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Competition and dry matter yield in intercrops of barley and legume for forage

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Abstract

For increasing land use efficiency intercropping plays a pivotal role. Barley (*Hordeum vulgare* L.), vetch (*Vicia villosa*), and grass pea (*Lathyrus sativus* L.) monocultures as well as mixtures of barley with each of the above legumes, in three seeding ratios (i.e., barley: legume 75:25, 50:50 and 25:75, based on seed numbers) were used to investigated forage yield and competition indices such as land equivalent ratio (LER),competitive ratio (CR), relative crowding coefficient (RCC), aggressivity (A), actual yield loss (AYL), monetary advantage index (MAI) and intercropping advantage (IA).The experimental was arranged asa randomized complete block design (RCBD) with three replications.The results showed that intercropping reduced the dry matter yield of the three component plants, compared with their respective monocrops. The greatest value of total dry matter yield was obtained from barley$_{25}$-grass pea$_{75}$ (5.44 t ha^{-1}) mixture, followed by grass pea sole crop (4.99 t ha^{-1}). The total AYL values were positive and greater than 0 in all mixtures, indicating an advantage from intercropping over sole crops. Intercropped barley had a higher relative crowding coefficient (K=1.64) than intercropped legumes (K=1.20), indicating that barley was more competitive than legumes in mixtures. Furthermore, grass pea was more competitive than vetch in mixtures with barley. The highest LER, SPI and MAI were obtained when barley was mixed at a rate of 25% with 75% seed rate of grass pea. It is concluded that intercropping of barley with grass pea has a good potential to improve the performance of forage with high land-use efficiency.

Keywords: ***Forage, Grass pea, Intercropping, Actual yield loss, LER, Monetary advantage.***

1. Introduction

Intercropping of cereals and legumes is important for the development of sustainable food production systems, particularly in cropping systems with limited external inputs [41]. This may be due to some of the potential benefits for intercropping systems such as high productivity and profitability [26], improvement of soil fertility through the addition of nitrogen by fixation and excretion from the component legume [20], efficient use of resources [22], reducing damage caused by pests, diseases and weeds [4, 37], control of legume root parasite infections [16], provides better lodging resistance [1], yield stability [15], and improvement of forage quality through the complementary effects of two or more crops grown simultaneously on the same area of land [3, 25, 36]. Barley (*Hordeum vulgare* L.) is a cereal that can grow fast, suppress weed pressure and provide high yield in terms of dry weight but protein content of the forage is low [16, 17, 42]. Although forage nutritional value of barley in intercropping systems is higher than oat, triticale, and winter wheat [36, 46], it still does not meet the on-farm protein demand of dairy operations. Mixing barley and legumes has been suggested to increase forage quality. Juskiw et al. [21] conducted three field studies to evaluate the productivity of barley (*Hordeum vulgare* L.), oat (*Avena sativa* L.), triticale (*Tritico secalerimpaui* Wittm.), and rye (*Secale cereal* L.) grown as monocrops or in various mixtures. They reported that few effects of seeding rate on yield or quality were found, but when effects were found, higher seeding rates were associated with higher yields, lower moisture content, and higher fiber content. Although, some exceptions occurred, forage yield and quality of cereal mixtures were generally intermediate to monocrop production, especially for moisture and fiber content, suggesting that planting species mixtures could extend the harvest period and

