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Intercropping annual medic (*Medicago scutellata* L.) with barley (*Hordeum vulgare* L.) may improve total forage and crude protein yield in semi-arid environment

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Abstract

In arid and semi-arid conditions, production of high-yielding quality forage is still a challenge. Intercropping of cereals with annual forage legumes may improve forage yield and increase on-farm protein production. A two-year field experiment was conducted during the growing seasons of 2009 and 2010 at the experimental farm of University of Tehran, Iran to determine whether intercropping of barley (*Hordeum vulgare* L.) and annual medic (*Medicago scutellata* L.) could produce sufficient amount of forage with higher protein content. A four-replicated randomized complete block design with eight cropping patterns [1B:1M (one row of barley: one row of annual medic), 2B:2M, 4B:4M, 6B:6M, 6B:2M, 4B:2M, 2B:4M, and 2B:6M] along with pure stands of barley and annual medic was implemented. Land equivalent ratio (LER) was the highest (1.19) when barley was intercropped with annual medic in 1B:1M arrangement indicating that 19% more land area would be required by a sole cropping system to produce similar yield in intercropping system. Calculated partial LER, aggresivity (A) and competitive ratio (CR) indicated that barley was the dominant species in most of the barley-annual medic cropping patterns. Based on results from LER, system productivity index (SPI) and monetary advantage index (MAI), it was concluded that 1B:1M cropping pattern was superior to either barley or annual medic monocropping. The results of this study revealed that the total protein yield of barley and annual medic forage in the selected intercropping patterns specifically 1B:1M could be enhanced while the total harvested dry matter remained unchanged.

Keywords: Aggresivity, annual medic, barley, intercropping, LER, monetary advantage.
Abbreviations: A_aggresivity index; CR_competition ratio; LER_land equivalent ratio; MAI_monetary advantage index; SPI_ system productivity index.

Introduction

Employing cereals with legumes in an intercropping system have several benefits including higher total yield (Dhima et al., 2007), better resource use efficiency (Jahanzad et al., 2011; Lithourgidis et al., 2011a), enhancing biological activities in the soil, and suppressing pests and diseases (Trenbath 1993; Smith and Mcsorley, 2000). Efficient use of natural biological cycles by rhizobium/legumes may stimulate yield of the non-legume crops in an intercropped system (Hauggaard-Nielsen et al., 2001). Intercropping of legumes and cereals has been suggested as a practical management practice to improve quality of forage produced in resource-limited conditions specifically in arid and semi-arid environments, where forage yield of monoculture legumes is often low (Osman and Nersoyan, 1986; Esmaeili et al., 2011). The advantage of intercropping of two or more crops to improve final yield compared with monoculture system depends on spatial arrangements (intercropping pattern) of participated crops (Herbert et al., 1984; Putnam et al., 1986; De Costa and Perera, 1998; Hauggaard-Nielson et al., 2001; Biabani et al., 2008; Sadeghpour and Jahanzad, 2012). Annual medic is a low-yielding but high nutritional legume forage, which normally lays on the soil surface and is considered as shade tolerant plant (Smeltekop et al., 2002). Cereals including barley can grow fast, suppress weed pressure and produce high biomass (Hashemi et al., 2013); however their quality in terms of protein content is poor (Lithourgidis et al., 2006; Dordas and Lithourgidis, 2011). As cereal forage, barley possesses higher nutritive value compared with oat (*Avena sativa* L.), triticale (×*Triticosecale* rimpaui Wittm.), and winter wheat (*Triticum aestivum* L.) (Ross et al., 2004; Vasilakoglou and Dhima, 2008). Existing reports indicated that the yield of barley and/or annual medic can be improved in an intercropped system (Simmons et al., 1995; Moynihan et al., 1996; Eshghizadeh et al., 2007). However, limited reports are available on the influence of various spatial arrangements on total forage and protein yield of intercropped barley and annual medic. In current study we used a wide range of cropping patterns to a) determine if intercropping of annual medic and barley in a low-input condition can improve overall forage dry matter and quality, and b) examine the competitive relationships of barley and annual medic in an intercrop system.

Results

Climate

The weather conditions in both years were different than the norm for research location. In 2009 and 2010 plants

Table 1. Monthly mean air temperature and total rainfall during the two growing seasons in the experimental site.

