

Evaluation of Forage Yield and Competition Indices for Intercropped Barley and Legumes

Abdollah Javanmard, Fariborz Shekari, Hasan Dehghanian

II. MATERIALS AND METHODS

Abstract—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 investigate forage yield and competition indices. 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 barley₂₅-grasspea₇₅ (5.44 t ha⁻¹) mixture, followed by grass pea sole crop (4.99 t ha⁻¹). The total actual yield loss (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 land equivalent ratio (LER), system productivity index (SPI) and monetary advantage index (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, land equivalent ratio (LER), monetary advantage.

I. INTRODUCTION

INTERCROPPING of cereals and legumes is important for the development of sustainable food production systems, particularly in cropping systems with limited external inputs [14]. This may be due to some of the potential benefits for intercropping systems such as high productivity and profitability [11], improvement of soil fertility through the addition of nitrogen by fixation and excretion from the component legume [9], efficient use of resources, reducing damage caused by pests, diseases and weeds [13], control of legume root parasite infections [8], provides better lodging resistance [2], yield stability [7], and improvement of forage quality through the complementary effects of two or more crops grown simultaneously on the same area of land [10]. 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.

Abdollah Javanmard is with the Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Maragheh, P.O. Box 55181-83111, Iran. C- Department of Agronomy and Plant Breeding, Faculty of Agriculture, University of Tabriz, Iran (e-mail: javansohaib@gmail.com).

A field experiment was conducted at the Research Station (latitude 37° 23' N, longitude 46° 16' E, altitude 1485 m) of the Faculty of Agriculture, University of Maragheh, Maragheh, Iran, in 2013 growing season. Barley (*Hordeum vulgare* 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 legume monocrops were 204, 118.8 and 247 Kg ha⁻¹, respectively (corresponding to 400, 250 and 250 seeds per m² 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 m² 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 m² 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 m² 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. At the stages of harvest samples from a 2 m² 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 [11]. The LER was calculated as:

$$LER = (LER_b + LER_L) = \left(\frac{Y_{bL}}{Y_{bb}}\right) + \left(\frac{Y_{Lb}}{Y_{LL}}\right), \quad (1)$$

where Y_{bb} and Y_{LL} are the yields of barley and legumes as a 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 [16]:

$$CR_{barley} = \left(\frac{LER_{barley}}{LER_{legume}}\right) \times \left(\frac{Z_{Lb}}{Z_{bL}}\right),$$
$$CR_{legume} = \left(\frac{LER_{legume}}{LER_{barley}}\right) \times \left(\frac{Z_{bL}}{Z_{Lb}}\right), \quad (2)$$

Another coefficient uses 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

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

where K_{bL} and K_{Lb} are relative crowding coefficient for barley and legume intercrop, respectively.

Monetary advantage index (MAI) was calculated as:

$$MAI = \left[\frac{(\text{value of combined intercrops}) \times (LER - 1)}{LER} \right] \quad (4)$$

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 [9], where P_{barley} is the commercial value of barley silage (the current price is €31 per Mg), and P_{legume} is the commercial value of legumes silage (the current price is €42 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 significant differences (LSD) at $P < 0.05$.

III. RESULTS AND DISCUSSION

A. Dry Matter Yield

Intercropping system significantly affected dry matter yield of barley, legumes and total dry matter yield (Table I). Barley and legumes produced more yield in monocrops compared to intercrops. The higher dry matter production of monocropped barley and legumes relative to intercropping treatments may be due to the less disturbances in the habitat in homogeneous environment under monocropping [17]. 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 [17]. Reference [7] 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 barley₂₅:grass pea₇₅ (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 [6], [11]. Our findings were relatively similar to [15] who reported that pea (*Pisum sativum* L.) barley intercrops produced the greatest dry matter yield. 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 [5], [15]. In general, pure grass pea and the mixture

were better than pure vetch and barley and their mixtures (Table I). 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 a 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 [15].

B. Proportion of Legume in Forage Dry Matter

The analyses of variance for the proportion of legume in dry matter indicated that there were significant differences among mixtures (Table I). In general, the 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 I). 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 [11]. Also, poor legumes performance may be attributed to its short stature relative to barley, and slow early-season growth that may have given barley a competitive advantage [15].

C. Relative Yield Total (RYT)

Relative yield of legumes decreased, and that of barley increased as barley seeding proportions increased (Table I). 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 [11]. The relative yield of barley in mixtures with vetch and mixture of barley₇₅:grass pea₂₅ was higher than that of barley₂₅:grass pea₇₅ and barley₅₀:grass pea₅₀ mixtures. This was probably because of the lower legume contribution in mixtures of vetch with barley and barley₇₅:grass pea₂₅ as compared with the mixtures of barley₂₅:grass pea₇₅ and barley₅₀:grass pea₅₀.