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result in higher- quality silage. Caballero and Goicoechea [11] and Thompson et al. [39] reported that the most suitable cereal for mixtures with vetch is oat (*Avena sativa* L.), whereas Thompson et al [38] and Roberts et al. [35] reported that barley (*HordeumVulgare* L.) and wheat (*Triticum aestivum* L.), respectively, are the most suitable cereals for mixtures. Different seeding ratios or planting patterns for cereal-legume intercropping have been practiced by many researcher [6, 16, 49]. Lithourgidis et al. [24] reported that the greater benefit for forage quality was found when common vetch was grown in a monoculture or in mixture with cereals. The mixture of common vetch with oat at the 65:35 seeding ratio gave higher forage yield than mixtures of common vetch with triticale and the highest crude protein (CP) content of all mixtures.Vasilakoglou and Dhima [46] indicated that intercropping of berseem clover with barley at the seeding rate of 750-113 seeds m^{-2} could be used as alternative practice of berseem clover sole crop for high forage and protein production. Competition among mixtures is thought to be the major aspect affecting yield as compared with solitary cropping of cereal. Species or cultivar selections, seeding ratios, and competition capability within mixtures may affect the growth of the species used in intercropping systems [12, 49].A number of indices such as land equivalent ratio, relative crowding coefficient, competitive ratio, actual yield loss, and intercropping advantage have been proposed to describe competition within and economic advantages of intercropping systems [6,16, 20, 26, 50]. Zhang et al. [51] concluded that alfalfa had higher relative crowding coefficients (RCC or K value), competitive ratio (CR), and aggressivity (A value) than corn. Also alfalfa was the superior competitor when grown with corn, and its productivity dominated the total biomass yields. Esmaeili et al. [18] indicated that yield advantage of intercropping of medic and barley over their monoculture was also confirmed by RCC and monetary advantage index (MAI) indices.Mathematical indices can help researchers summarize, interpret, and display the results from plant competition trails [47]. Indices can express various attributes of competition in plant communities, including competition intensity, competitive effects, and the outcome of competition. They help in the interpretation of complex data and allow comparison of results from different studies with the use of the same index. Among indices being used for assessing competition between intercrops, land equivalent ratio is the most commonly used for intercrop versus sole crop comparisons [2]. However, such indices have not been used for barley and vetch or grass pea intercropping to evaluate the competition among species and also economic advantages of each intercropping system in Iran. The objectives of the present study were [i]to evaluate barley and legumes intercrops compared to mono-crops with regard to the biomass production, [ii] to estimate the effect of competition within barley- legume intercropping systems, e.g., barley-vetch and barley-grass pea and, therefore [iii] to examine different competition indices in these intercropping systems.

2. Materials and Methods

2.1 Plant material and treatments

A field experiment was conducted at the Research Station (lattitude 37°23'N, longitude 46°16'E, altitude 1485 m) of the Faculty of Agriculture, University of Maragheh, Maragheh, Iran, in 2013 growing season. Composite soil samples for each block were taken before planting from 0 to 30 cm depth for chemical analysis of pH, organic matter, available P and N and texture (clay, silt and sand). Soil texture was sandy loam with pH 7.96 and 0.7% organic matter. The seed-bed was well prepared through two perpendicular plowing and removing residual of the previous crop and weeds. Prior to planting, seeds were treated with benomyl at 0.2% [wt/wt] in order to protect them from soil-borne pathogens. Barley [*hordeumvulgare* L.] and two legume monocrops, vetch (*Vicia villosa*) and grass pea (Lathyrus *sativus* L.) as well as mixtures of barley with each of the above two legumes in three seeding ratios (i.e. 75:25, 50:50 and 25:75) based on seed numbers were sown in the 20th April.The seeding rates for barley and two legume monocrops were 204, 118.8 and 247Kg ha^{-1}, respectively (corresponding to 400, 250 and 250 seeds per m^2 for barley,vetch and grass pea respectively). The seeding rates for intercrops were 153, 31.7 and 62.5 kg ha^{-1} for the 75:25 seeding ratio (corresponding to 300, 63 and 63 seeds per $m^2$for barley, vetch and grass pea respectively), 85.33, 61.66 and 125 kg $ha^{-1}$for the 50:50 seeding rates (corresponding to 200, 125 and 125 seeds per m^2 for barley, vetch and grass pea respectively), and 51, 91.66 and 187.5 kg ha^{-1} for the 25:75 seeding rates (corresponding to 100, 188 and 188 seeds per m^2 for barley, vetch and grass pea respectively). The row spacing was 20 cm and the seeds of both species were mixed then sown simultaneously. The experimental design was a randomized complete block with 9 treatments (three monocrops and six mixtures of barley with legumes) replicated three times. The experimental plot size was 2.4 m × 4 m and plots were separated by a 2 m buffer zone. All crops were kept free of weeds by implementing hand hoeing, where necessary. Barley and legumes were harvested at the milk and flowering stages, respectively. At the stages of harvest samples from a 2 m^2 area of each plot were cut from ground level and separated for the determination of final yield and also of legumes percentage. The samples (0.5 kg biomass for each species) were dried at 65°C to constant weight to determine the relative water content. After dry matter determination, the forage yield was calculated on a 650 g kg^{-1} water basis of the dry matter [26].