Month	Temperature (°C)			Rainfall (mm)		
	2009	2010	30-year average	2009	2010	30-year average
March	9.7	10.9	10.8	12.6	46.7	47.7
April	16.4	17.2	12.2	4.5	43.2	34.7
May	25.0	23.2	13.9	3.1	10.3	20.8
June	23.6	27.9	15.9	0.0	0.0	2.3
July	26.4	26.6	16.1	0.3	0.0	3.1
Total	-	-	-	20.5	100.2	108.6

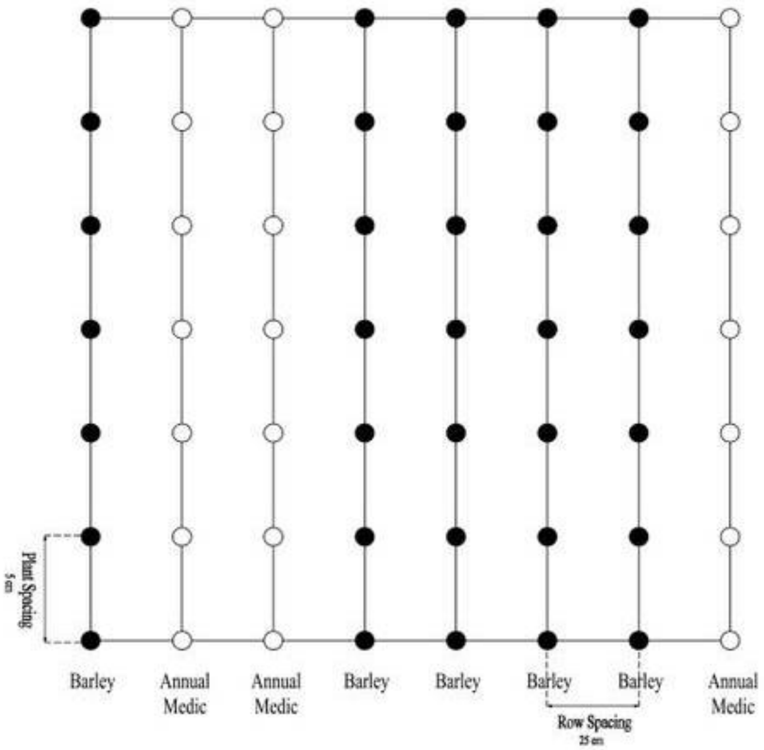

Fig 1. Cropping pattern of barley and annual medic intercropping (4B:2M).

experienced warmer and dryer season (Table 1). The total precipitations during growing seasons were 20.5 mm and 100.2 mm in 2009 and 2010, respectively. However, neither the amount of precipitation in both years nor interaction of year by cropping pattern had significant effect on biomass yield and protein content of the forage. Thus, means of cropping pattern averaged across growing seasons are presented in this report.

Forage and protein yield

As expected, pure stand of barley produced highest biomass (4006 kg ha^{-1}) averaged over the two years (Table 2). When the number of rows in 50:50 replacement intercropping treatments decreased from 6B:6M (strip intercropping) to 4B:4M, 2B:2M, and 1B:1M, barley biomass increased by 9%, 18%, and 24%, respectively. Annual medic forage dry matter yield was also significantly influenced by cropping pattern, with higher medic dry matter yield resulted from increasing annual medic rows in the intercrop (Table 2). The highest medic forage yield (2427 kg ha^{-1}) was obtained from its pure stand. In contrast, the 2M:6B ratio produced the lowest yield (924 kg ha^{-1}) primarily due to severe competition from barley plants as the dominant intercropped component. No significant difference was found in total dry matter harvested from barley pure stand (4006 kg ha^{-1}) and 1B:1M (3941 kg ha^{-1}). As expected, annual medic sole crop had the lowest biomass (2366 kg ha^{-1}) among all cropping patterns. The results from the current study indicated that the 1B:1M ratio produced the highest crude protein yield (1101 kg ha^{-1}) followed by 2B:2M (1037 kg ha^{-1}). As a legume plant, annual medic naturally contains higher crude protein compared with grasses however its crude protein yield ranks it least in this study due to its low biomass productivity among all of the treatments (Table 2).

