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Evaluation of grain yield and yield components in intercropping of maize and bean

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Abstract. Intercropping is a practice of growing more than one crop simultaneously in alternating rows of the same field. The present experimental plots were laid out in a randomized complete block design with three replications. Field experiment comprised five treatments including three different intercropping patterns (3:1, 2:2 and 1:3) and monocultures of common bean and maize. Analysis of variance indicated that cropping system influenced significantly bean and maize characters. The seed yield of bean in sole planting (1672.35 kg ha^{-1}) was significantly higher to rest of the treatment combinations. The ratio of 3 Maize: 1 bean intercropping recorded significantly higher grain yield (13044 kg ha^{-1}). The partial land equivalent ratio (LER_{bean}) values were higher than 0.50 in the 3:1 rows (bean: maize) mixtures. However, the partial LER_{maize} was higher than 0.50 in all planting ratios except of 1:3 rows (maize: bean). The highest value of LER was obtained in 3:1 (maize: bean) cropping pattern. The total relative crowding coefficient (RCC) was much higher than one in the all of the intercropping systems, which indicating there is a yield advantage for intercropping. The Competitive ratio value (CR) of bean was less than maize, which this means that bean is less competitive than maize in the intercropping system. It is concluded that maize and bean intercropping systems do have a substantial yield advantage compared to single crop systems.

Key words: bean**,** corn, intercropping, sole cropping, yield advantage.

Introduction

Intercropping is a method for growing of more than one crop concurrently in alternating rows of the same field (Beets 1990). Intercropping with maize has several advantages such as increase in yield per area of land, reduction in farm inputs, diversification of diet, addition of cash crops, increased labor utilization efficiency, reduced risk of crop failure and led to a staple crop (Willey 1985). Intercropping maize with a legume reduced the amount of nutrients captured from the soil in comparison to a sole maize cropping (Adu-Gyamfi et al. 2007).

Different competition indices calculated the advantage of intercropping and the effect of competition between the two species. The effectiveness of intercropping according to used of the resources of the environment in comparison to sole cropping was indicated by land equivalent ratio (LER). LER was utilized to compare the yields of monocropped and intercropped fields and indicated the requirement of relative land area growing in sole crops to produce the yields obtained when growing intercrops (Willey 1985). Relative crowding coefficient (RCC) is the second coefficient that is a measure of the relative dominance of one species over the other in a mixture (Banik et al. 2006). The other way to estimate competition between different species is competitive ratio (CR), which gives more desirable competitive ability for the crops and is also beneficial than RCC. The competitive ratio is an important tool for determination of competitive ability of one crop with the other (Willey & Rao 1980, Dhima et al. 2007).

Many researchers studied the intercropping of maize and bean crops. Rao & Morgado (1984) stated the optimum plant population for maize in sole cropping is 40,000 plants ha^{-1} under rainfed conditions and the half of this population may be used in intercropping in row arrangements of one row of maize to two or three rows of beans. Morgado & Willey (2008) studied the maize-bean intercropping system and indicated the grain yields of maize and beans were influenced by intercropping and the effect was more detrimental to the legume mainly at the highest maize plant population. Tsubo et al. (2005) studied the intercropping of maize and bean and indicated that initial soil water content has the greatest influence on intercropping productivity. The maize yield is not affected by bean intercropping due to not influence of bean plant density on maize or bean yields, while the yields of bean were decreased in the intercropped system. Shahbazi & Sarajuoghi (2012) evaluated maize yield in an intercropping with mung bean and indicated that 3:1 (maize: mung bean) ratio provided the highest yield and yield components. Yilmaz et al. (2008) compared the alternate planting combinations of maize and common bean with sole cropping of each species. Competition indices indicated in comparison to solitary cropping, the maize- bean intercropping, without considering planting patterns, at the mix proportions of 67:50 plant density had advantages due to its better yield, land use efficiency, and economics. Tsubo and Walker (2002) studied the maize–bean intercropping and indicated the highest yield has been recorded in many intercropping systems in comparison to monocropping. Echarte et al. (2011) reported that yield reductions from sole crop to intercrop at maize–sunflower intercropping averaged 20%. Alford et al. (2003) indicated maize grain yields were reduced by the presence of pasture legume in some treatments, while others were comparable to the check yields. Black medic (*Medicago lupulina* L.) did not reduce maize yields, but barrel medic (*M. truncatula* Gaertn.) and sphere medic (*M. sphaerocarpus* L.) reduced maize yields by 17%. Baributsa e al. (2008) indicated interseeded cover crops such as red clover (*Trifolium pratense* L.) or chickling vetch (*Lathyrussativus* L., var. AC Greenfi x) did not affect maize yield. Herbert et al. (1984) indicated the advantageous of intercropping of maize and soybean (*Glycine max* (L.) Merr) in alternating rows compared to sole culture of two crops. Bryan and Materu (1987) studied the intercropping of maize with three species of legumes containing climbing beans, cowpeas and velvet beans and revealed maize–cowpeas produced more total dry matter than maize–climbing beans. Cowpeas increased the total yield of crude protein by over 15% without lowering total dry matter yield of the intercrop compared to maize alone and are as a favorable legume for intercropping with maize.