2.2. Competition indices

The advantage of intercropping and the effect of competition between two species used in a mixture were calculated using different competition indices as follows: the land equivalent ratio (LER) was used as the criterion for mixed stand advantage as both barley and legume were desired species in the mixtures [48]. In particular, LER indicates the efficiency of intercropping for using the environmental resources compared with monocropping. The value of unity is considered the critical value for this index. When LER is greater than one the intercropping favors the growth and yield of the intercropped species, whereas when LER is lower than one the intercropping negatively affects the growth and yield of the species [29]. The LER was calculated as:

$$LER = (\mathrm{LER_b} + \mathrm{LER_L}) = \left(\frac{\mathrm{Y_{bL}}}{\mathrm{Y_{bb}}}\right) + \left(\frac{\mathrm{Y_{Lb}}}{\mathrm{Y_{LL}}}\right), \quad \text{[Eq. 1]}$$

Where Y_{bb} and Y_{LL} are the yields of barley and legumes as sole crop, respectively, and Y_{bL} and Y_{Lb} are yields of barley and legumes in the mixture, respectively.

Competitive ratio was calculated by following the formula as advocated by Willey and Rao [48]:

$$CR_{barley} = \left(\frac{\mathrm{LER_{barley}}}{\mathrm{LER_{legume}}}\right) \times \left(\frac{\mathrm{Z_{Lb}}}{\mathrm{Z_{bL}}}\right), CR_{Legume} = \left(\frac{\mathrm{LER_{legume}}}{\mathrm{LER_{barley}}}\right) \times \left(\frac{\mathrm{Z_{bL}}}{\mathrm{Z_{bL}}}\right), \quad \text{[Eq. 2]}$$

Another coefficient that used the relative crowding coefficient [RCC or K] which is a measure of the relative dominance of one species over the other in a mixture. Relative crowding coefficient was calculated following the formula [47]:

$$\mathrm{K_{bL}} \times \mathrm{K_{Lb}} = \left[\frac{(\mathrm{Y_{bL}} \times \mathrm{Z_{Lb}})}{\{(\mathrm{Y_{bb}} - \mathrm{Y_{bL}}) \times \mathrm{Z_{bL}}\}}\right] \times \left[\frac{(\mathrm{Y_{Lb}} \times \mathrm{Z_{bL}})}{\{(\mathrm{Y_{LL}} - \mathrm{Y_{Lb}}) \times \mathrm{Z_{Lb}}\}}\right], \quad \text{[Eq. 3]}$$

Where K_{bL} and K_{Lb} are relative crowding coefficient for barley and legume intercrop, respectively. Aggressivity is another index that is often used to indicate how much the relative yield increase in 'a' crop is greater than that of 'b' crop in an intercropping system [27]. The aggressivity is derived from the equation:

$$A_{barley} = \left(\frac{\mathrm{Y_{bL}}}{\mathrm{Y_{bb}} \times \mathrm{Z_{bL}}}\right) - \left(\frac{\mathrm{Y_{Lb}}}{\mathrm{Y_{LL}} \times \mathrm{Z_{Lb}}}\right), \quad \text{[Eq. 4]}$$

If $A_{barley=0}$, both crops are equally competitive, if A_{barley} is positive then the barley is the dominated species, if A_{barley} is negative, then the cereal species is weak. Accordingly, aggressivity for legumes (vetch and grass pea) can be derived from the equation:

$$A_{legume} = \left(\frac{\mathrm{Y_{Lb}}}{\mathrm{Y_{LL}} \times \mathrm{Z_{Lb}}}\right) - \left(\frac{\mathrm{Y_{bL}}}{\mathrm{Y_{bb}} \times \mathrm{Z_{bL}}}\right), \quad \text{[Eq. 5]}$$

The next index that was used was the actual yield loss (AYL) index, which gave more acurate information about the competition than the other indices between and within the component crops and the behavior of each species in the intercropping system, as it is based on yield per plant [7]. The AYL is the proportionate yield loss or gain of intercrops in comparison to the respective sole crop, i.e., it takes into account the actual sown proportion of the component crops with its pure stand. In addition, partial actual yield loss (AYL_{Legume} or AYL_{barley}) represent the proportionate yield loss or gain of each species when have grown as intercrops, relative to their yield in pure stand. The AYL is calculated according to the following formula [8]:

$$\mathrm{AYL} = \mathrm{AYL_{barley}} + \mathrm{AYL_{legume}} = \left[\left\{\frac{\left(\mathrm{Y_{bL}}/\mathrm{Z_{bL}}\right)}{\left(\mathrm{Y_{bb}}/\mathrm{Z_{bb}}\right)}\right\} - 1\right] + \left[\left\{\frac{\left(\mathrm{Y_{Lb}}/\mathrm{Z_{Lb}}\right)}{\left(\mathrm{Y_{LL}}/\mathrm{Z_{LL}}\right)}\right\} - 1\right], \quad \text{[Eq. 6]}$$