Competition Indices

The LER exceeded unity in most of the cropping patterns with the exceptions of 4B:4M and 6B:6M, which was 2% and 8% lower than the unity, respectively (Table 2). Partial LER in barley improved as the proportion of annual medic decreased in the cropping patterns. Barley over yielded by 27% (ranging from 0.1 to 69% depending on the intercropping pattern) when intercropped with annual medic but under yielded in 6B:6M (-1%) and 6B:2M (-6%) cropping patterns. Over-yielding for annual medic ranged from 6 to 52% when intercropped with barley. However, under-yielding was observed in 4B:4M and 2B:4M cropping

Table 2. Dry matter yield of barley (FYB), annual medic (FYM), total forage dry matter (FYT), crude protein yield (CPY) of monocultures and intercrops, the land equivalent ratios (LER) of intercrops and percent over-yielding of barley and annual medic.

Treatment	FYB (kg ha^{-1})	FYM (kg ha^{-1})	FYT (kg ha^{-1})	CPY (kg ha^{-1})	LER_B	LER_M	LER_T	Over-yielding Barley (%)	Over-yielding Medic (%)
1B:1M	2614 c	1327 c	3941 a	1101 a	0.65 b	0.54 b	1.19 a	30	9
2B:2M	2380 d	1288 d	3668 b	1037 b	0.59 c	0.53 c	1.12 b	19	6
4B:4M	2143 e	1102 ef	3245 c	889 e	0.53 b	0.45 dc	0.98 e	7	-9
6B:6M	1982 f	1052 f	3034 d	833 f	0.49 d	0.43 e	0.92 f	-1	-13
Barley	4006 a	-	4006 a	953 d	-	-	-	-	-
6B:2M	2833 b	924 g	3732 b	974 cd	0.70 a	0.38 f	1.0 bc	-6	52
4B:2M	2675 c	1122 e	3797 b	1002 bc	0.66 b	0.46 d	1.12 b	0.1	39
2B:4M	1856 g	1372 c	3228 c	960 cd	0.46 f	0.56 b	1.02 d	39	-18
2B:6M	1697 h	1512 b	3209 c	965 cd	0.42 g	0.62 a	1.04 d	69	-17
Medic	-	2427 a	2427 e	735 g	-	-	-	-	-
L.S	**	**	**	**	**	**	**	**	**

Means in the same column followed by different letters differ significantly at P<0.05. Means are averaged over two growing seasons. (2009 and 2010) and four replications. ** P<0.01. L.S: Level of Significance.

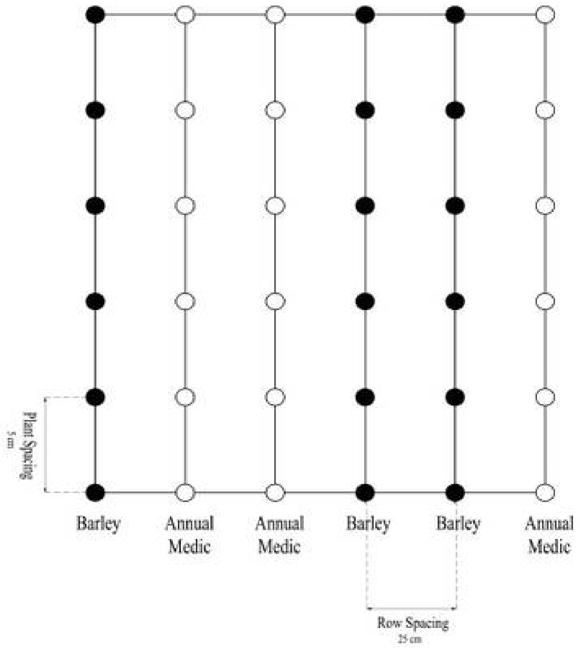

Fig 2. Cropping pattern of barley and annual medic intercropping (2B:2M).