The objectives of this study were to improve the understanding of maize and bean yield determination in maize–bean intercrops, and to estimate the effect of competition within maize-common bean intercropping.

Material and Methods

This study were carried out during 2011 and 2012 growing seasons at Rezvanshar (37° 54' N and 49° 12 'E) in Guilan, Iran, which lies at an altitude of 15 m above sea level.

The experimental plots (12:0m × 3:0m) were laid out in a randomized complete block design with three replications. Field experiments comprised five treatments including three different intercropping patterns and monocultures of common bean (*Phaseolus vulgaris* L. cv. a landrace from Guilan) and maize (*Zea mays* L. cv. 704 S.C.). The intercropping treatments included one row of maize between three rows of common bean, two rows of common bean between two rows of maize and one row of common bean between three rows of maize. The spaces for maize and common bean were 60 × 20 cm and 60 × 10 cm, respectively. A basal application of 100 kg ha^{-1} Di Ammonium Phosphate, 100 kg ha^{-1} Potassium Soleplate and 1/2 of the urea (50 kg ha^{-1}) was applied to plot in the furrow before planting. The remainder of the urea (50 kg ha^{-1}) was applied at 25 days after sowing.

The plots were maintained clean by weeding three times and insect pests were controlled by application of insecticides. Ten plants from each plot were sampled randomly for the determination of yield components. The whole plot was harvested for bean and maize seed yield. The traits containing number of rows per ear, number of grains per row, number of ears per plant, number of grains per ear, hundred grain weight, biomass yield and seed yield were measured in maize. The measured traits in bean included number of pods per plant, number of seeds per pod, pod length, seed width and length, hundred seed weight and seed yield.

Competitions indices and monetary advantages

The benefit of intrcropping and the effect of competition between the bean and maize in this experiment were calculated using different competition indices. The land equivalent ratio (LER) is calculated by dividing the amount of the intercropped yield by the amount of the monocropped yield for each crop in the field. Add the partial LERs together to find the total LER. LER greater than one indicates that more sole cropped land than intercropped is required to produce a given amount of product. In contrast, when LER is lower than 1, the intercropping negatively affects the growth and yield of plants grown in mixtures (Willey, 1979). The LERs were calculated using this formula (Dhima et al., 2007):

$$LER_{maize} = \frac{Y_{mb}}{Y_m}$$

$$LER_{bean} = \frac{Y_{bm}}{Y_b}$$

$$LER = LER_{maize} + LER_{bean}$$

Where, Y_m and Y_b are the yields of maize and bean as sole crops, respectively. Y_{mb} and Y_{bm} are the yields of maize and bean as intercrops, respectively.

The second coefficient index was the relative crowding coefficient (RCC) which is calculated as: (Yilmaz 2008).

$RCC = (RCC_{maize} \times RCC_{bean})$, where

$RCC_{maize} = (Y_{mb} \times Z_{bm})/[(Y_m - Y_{mb}) \times Z_{mb}]$, and

$RCC_{bean} = (Y_{bm} \times Z_{mb})/[(Y_b - Y_{bm}) \times Z_{bm}]$.

Where, Z_{mb} and Z_{bm} were the proportions of maize and bean in the mixture, respectively. When the value of RCC is greater than 1, there is a yield advantage; when RCC is equal to 1, there is no yield advantage; and, when it is less than 1, there is a disadvantage (Dhima et al., 2007).

The CR represents the ratio of individual LERs of two crops and takes into account the proportion of the crops in which they are initially sown. Then, the CR index was calculated using the following formula (Dhima et al. 2007):

$CR_{maize} = (LER_{maize} / LER_{bean})(Z_{bm} / Z_{mb})$, and

$CR_{bean} = (LER_{bean} / LER_{maize})(Z_{mb} / Z_{bm})$

Data analysis

All measured variables were assumed to be normally distributed and statistical analyses by ANOVA were performed using SAS software (SAS 2002). The significance of difference between treatments were estimated using the least significance differences test (LSD) with α=0.05 if a main effect was significant.