Where Y_{bl} representing the yield of intercrop barley in combination with legume, Y_{lb} the yield of intercrop legume in combination with barley. Z_{bl} representing the sown proportion of intercrop a barley incombination with legume and Z_{lb} the sown proportion of intercrop a legume in combination with barley.The AYL can have positive or negative values indicating an advantage or disadvantage accrued in intercrops when the main objective is to compare yield. Moreover, none of the above competition indices provides any information on the economic advantage of the intercropping system. For this reason, monetary advantage index (MAI) was calculated as:

$$\mathrm{MAI} = \left[\frac{(\mathrm{valueofcombinedintercrops}) \times (\mathrm{LER} - 1)}{\mathrm{LER}}\right], \text{[Eq. 7]}$$

Value of combined intercrops was calculated as: $Y_{bl}P_{barley} + Y_{lb}P_{legume}$, the higher the MAI value the more profitable is the cropping system [20]. Also, intercropping advantage (IA) was calculated using the formula [7],

$$\mathrm{IA_{barley}} = \mathrm{AYL_{barley}} \times \mathrm{P_{barley}}, \mathrm{IA_{legume}} = \mathrm{AYL_{legume}} \times \mathrm{P_{legume}}, \quad \text{[Eq. 8]}$$

Where $\mathrm{P_{barley}}$ is the commercial value of barley silage (the current price is 31 Euro per Mg), and $\mathrm{P_{legume}}$ is the commercial value of legumes silage (the current price is 42 Euro per Mg).

Data were initially subjected to analysis of variance (ANOVA) using the SAS computer software program, assuming the measured variables to be normally distributed (SAS, 2003).Homogeneity of variances was examined with Bartlett's test. Treatments means were separated by least signification differences (LSD) at $P < 0.05$.

3. Results and Discussion

3.1. Dry matter yield

Intercropping system significantly affected dry matter yield of barley, legumes and total dry matter yield (Table 1). Barley and legumes produced more yield in monocrops compared to intercrops. The higher dry matter production of monocropped barley and legumes relative tointercropping treatments may be due to the less disturbances in the habital in homogeneous environment under monocropping [6, 50].The lower equivalent biomass of grass pea and vetch when intercropped compared to respective monocrops was due to lower total productivity because there was competition in the intercropping [50].Dabbagh Mohammadi Nassab et al. [15] and Mbath et al. [28] reported that intercropping reduced the yields of soybean, maize and sunflower as compared with their sole crops. Comparison of cropping system for total dry matter yield showed that the greatest value of total dry matter yield was obtained from barley$_{25}$-grass pea$_{75}$ [5.44 t ha^{-1}] mixture, followed by grass pea pure stand (4.99 t ha^{-1}).In particular, all intercrops of barley with grass pea and vetch produced on the average about 66.8, 50.9, 32.8% and 26.6,11.3, 7.9% more dry matter yield than barley monocrop, respectively. Many studies have reported a yield increase of forage legume-cereal intercrops relative to cereal sole crops [10, 12, 19, 27]. Osman and Nersoyan [33] reported that the highest yield was found in legume-cereal mixtures at ratio 63:33 which had the highest proportion of legume in the mixtures tested. Similarly, Bedoussac and Justes [9] found 20% higher dry matter yield in pea-wheat intercrop than wheat monoculture.Our findings were relatively similar to Strydhorst et al. [44] who reported that pea (*Pisum sativum* L.)–barley intercrops produced the greatest dry matter yield. In contrast, Chapko [14] and Aasen et al. [1] reported no yield improvement in legume-cereal forage mixtures compared to cereal forage sole crops. In many cases, it has been reported that yields of mixtures between legumes and cereals were intermediate or even lower than yields of monocultures due to competition between the intercropped species [26, 45].The barley-grass pea mixture produced on average about 31.7, 35.5 and 23% more dry matter yield than the mixtures of barley with vetch. Greater competitive nature of one species over the other in an intercrop system has often been attributed to poor legume–cereal intercrop dry matter production [44]. Successful intercrops occur when each species occupies and accesses resources from different ecological niches while minimizing competitive interactions [4]. In general, pure grass pea and the mixture were better than pure vetch and barley and their mixtures [Table 1]. Higher barley-grass pea dry matter yields compared with the barley-vetch indicated the greater compatibility of barley and grass pea for intercropping. For example, grass pea and barley may have different peak time for water and nutrient uptake or their leaf arrangements may allow for greater light utilization. In contrast, if a particular combination of species and or varieties occupy similar ecological niches, it is unlikely that forage intercrop yield advantages will be observed

[44].In general, when two plants grow near one another, basic physiological principles suggest that they will compete for environmental resources regardless of facilitation. If competition and facilitation are both operative, the net effect could switch from positive to negative as a function of density [45].