patterns where a yield reduction up to 18% was found. The highest system productivity index (SPI) (6.50) was found in 1B:1M cropping pattern whereas the lowest SPI (5.05) was observed in 6B:6M. We found similar results of relative crowding coefficient (RCC) values to LER. Among all 50:50 cropping patterns, barley was the dominant species where the K_B values were higher than that of annual medic. Total K values in strip intercropping patterns below one (4B:4M, 6B:6M) showed disadvantages for these cropping patterns. Aggressivity values were positive for barley in most of the cropping systems (Table 3). These results emphasized the dominance of barley in the barley-annual medic cropping patterns. Conformity between aggressivity and LER was also observed with the exceptions of 6B:2M and 4B:2M (Tables 2, 3). Similar trend with LER and aggressivity was observed for the results of competitive ratio (CR) where barley was the dominant species in the cropping patterns. 6B:2M cropping pattern was the only exception where barley was not the dominant species. The monetary advantage index (MAI) was positive in all of the cropping patterns excluding 4B:4M and 6B:6M where negative values indicated that these cropping patterns were not economically advantageous (Table 3). The MAI data were conformed to those of LER and RCC. The highest MAI was observed in 1B:1M (24.90) followed by 4B:2M (15.96) (Table 3).

Discussion

Forage and protein yield

As expected, pure stand of barley produced the highest dry matter yield (Table 2). It was convincible that due to full land area allocated to the sole culture of barley, it produced greater dry matter yield compared with the intercropping treatments. Similarly, Vasilakoglou and Dhima (2008) in a barley-clover intercropping study, found the highest biomass production in barley pure culture. Our findings were in line with others indicated that cereal monoculture yield higher forage dry matter than when it was mixed with legumes (Herbert et al., 1984; Ross et al., 2004; Jahanzad et al., 2011). In general, cereals have been reported to produce higher biomass yield compared with legumes mainly because of

Table 3. Relative crowding coefficient (K), competitive ratio (CR), aggressivity (A), monetary advantage index (MAI) and system productivity index (SPI) of barley and annual medic in different cropping ratios.

Treatment	KB	KM	KT	CRB	CRM	AB	AM	MAI	SPIB
1B:1M	1.91b	1.22b	2.33a	1.20c	0.83b	+0.21b	-0.21b	24.9a	6.50a
2B:2M	1.48c	1.14b	1.68c	1.11c	0.90b	+0.14c	-0.14c	15.4b	6.05b
4B:4M	1.20d	0.81c	0.97e	1.17c	0.85b	+0.17bc	-0.17c	-2.62f	5.35c
6B:6M	0.99e	0.76c	0.75f	1.14c	0.87b	+0.13c	-0.13c	-10.35g	5.05d
Barley	-	-	-	-	-	-	-	-	-
6B:2M	0.82g	1.85a	1.52c	0.61d	1.45a	-0.58e	+0.58a	10.66c	6.15ab
4B:2M	1.03e	1.71a	1.76bc	1.07c	0.93b	-0.40d	+0.40b	15.96b	6.25b
2B:4M	1.72c	0.65cd	1.12d	1.64b	0.61c	+0.55a	-0.55d	2.51e	5.30c
2B:6M	2.22a	0.56e	1.24d	2.03a	0.49d	+0.65a	-0.65d	5.17d	5.28c
Medic	-	-		-	-	-	-	-	-
L.S	**	**	**	**	**	**	**	**	**

Means in the same column followed by different letters differ significantly at P<0.05. Means are averaged over two growing seasons (2009 and 2010) and four replications. ** P<0.01. L.S: Level of Significance.

