukai S (2012) Effects of nitrogen supply on canopy development of maize and sunflower. Crop and Pasture Science 62: 1045–1055. https://doi.org/10.1071/CP11165

Monti M, Pellicanò A, Santonoceto C, Preiti G, Pristeri A (2016) Yield components and nitrogen use in cereal-pea intercrops in Mediterranean environment. Field Crops Research 196: 379–388. https://doi.org/10.1016/j.fcr.2016.07.017

Nasrolahzadeh S, Shirkhani A, Zehtab Salmasi S, Choukan R (2016) Effects of biofertilizer and chemical fertilizer on maize yield and leaf characters in different irrigation conditions. Applied Field Crops Research 29: 72–86. https://doi.org/10.22092/aj.2017.109048.1111

Nejad M, Ghanbari A, Sirousmehr A (2018) Evaluation of the ecophysiological aspects and forage quality indices in the intercropping of maize (*Zea mays* L.) and cowpea (*Vigna unguiculata* L.). Agroecology 10: 267–280. https://doi.org/10.22067/jag.v10i1.60479

Raei Y, Sayyadi Ahmadabad M, Ghassemi-Golezani K, Ghassemi S (2020) The Effect of Biological and Chemical Nitrogen Fertilizers on Pinto Bean (*Phaseolus vulgaris* L.) and Black Mustard (*Brasassica nigra* L.) Intercropping. Journal of Agricultural Science and Sustainable Production 30: 21–40.

Ren Y, Liu J, Wang Z, Zhang S (2016) Planting density and sowing proportions of maize–soybean intercrops affected competitive interactions and water-use efficiencies on the Loess Plateau, China. European Journal of Agronomy 72: 70–79. https://doi.org/10.1016/j.eja.2015.10.001

Rezaee Chiane E, Dabagh Mohammadi Nasab A, Shakiba MR, Ghasemi Golazani K, Aharizade S (2010) Evaluation of light interception and canopy characteristics in mono-cropping and intercropping of maize (*Zea mays* L.) and faba bean (*Vicia faba* L.). Journal of Agroecology 2: 437–447. https//doi.org/10.22067/jag.v2i3.7658

Rezaei-chiyaneh E (2016) Evaluation of Quantitative and Qualitative Traits of Black Cumin (*Nigella sativa* L.) and Basil (*Ocimum basilicum* L.) in Different Intercropping Patterns with Bean (*Phaseolusvulgaris* L.). Journal of Agroecology 8: 263–280. https://doi.org/10.22067/jag.v8i2.47354

Sadeghpour A, Jahanzad E, Esmaeili A, Hosseini M, Hashemi M (2013) Forage yield, quality and economic benefit of intercropped barley and annual medic in semi-arid conditions: Additive series. Field Crops Research 148: 43–48. https://doi.org/10.1016/j.fcr.2013.03.021

Stoltz E, Nadeau E (2014) Effects of intercropping on yield, weed incidence, forage quality and soil residual N in organically grown forage maize (*Zea mays* L.) and faba bean (*Vicia faba* L.). Field Crops Research 169: 21–29. https://doi.org/10.1016/j.fcr.2014.09.004

Tabarzad A, Ghaemi AA, Zand-Parsa S (2016) Extinction coefficients and radiation use efficiency of barley under different irrigation regimes and sowing dates. Agricultural water management 178: 126–136. https://doi.org/10.1016/j.agwat.2016.09.020

Teixeira EI, George M, Herreman T, Brown H, Fletcher A, Chakwizira E, de Ruiter J, Maley S, Noble A (2014) The impact of water and nitrogen limitation on maize biomass and resource-use efficiencies for radiation, water and nitrogen. Field Crops Research 168: 109–118. https://doi.org/10.1016/j.fcr.2014.08.002

Ullah H, Santiago-Arenas R, Ferdous Z, Attia A, Datta A (2019) Improving water use efficiency, nitrogen use efficiency, and radiation use efficiency in field crops under drought stress: A review. Advances in agronomy 156: 109–157. https://doi.org/10.1016/bs.agron.2019.02.002

Van Soest Pv, Robertson JB, Lewis BA (1991) Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science 74: 3583–3597. https://doi.org/10.3168/jds.S0022-0302(91)78551-2

Yan S, Du X, Wu F, Li L, Li C, Meng Z (2014) Proteomics insights into the basis of interspecific facilitation for maize (*Zea mays*) in faba bean (*Vicia faba*)/maize intercropping. Journal of Proteomics 109: 111–124. https://doi.org/10.1016/j.jprot.2014.06.027

Yang F, Huang S, Gao R, Liu W, Yong T, Wang X, Wu X, Yang W (2014) Growth of soybean seedlings in relay strip intercropping systems in relation to light quantity and red: far-red ratio. Field Crops Research 155: 245–253. https://doi.org/10.1016/j.fcr.2013.08.011

Yildirim M, Bahar E (2017) Water and radiation use-efficiencies of tomato (*Lycopersicum esculentum* L.) at three different planting densities in open field. Mediterranean Agricultural Sciences 30: 39–45.

Yolcu H, Polat M, Aksakal V (2009) Morphologic, yield and quality parameters of some annual forages as sole crops and intercropping mixtures in dry conditions for livestock. Journal of Food, Agriculture & Environment 7: 594–599.

Zhu S, Vivanco JM, Manter DK (2016) Nitrogen fertilizer rate affects root exudation, the rhizosphere microbiome and nitrogen-use-efficiency of maize. Applied Soil Ecology 107: 324–333. https://doi.org/10.1016/j.apsoil.2016.07.009

E-mail and ORCID

Hossein Neyestani (Hossein.1365@yahoo.com)
Hamid Abbasdokht (Corresponding author, Habbasdokht@yahoo.com)
Ahmad Gholami (Ahgholami273@gmail.com)