3.2. Proportion of legume in forage dry matter

The analyses of variance for proportion of legume in dry matter indicated that there were significant differences among mixtures (Table 1). In general, proportion of legume decreased as the percentage of barley seed increased in the mixture. There were a decrease of 6.6% [from 79.3 to 74.1%] and 42% [from 74.1 to 43.1%] of grass pea contribution when seeding ratio of barley increased from 25 to 50 and 50 to 75% in mixtures of grass pea with barley. A similar trend was observed in mixtures of vetch with barley as there were a corresponding decrease of about 24.4% (from 62.8 to 47.5%) and 25.9% (from 47.5 to 35.2%). On the other hand, grass pea contribution in mixtures was better than vetch contribution (Table 1). The observed decrease of legumes contribution in dry matter of the mixtures could be attributed to competition between two species when grown together, probably because the cereals produced many tillers and therefore showed higher competitive ability than legumes [26]. Also, poor legumes performance may be attributed to its short stature relative to barley, and slow early-season growth which may have given barley a competitive advantage [44].Carruthers et al. [13] noted the unsuitability of lupine (*Lupinus perennis*) for intercropping as lupine yields in intercrops were reduced by 94 to 100% compared to sole crop lupine yields and attributed poor lupine yields to shading by intercropped corn.

3.3. RYT

Relative yield of legumes decreased and that of barley increased as barley seeding proportions increased (Table 1). The RYT of the mixtures exhibited an increasing trend as legume proportion increased. Moreover, the greatest RYT (1.21) was calculated in the grass pea-barley mixture at the 75:25 seeding ratio. This indicates that 21% more area would be required for a sole cropping system to equal the yield from an intercropping system [26]. The relative yield of barley in mixtures with vetch and mixture of barley$_{75}$: grass pea$_{25}$ was higher than that of barley$_{25}$:grass pea$_{75}$ and barley$_{50}$:grass pea$_{50}$ mixtures. This was probably because of the lower legume contribution in mixtures of vetch with barley and barley$_{75}$: grass pea$_{25}$ as compared with the mixtures ofbarley$_{25}$: grass pea$_{75}$ and barley$_{50}$: grass pea$_{50}$.

3.4. LER

Analysis of variance showed significant differences between treatments for both LER$_{cereal}$ and LER$_{legume}$, whereas no significant difference was noted for LER$_{total}$.Partial LER of legumes increased as the proportion of barley decreased (Table 2). Partial LER$_{vetch}$ was lower as compared with the LER$_{grass\ pea}$. The partial LER$_{barley}$ was higher than 0.5 in the grass pea$_{25}$:barley$_{75}$, vetch$_{50}$:barley$_{50}$ and vetch$_{25}$:barley$_{75}$ mixtures. This indicates that there was an advantage for barley in these intercropping systems. Moreover, partial LER$_{vetch}$ and LER$_{grass\ pea}$ were higher than 0.5 in the barley$_{25}$:grass pea$_{75}$, barley$_{50}$:grass pea$_{50}$ and vetch$_{75}$:barley$_{25}$ mixtures, respectively. Yield advantage in terms of total LER was greatest in the cases of grass pea-barley mixture (1.21) at the 75:25 seeding ratio and of vetch-barley mixture mixture (1.16) at the 75:25 seeding ratio (Table 2). This indicates an advantage from intercropping over pure stands in terms of the use of environmental resources for plant growth and better land utilization [6, 16]. Mean values of LER ranging from 0.96 to 1.21 were obtained from different mixed proportions of barley and legumes. These finding are in agreement with those of Bedoussac and Justes [9] who reported a mixed stand advantage with pea-wheat mixtures which was different at the different growth stages. Also, Dhima et al. [16] found LER values from1.05to1.09 in mixtures of common vetch with different grain cereals such as wheat, triticale, barley and oat.