being taller and could intercept relatively high solar radiation (Gosh et al., 2006). In our study, barley plant height ranged from 80-100 cm which was 30-50 cm taller than annual medic plants (data not shown). When some planting rows of barley were replaced with annual medic the barley biomass yield reduced compared with its sole cropping. Ross et al. (2004) reported that decreasing barley density resulted in barley forage yield reduction compared with barley sole culture. The highest annual medic yield was found in its pure stand due to the same logic mentioned for pure stand of barley. The reduction in annual medic yield intensified with increasing barley rows. Ross et al. (2004) reported that barley, especially in high densities, suppressed clover which resulted in lower clover yield in intercrops. Similarly, in our study, the lowest dry matter yield of annual medic was obtained from 2M:6B ratio (924 kg ha^{-1}) where annual medic was intensively suppressed by barley plants. Generally, natural sensitivity of annual medic to weeds along with inter-specific competition with barley decreased forage dry matter of this legume significantly. These results were in agreement with earlier findings of Lithourgidis et al. (2006) and Jahanzad et al. (2011) who reported that legume yield could be suppressed by higher number of cereal rows in the intercropping system. Total forage dry matter yield of all intercrops were lower than that of barley pure stand with the exception of 1B:1M (3941 kg ha^{-1}). Improvement in forage dry matter production of barley in 1B:1M may be attributed to the lower intra-species competition between barley plants as well as better efficient use of resources such as radiation due to a wavy canopy created in this specific cropping pattern. On the other hand, intercrops produced significantly higher biomass compared with annual medic sole culture. Vasilakoglou and Dhima (2008) found similar biomass production between intercrops and barley sole culture but reported higher total dry matter yield compared with annual medic pure stand. Many studies (Ross et al., 2004; Lithourgidis et al., 2006; Vasilakoglou and Dhima, 2008) were focused on cereal-legume plant densities compared with row arrangement which make the comparisons difficult. The overall crude protein yield from annual medic was the lowest (736 kg ha^{-1}) mainly because of its low dry matter production despite of being rich in terms of protein content. These results suggest that relying on annual medic alone as a source of on-farm protein is not sufficient to satisfy the growers' need. On the other hand, cereals are reported to be superior in terms of producing forage dry matter than legumes (Hauggaard-Nielson et al., 2001; Carr et al., 2004; Lithourgidis et al., 2007). Despite similar dry matter yield obtained from pure stand of barley and 1B:1M intercropping, protein yield produced by 1B:1M cropping pattern was almost 14% higher than that of barley monoculture. Overall, higher forage dry matter is often desirable when accompanied with higher protein content in the forage (Lithourgidis et al., 2006, 2007). It could be concluded that although annual medic may reduce the total forage yield but it will improve the quality of the forage through increasing its crude protein content.

Competition Indices

Various indices including land equivalent ratio (LER), relative crowding coefficient (K), competitive ratio (CR), aggressivity (A), system productivity index (SPI), and monetary advantage (MA), have been used to quantify the competition and potential economic advantage of intercropping systems compared with pure stands (Banik et al., 2000; Ghosh, 2004; Midya et al., 2005; Lithouragidis et al., 2011b). These mathematical indices can help researchers to summarize, interpret, and display the results from plant competition in intercropping trials (Weigelt and Jolliffe, 2003). Land equivalent ratio is the most commonly used indices for assessing competition in intercropping system in contrast to pure stands, (Agegnehu et al., 2006). The highest total LER was obtained from1B:1M (1.19) which indicated a 19% improvement in land area compared with monoculture system. This yield advantage could be due to better use of the environmental resources for plant growth. More specifically, creation of a wavy canopy architecture created in 1B:1M cropping pattern (Banik et al., 2000; Esmaeili et al., 2011; Lithourgidis et al., 2011a). Higher LERs in intercropping forage systems have been reported in many studies (Jahanzad et al., 2011; Lithourgidis et al., 2011b; Mariotti et al., 2012) indicating there is a potential benefit from intercropping of cereals and legumes compared with their monoculture cultivations. Land equivalent ratio below unity in 4B:4M and 6B:6M showed that intercropping may not be beneficial in all cropping patterns. Midya et al. (2005) and Vasilakoglou and Dhima (2008) concluded that intercropping of two or more forage crops may not necessarily lead to higher LER. Over-yielding percentage suggested by Li et al. (2007, 2011) determines the benefit of species “A” when intercropped with species “B”. In current study, increasing number of barley rows in the cropping patterns decreased the over-yielding percentage of barley primarily due to higher intra-specific competition (Table 2). Similar trend was observed for annual medic where decreasing the number of annual medic rows in the cropping patterns led to increase in over-yielding percentage of annual medic (Table 2). System productivity index (SPI) presents the most productive and stable cropping pattern (Agegnehu et al., 2006; Lithourgidis et al., 2011). According to Lithourgidis et al. (2011b), SPI values are generally conform the LER and K values. In our study the highest SPI was achieved from 1B:1M intercropping system (Table 3). Similar to Lithourgidis et al. (2011b), we found a positive correlation between SPI and LER values (r^2=0.86) where the highest LER and K values both obtained from 1B:1M intercropping pattern. The tendency of barley as the dominant species in most of the intercropping patterns in this study was confirmed by partial K, A, and CR values. However, annual medic was the dominant species in the intercrops only when 6 rows of barley were present in the intercropping. This could partially be due to the intra-specific competition between barley plants where annual medic suppressed by barley, yet managed to remain the dominant species. In other words, although annual medic was suppressed by barley, its production was still high with respect to its limited land area in this cropping pattern. These results were in agreement with over-yielding percentage results in which the presence of 6 rows of barley in the cropping pattern led to the over-yielding of annual medic. Several reports have suggested that cereals are the competitive species when intercropped with legumes (Ghosh et al., 2004; Banik et al., 2006; Sadeghpour et al., 2013). In accordance with our findings, Lithourgidis et al. (2011b) reported that wheat (*Triticum aestivum* L.) intercropped with vetch (*Vicia* spp) showed greater competitive ability to exploit the environmental resources. The positive MAI values in most cropping patterns indicated the profitability of intercrops compared with monocropping system (Sadeghpour et al., 2013). The highest MAI value resulted from 1B:1M indicating the economical feasibility of this cropping pattern. Ghosh et al. (2004) and Dhima et al. (2007) reported that higher LER is closely related to higher MAI values which emphasize the economic benefits from intercropping. MAI values were also significantly correlated with SPI values (Table 3). Similarly, Dordas et al. (2012) reported that LER, SPI, and MAI values were highest for oat-pea compared with barley-pea intercrops and therefore concluded that oat-pea mixture was more profitable than barley-pea.