D. Land Equivalent Ratio (LER)

Partial LER of legumes increased as the proportion of barley decreased (Table II). Partial LER_{vetch} was lower as compared with the LER_{grass pea}. The partial LER_{barley} was higher than 0.5 in the grass pea₂₅:barley₇₅, vetch₅₀:barley₅₀ and vetch₂₅:barley₇₅ 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 barley₂₅:grass pea₇₅, barley₅₀:grass pea₅₀ and

vetch₇₅:barley₂₅ 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 (1.16) at the 75:25 seeding ratio (Table II). This indicates an advantage from intercropping over pure stands in terms of the use of environmental resources for plant growth and better land utilization [8]. Mean values of LER ranging from 0.96 to 1.21 were obtained from different mixed proportions of barley and legumes. Reference [8] found LER values from 1.05 to 1.09 in mixtures of common vetch with different grain cereals such as wheat, triticale, barley and oat.

E. Relative Crowding Coefficient

The partial K values of barley were higher than partial K of legumes in the case of grass pea₇₅-barley₂₅, vetch₇₅-barley₂₅ and vetch₅₀-barley₅₀ intercrops (Table II). This indicates that barley is more competitive than associated crop [8]. However,

K_{legume} was higher than the K_{barley} in the case of grass pea₅₀-barley₅₀, grass pea₂₅-barley₇₅ and vetch₂₅-barley₇₅ 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 K value was above one in the case of grass pea₅₀-barley₅₀, grass pea₂₅-barley₇₅, vetch₇₅-barley₂₅ and vetch₅₀-barley₅₀ mixtures, which indicates a definite yield advantage due to intercropping [4]. In vetch₂₅-barley₇₅ mixture, the K value was below one, which indicates that there was a yield disadvantage [9].

TABLE I
DRY MATTER YIELD (T HA⁻¹), LEGUME CONTRIBUTION AND RELATIVE YIELDS OF MONOCULTURES AND MIXTURES OF BARLEY WITH GRASSPEA 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 -grasspea ₇₅	1.10	4.34	5.44	79.38	0.339	0.872	1.21
Barley ₅₀ -grasspea ₅₀	1.27	3.64	4.92	74.12	0.399	0.732	1.13
Barley ₇₅ -grasspea ₂₅	2.46	1.87	4.33	43.11	0.744	0.379	1.12
grasspea	-	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 II
LAND EQUIVALENT RATIO (LER) AND RELATIVE CROWDING COEFFICIENT (K) FOR SOLE STANDS AND MIXTURE OF BARLEY WITH GRASSPEA 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 -grasspea ₇₅	0.339	0.872	1.21	1.54	-2.36	-3.53
Barley ₅₀ -grasspea ₅₀	0.399	0.732	1.13	0.72	4.39	4.006
Barley ₇₅ -grasspea ₂₅	0.744	0.379	1.12	1.61	2.19	2.41
Grasspea	-	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

F. Competitive Ratio (CR)

Intercropped grass pea and vetch had higher competitive ratio in barley₅₀-grass pea₅₀, barley₇₅-grass pea₂₅ and barley₇₅-vetch₂₅ mixtures respectively, indicating that grass pea and vetch is more competitive than barley in these intercropping systems (Table III). 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.

G. System Productivity Index (SPI)

The highest system productivity index (SPI) was found in barley₂₅-grass pea₇₅ mixture, in which LER had also greater values (Table IV), indicating higher productivity and stability

of these intercrops [1]. Similarly, [12] reported that the SPI of sorghum-cowpea (1:3) mixture showed greater yield stability than of other mixtures.

H. Monetary Advantage Index (MAI)

The MAI values were positive (except for the barley₅₀-vetch₅₀ and barley₇₅-vetch₂₅ mixtures), which indicates a definite yield advantage due to intercropping [11]. The value of MAI was higher in barley-grass pea mixtures than the barley-vetch mixtures (Table IV). 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 barley₇₅-vetch₁₅. These findings are also parallel to those of LER and competitive indices. References [8] and [9] reported that if LER was higher, there was also economic benefit expressed with MAI values. Reference [3] 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.

TABLE III
COMPETITIVE RATIO (CR) FOR MIXTURES OF BARLEY WITH GRASS PEA AND VETCH IN THREE SEEDING RATIOS

Crop	Competitive ratio	
	CR _{barley}	CR _{legume}
Barley ₂₅ -grasspea ₇₅	1.191	0.857
Barley ₅₀ -grasspea ₅₀	0.539	1.846
Barley ₇₅ -grasspea ₂₅	0.771	1.629
Barley ₂₅ -vetch ₇₅	2.277	0.465
Barley ₅₀ -vetch ₅₀	1.428	0.739
Barley ₇₅ -vetch ₂₅	0.820	1.269
LSD _{0.05}	0.679	0.842

TABLE IV
MONETARY ADVANTAGE INDEX (MAI) AND SYSTEM PRODUCTIVITY INDEX (SPI) FOR MIXTURES OF BARLEY WITH GRASSPEA AND VETCH IN THREE SEEDING RATIOS

Crop	MAI	SPI
Barley ₂₅ -grasspea ₇₅	37.21	8.66
Barley ₅₀ -grasspea ₅₀	20.69	7.80
Barley ₇₅ -grasspea 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

IV. CONCLUSION

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. 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 barley₂₅-grass pea₇₅ and barley₅₀-grass pea₅₀. 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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