3.5. Relative crowding coefficient

The partial K values of barley were higher than partial K of legumes in the case of grass pea$_{75}$-barley$_{25}$, vetch$_{75}$-barley$_{25}$ and vetch$_{50}$-barley$_{50}$ intercrops (Table 2). This indicates that barley is more competitive than associated crop [16]. However, K$_{legume}$ was higher than the K$_{barley}$ in the case of grass pea$_{50}$-barley$_{50}$, grass pea$_{25}$-barley$_{75}$ and vetch$_{25}$-barley$_{75}$ mixtures. Overall, on the average, the intercropped barley had higher relative crowding coefficient (K=1.64) values than the intercropping legumes (K=1.20), indicating that barley was more competitive than legumes in mixtures. In addition, K values for grass pea were higher compared to vetch, indicating that grass pea more competitive than vetch in case of legume-barley mixtures at the 50:50 and 25:75 seeding ratio. The total Kvalue was above one in the case of grass pea_{50}-$barley_{50}$, grass pea_{25}-$barley_{75}$, $vetch_{75}$-$barley_{25}$ and $vetch_{50}$-$barley_{50}$ mixtures, which indicates a definite yield advantage due to intercropping [7]. In $vetch_{25}$-$barley_{75}$ mixture, the K value was below one, which indicates that there was a yield disadvantage [20].

3.6. Aggressivity [A]

The results of aggressivityconformedto those of LER. In particular, grass pea and vetch were the dominant species ($A_{grass\ pea}$ and A_{vetch} positive) in the $barley_{25}$-grass pea_{75}, $barley_{50}$-grass pea_{50} and $barley_{25}$-$vetch_{75}$ mixtures (Table 3). Moreover, the value of A for grass pea was greater than vetch in $barley_{25}$-$legume_{75}$ and $barley_{50}$-$legume_{50}$ mixtures. This indicated that grass pea was more competitive than vetch. In the $barley_{75}$-grass pea_{25}, $barley_{50}$-$vetch_{50}$ and $barley_{75}$-$vetch_{25}$ mixtures, barley was the dominant species as measured by the positive value of aggressivity. Thus, barley was able to acquire more resources than legumes, and its yield influenced the total biomass of the intercropping system. Cereals (maize, sorghum and pearl millet) were also the dominant species in groundnut-cereal intercropping system [20]. While, for alfalfa-corn intercropping, aggressivity was higher for alfalfa in most mixtures than for corn [51].Agegnehu et al. [2] and Oseni [32] suggested that cereals my not always be the dominant crops in the intercropping with legumes.

3.7. Competitive ratio (CR)

Intercropped grass pea and vetch had higher competitive ratio in $barley_{50}$-grass pea_{50}, $barley_{75}$-grass pea_{25} and $barley_{75}$-$vetch_{25}$ mixtures respectively, indicating that grass pea and vetch is more competitive than barley in these intercropping systems (Table 3). However, in all other mixtures the value of CR for barley was greater than for legumes indicating the dominance of barley under these crop mixtures. This clearly shows that in some mixture, legumes were more competitive than the associated barley, while in other mixtures the barley was more competitive. In most cases, the CR of legumes decreased as the proportion of barley increased in the mixtures. Moreover, the value of CR for grass pea was greater than vetch in all mixtures. This indicates that grass pea was more competitive than vetch.

3.8. Actual yield loss (AYL)

AYL_{barley} had positive values in the $barley_{25}$-$vetch_{75}$, $barley_{50}$-$vetch_{50}$ and $barley_{75}$-$vetch_{25}$ mixtures (Table 4), which indicates a yield advantage for barley, probably because of the positive effect of legume on barley when grown in association [7, 16]. It was also revealed that in $barley_{75}$-$vetch_{25}$ and $barley_{50}$-$vetch_{50}$ mixtures, the barley was the dominant one because the partial AYL of barley was greater than the partial AYL of vetch. According to Banik et al. [7], the AYL index can give more precise information than the other indiceson interand intra-specific competition of the component crops and the behavior of each species involved in the intercropping system. Quantification of yield loss or gain due to association with other species or the variation of the plant population could not be obtained through partial LER_s, whereas partial AYL shows the yield loss or gain by its sign and as well as its value [16].Positive or negative values of AYL indicate an advantage or disadvantage in intercrops when the main objective is to compare yield on each plant basis [40]. There was a 4.9% [AYL_{barley}= - 0.049], 20.3% (AYL_{barley}= - 0.203) and 0.8% (AYL_{barley}= - 0.008) decrease in dry matter yield of barley in the $barley_{25}$-grass pea_{75}, $barley_{50}$-grass pea_{50} and $barley_{75}$-grass pea_{25} mixtures, respectively, as compared to its sole crop yield (Table 4). In contrast,the AYL_{barley} had positive value in barley-vetch mixtures at the all seeding ratio, indicating an advantage of intercropping over sole stands. The total AYL values were positive and greater than 0 in all mixtures, indicating an advantage from intercropping over pure stands. In $barley_{25}$-grass pea_{75}, $barley_{50}$-grass pea_{50} and $barley_{75}$-grass pea_{25} mixtures, the yield gain of grass pea ($AYL_{grass\ pea}$=+0.163,0.463 and 0.515) compensated for the yield loss of the corresponding species when grown in mixture. Although the partial AYL of vetch was negative in $barley_{25}$-$vetch_{75}$ and $barley_{50}$-$vetch_{50}$ mixtures, but this could compensate the yield loss of the corresponding species in mixture indicating an advantage of intercropping (AYL_{total} positive).