Materials and methods

Experimental site

A two-year field experiment was conducted in 2009 and 2010 growing seasons at the experimental farm of University of Tehran, Karaj, Iran (35° 48´N, 50°57´W, 1312.5m elevation) with a semi-arid environment. Soil samples taken from 0-30 cm just before the onset of the study revealed that soil was a loamy soil with pH of 7.8, organic matter content of 1200 mg/kg, nitrogen, phosphorus and potassium content of 9, 151 and 142 mg/kg, respectively. The same field was used in both years.

Crop management and experimental design

Intercropping ratios consisted of 1B:1M, 2B:2M, 4B:4M, 6B:6M, 6B:2M, 4B:2M, 2B:4M, and 2B:6M (one row barley: one row annual medic, etc.) along with pure stands of both barley (*Hordeum vulgare*) and annual medic (*Medicago scutellata*) crops. Treatments were statistically analyzed based on a randomized complete block design with four replications. Iranian native cultivar of barley (Karoon × Kavir) and an annual medic (Robinson), a native of Australia were used in this study. Fields were under cultivation of wheat prior to this experiment. Before seeding, the cultivation area was moldboard plowed, harrowed and then divided into four blocks, each contained ten experimental plots. Plots consisted of various row numbers depending on intercropping ratios (Figure 1 and 2). Barley was seeded at the rate of 140 kg ha^{-1} and annual medic was sown at the rate of 20 kg ha^{-1} which is commonly used by famers in the area. Plots were 5 m long with row spacing of 0.25m, and plant spacing was 5cm for both barley and annual medic. Weeds were controlled twice manually early in the growing seasons. Seeds were planted on March 13th in 2009 and March 17th in 2010. One row of barley or annual medic was planted next to both sides of experimental plots where barley bordered to annual medic and annual medic bordered to barley. The plots were irrigated during the period between March and July when required.

Measurements and data analysis

Barley and annual medic were harvested on June 6th 2009 and 10th 2010 growing seasons when barely grains were at milk stage and annual medic was at 10-20% of flowering stage. Excluding guard rows, four meters of each row within each plot was harvested by hand. Forage yields of both crops were determined separately and then adjusted based on cropping pattern (number of rows per plot). A sub sample was dried in a forced air oven at 65˚C for 72 h to determine the moisture content of each crop. Another sub sample from each plot was taken at the harvest time for determination of protein content. Samples again were dried in a forced air oven at 65 ˚C for 72 h and prepared for chemical analysis. The samples were ground with a Wiley mill to pass a 1 mm screen and analyzed for protein content. Total N was determined using the Kjeldahl method (Bremner, 1965) and crude protein (CP) for both crops was calculated by multiplying the N content by 6.25 (AOAC, 1980; Jahanzad et al., 2013). Intercropping advantage and competition between barley and annual medic in intercrops were calculated according to Willey and Rao (1980). Land equivalent ratio (LER) was used to quantify the efficiency of the intercropping treatments.