3.9. System productivity index (SPI)

The highest system productivity index (SPI) was found in $barley_{25}$-grass pea_{75} mixture, in which LER had also greater values (Table 5), indicating higher productivity and stability of these intercrops [2, 26]. Similarly, Odo [31] reported that the SPI of sorghum-cowpea [1:3] mixture showed greater yield stability than of other mixtures.

3.10. Monetary advantage index (MAI) and intercropping advantage (IA)

The MAI values were positive (except for the barley$_{50}$-vetch$_{50}$ and barley$_{75}$-vetch$_{25}$ mixtures), which indicates a definite yield advantage due to intercropping [26, 34]. The value of MAI was higher in barley-grass pea mixtures than the barley-vetch mixtures (Table 5). Moreover, the highest MAI value was for the barley-grass pea mixture [37.21] at the 25:75 seeding ratio followed by the barley-grass pea mixture [20.69] at the 50:50 seeding ratio.The lowest MAI value belonged to barley$_{75}$-vetch$_{15}$. These finding are also parallel to those of LER and competitive indices. Ghosh [20] and Dhima et al. [16] reported that if LER was higher, there was also economic benefit expressed with MAI values. Banik et al. [6] reported intercropping advantage due to positive MAI values. The advantage of the intercropping systems found in this study can be attributed to better utilization of growth resources. The IA, which is an indicator of the economic feasibility of intercropping systems, affirmed that the most advantageous mixtures were observed in barley$_{25}$-vetch$_{75}$ and barley$_{75}$-grass pea$_{25}$ mixtures with the highest IA values of +25.51 and 21.38, respectively.The lowest IA value of +2.97 showed that barley$_{75}$-vetch$_{25}$ lead to highest loss.

Table 1. Dry matter yield (t ha^{-1}), legume contribution and relative yields of monocultures and mixtures of barley with grass pea or vetch at three seeding ratios.

Crop	Dry matter yield [t ha^{-1}]			Legume contribution [%]	Relative yield		
	Barley	Legume	Total		Barley	Legume	Total
Barley	3.26	-	3.26	0	1		1
Barley$_{25}$-grass pea$_{75}$	1.10	4.34	5.44	79.38	0.339	0.872	1.21
Barley$_{50}$-grass pea$_{50}$	1.27	3.64	4.92	74.12	0.399	0.732	1.13
Barley$_{75}$-grass pea$_{25}$	2.46	1.87	4.33	43.11	0.744	0.379	1.12
grass pea	-	4.99	4.99	100	-	1	1
Barley$_{25}$-vetch$_{75}$	1.53	2.60	4.13	65.85	0.49	0.674	1.16
Barley$_{50}$-vetch$_{50}$	1.86	1.77	3.63	47.54	0.592	0.419	1.01
Barley$_{75}$-vetch$_{25}$	2.21	1.31	3.52	35.19	0.68	0.285	0.96
Vetch	-	4.42	4.42	100	-	1	1
LSD $_{0.05}$	0.76	1.71	1.55	17.52	0.207	0.281	0.311

Table 2. Land equivalent ratio [LER] and relative crowding coefficient [K] for sole stands and mixture of barley with grass pea and vetch in three seeding ratios.

Crop	Land equivalent ratio			Relative crowding coefficient		
	LER_{barley}	LER_{legume}	LER_{total}	K_{barley}	K_{Legume}	K
Barley	1		1	1		1
Barley$_{25}$-grass pea$_{75}$	0.339	0.872	1.21	1.54	-2.36	-3.53
Barley$_{50}$-grass pea$_{50}$	0.399	0.732	1.13	0.72	4.39	4.006
Barley$_{75}$-grass pea$_{25}$	0.744	0.379	1.12	1.61	2.19	2.41
grass pea		1	1		1	1
Barley$_{25}$-vetch$_{75}$	0.490	0.674	1.16	3.42	1.03	4.25
Barley$_{50}$-vetch$_{50}$	0.592	0.419	1.01	1.84	0.73	1.35
Barley$_{75}$-vetch$_{25}$	0.680	0.285	0.96	0.72	1.21	0.85
Vetch		1	1		1	1
LSD $_{0.05}$	0.228	0.281	0.379	2.49	6.13	9.65

Table 3. Aggressivity (A) and competitive ratio (CR) for mixtures of barley with grass pea and vetch in three seeding ratios.