LER= $(Y_{bm}/Y_{bb}) + (Y_{mb}/Y_{mm})$

where Y_{bb} and Y_{mm} are yields of pure stands of barley and annual medic, Y_{bm} and Y_{mb} are yields of barley and annual medic in intercropping system, respectively. LER values greater than unity indicate an advantage of intercropping over monoculture. LER was also used to calculate monetary analysis.

Over-yielding as another index was calculated by the following formula:

Over-yielding (%) = $(Y_{\text{intercrop}} - P \times Y_{\text{pure stand}}) / (P \times Y_{\text{pure stand}}) \times 100$

where P is the proportion of the crop in the intercrop.

Over-yielding for forage dry matter of intercropped plants relative to their pure stands was assessed by changes in yield of various intercropped patterns over the corresponding monoculture. Positive over-yielding indicates an advantage and a negative value denotes yield disadvantage of the intercropping system (Li et al., 2011).

System productivity index (SPI) was also used to standardize the yield of the secondary crop (annual medic) with primary crop (barley) (Agegnehu et al., 2006; Lithourgidis et al., 2011a) and calculated by following formula:

SPI = $(Y_{bb}/Y_{mm})\, Y_{mb} + Y_{bm}$

where Y_{bb} and Y_{mm} are the average yields of barley and annual medic in pure stands and Y_{bm} and Y_{mb} are the mean yields of barley and annual medic in intercropping.

Relative crowding coefficient (RCC) is a measure of relative dominance of one component crop over the other in an intercropping system. For crop 'a' in association with 'b':

$K_{bm} = Y_{bm}\, X_{mb} / (Y_{bb} - Y_{bm})\, X_{bm}$

where X_{bm} is the proportion of barley in a mixture with annual medic and X_{mb} is the proportion of annual medic in mixture with barley. If the product of the two coefficients; i.e. $K = (K_{bm}\, K_{mb})$ is greater than 1, there is a yield advantage for intercropping whereas $K=1$ indicates of no yield advantage. When K value is less than unity, there is a yield disadvantage of intercropping system compared with monoculture (Ghosh, 2004).

Aggressivity represents a simple evaluation of the relative yield increase in 'a' crop over 'b' crop in an intercropping system and can be calculated as follow:

$A_{bm} = (Y_{bm} / Y_{bb}\, X_{bm}) - (Y_{mb} / Y_{mm}\, X_{mb})$

When A_{bm}= 0, both crops are equally competitive, if A_{bm} is positive, barley is dominant, whereas if A_{bm} is negative, annual medic is considered dominant crop.

Competition ratio (CR) indicates the degree that one species competes with the other component in an intercropped system (Willey and Rao, 1980).

$CR_b = (LER_b / LER_m)\, (X_{mb} / X_{bm})$

The CR represents the ratio of individual LERs of the two intercropped components and takes into account the proportion of the crops in which they are initially planted.

When CR is below 1 there is a positive benefit for intercropping and the species can be grown in a mixture.

The monetary advantage index (MAI) was calculated as described by Ghosh (2004).

MAI = monetary value of combined intercrops × (LER−1) / LER.

The higher the index value, the more profitable is the cropping system (Dhima et al., 2007).

Analysis of variance was performed using SAS statistical software version 9.1 (SAS Institute, 2003). Effects were considered significant for P-values ≤ 0.05 from the F-test. Duncan multiple range test was conducted for mean comparison.

Conclusion

The results of this study revealed that the total protein yield of barley and annual medic forage in selected intercropping patterns could be enhanced while the total harvested dry matter remained unchanged. The calculated LER exceeded unity in most cropping systems, indicating that intercropping was advantageous over monocropping due to higher exploitation of the limited environmental resources. LER values along with SPI and MAI values demonstrated the economic feasibility of cropping systems particularly, in 1B:1M (one row barley: one row annual medic) cropping pattern, where the highest LER, SPI, and MAI values were recorded. Overall, 1B:1M cropping pattern can be recommended to growers in arid and semi-arid environments as a more sustainable management practice to improve forage quality and therefore to enhance economic benefit for forage production.

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