Crop	Aggressivity		Competitive ratio	
	A_{barley}	A_{legume}	CR_{barley}	CR_{legume}
$Barley_{25}$-grass pea_{75}	-0.569	0.569	1.191	0.857
$Barley_{50}$-grass pea_{50}	-0.167	0.167	0.539	1.846
$Barley_{75}$-grass pea_{25}	0.463	0.463	0.771	1.629
$Barley_{25}$-$vetch_{75}$	-0.383	0.383	2.277	0.465
$Barley_{50}$-$vetch_{50}$	0.087	-0.087	1.428	0.739
$Barley_{75}$-$vetch_{25}$	0.439	-0.439	0.820	1.269
$LSD_{0.05}$	0.201	0.201	0.679	0.842

Table 4. Actual yield loss (AYL) and intercropping advantage (IA) for mixtures of barley with grass pea and vetch in three seeding ratios.

Crop	Actual yield loss			Intercropping advantage		
	AYL_{barley}	AYL_{legume}	AYL_{total}	IA_{barley}	IA_{legume}	IA_{total}
$Barley_{25}$-grass pea_{75}	-0.049	0.163	0.114	-1.51	6.83	5.33
$Barley_{50}$-grass pea_{50}	-0.203	+0.463	0.260	-6.28	19.45	13.16
$Barley_{75}$-grass pea_{25}	-0.008	0.515	0.507	-0.25	21.64	21.38
$Barley_{25}$-$vetch_{75}$	+0.96	-0.101	0.859	29.73	-4.25	25.51
$Barley_{50}$-$vetch_{50}$	+0.426	-0.162	0.264	13.19	-6.78	6.41
$Barley_{75}$-$vetch_{25}$	-0.093	0.140	0.046	-2.89	5.87	2.97
$LSD_{0.05}$	0.689	0.646	0.967	21.35	27.13	35.33

Table 5. Monetary advantage index (MAI) and system productivity index (SPI) for mixtures of barley with grass pea and vetch in three seeding ratios.

Crop	MAI	SPI
$Barley_{25}$-grass pea_{75}	37.21	8.66
$Barley_{50}$-grass pea_{50}	20.69	7.80
$Barley_{75}$-grass pea_{25}	16.46	6.85
$Barley_{25}$-$vetch_{75}$	10.12	5.52
$Barley_{50}$-$vetch_{50}$	-3.98	5.09
$Barley_{75}$-$vetch_{25}$	-5.25	5.04
$LSD_{0.05}$	62.91	3.913

The differences found between mixtures in this study can be attributed to the aggressivity of the cereal and also to other factors such as morphology and the different requirements for nutrients. In particular, the tall-growing barley intercropped with legumes (i.e., grass pea and vetch), or the high barley proportion in the mixtures can affect nitrogen fixation because of reduced light interception by legume due to shading by the barley. This can result in poor nodulation, growth and competitive ability of legumes in the mixtures [16].

4. Conclusions

The results of the present study clearly indicated that intercropping barley with grass pea and vetch affects the individual yield of the species, in addition to the competition between the components of the mixture and also the economics of the cropping system. There was reduction in dry matter yield of crops under intercropping over monocropping due to competition. The greatest value of total dry matter yield was found in barley-grass pea mixture at the 25:75 seeding ratio, which had the highest proportion of grass pea, followed by grass pea monocrop. The mixture of barley with grass pea at the all seeding ratio gave higher dry matter yield than mixtures of barley with vetch. Moreover, the most mixtures of barley with grass pea and vetch had a yield advantage for exploiting the available environment resources compared to their respective monocrops. When barley and grass pea were intercropped with 25:75 seeding ratio, the overall yield was improved by 21 percent. Furthermore, grass pea intercropped with barley was more competitive than vetch. Among the different intercrops, the maximum economic profit was noted in mixtures of barley$_{25}$-grass pea$_{75}$ and barley$_{50}$-grass pea$_{50}$. These mixtures could be economically and environmentally promising in the development of sustainable crop production and thus can be adopted by farmers for maximization of economic yields.

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