Results and Discussion

Analysis of variance

Analysis of variance indicated that cropping system significantly influenced bean characters including number of pods per plant, pod length, seed length and width, hundred seed weight and seed yield (Table 1). Analysis of variance also indicated maize grain yield, hundred grain weight, number of grains per ear and number of ear per plant were significantly responsive to cropping system (Table 2).

The comparison of mean

Bean yield and yield components

Cropping systems differed significantly for bean seed yield. The seed yield of bean in sole planting (1672.35 kg ha^{-1}) was significantly higher to rest of the treatment combinations. Among different cropping systems, 1 maize + 3 bean (1334.67 kg ha^{-1}), 2 maize + 2 bean (702.50 kg ha^{-1}) and 3 maize + 1 bean (263.41 kg ha^{-1}) recorded lowest seed yield, respectively. Therefore, significantly lower bean seed yield (263.41 kg ha^{-1}) was recorded with one row of common bean and three rows of maize. The pod length of bean was significantly influenced due to inclusion of intercrop. Significantly higher pod length (13.6 cm) was recorded in sole bean cropping. Significantly lower pod length (11.43 cm) was recorded in intercropping of 3:1 (maize: bean) ratios. The seed length and width of sole bean and all of bean–maize combinations were on par with each other. Cropping systems differed significantly for hundred seed weight. Significantly higher hundred seed weight (46.66 g) was recorded in sole bean system over rest of the treatment combinations. Among different cropping systems, 3 maize + 1 bean (35 g) recorded lowest hundred seed weight. Treatments differed significantly for number of seeds per pod and number of pods per plant. Number of seeds per pod (5.3) and number of pods per plant (24.22) were significantly higher for sole bean cropping than the other combinations. However, significantly lower number of seeds per pod (4.13) and number of pods per plant (11.87) was recorded in 3 maize: 1 bean intercropping system (Table 3).

Maize yield and yield components

The data recorded on maize yield and yield components at

Table 1. Analysis of variance for yield and yield components of bean in intercropping ratios.

SOV	df	MS						
		SY	PL	HSW	SW	SL	NSP	NPP
Block	2	10341.58^{ns}	0.11^{ns}	8.33	0.003^{ns}	0.043^{ns}	0.017^{ns}	6.70^{ns}
Intercropping system	3	1194902.75**	2.44**	72.22**	0.084**	0.054^{ns}	0.78^{ns}	83.66*
Error	6	4863.58	0.17	5.55	0.0077	0.067	0.33	11.62
C.V (%)		7.02	3.31	5.65	1.16	2.30	12.63	19.58

ns: Not significant; * and**: Significant at 5% and 1% probability levels, respectively.
NPP: number of pods per plant; NSP: number of seeds per pod: PL: pod length: SL: seed length; SW: seed width; HSW: hundred seed weight; SY: seed yield.

Table 2. Analysis of variance for yield and yield components of maize in intercropping ratios.

SOV	df	MS					
		GY	HSW	NGE	NEP	NGR	NRE
Block	2	18828.0^{ns}	6.25^{ns}	75.83**	0.017^{ns}	5.35^{ns}	0.003^{ns}
Intercropping system	3	50349600**	466.66**	18279.69**	0.21**	30.10^{ns}	0.888*
Error	6	11196.00	22.91	13.97	0.013	9.5	0.10
C.V (%)		8.07	9.57	0.54	5.64	6.45	0.66

ns: Not significant; * and**: Significant at 5% and 1% probability levels, respectively.
NRE: number of rows per ear: NGR: number of grains per row; NEP: number of ears per plant; NGE: number of grains per ear: HSW: hundred grain weight; GY: grain yield.

Table 3. Mean comparison of yield and yield components of bean in intercropping ratios.

Planting ratio (B:bean -M:maize)	SY (kg ha^{-1})	PL (cm)	HSW (g)	SW (mm)	SL (mm)	NSP	NPP
BBBB(0%-100%)	1672.35^{a}	13.6^{a}	46.66^{a}	7.6^{a}	11.5^{a}	5.3^{a}	24.22^{a}
MBBB(25%-75%)	1334.67^{b}	12.76^{b}	43.33^{ab}	7.73^{a}	11.33^{a}	4.33^{ab}	18.43^{ab}
MMBB(50%-50%)	702.50^{c}	12.33^{b}	41.66^{b}	7.6^{a}	11.20^{a}	4.53^{ab}	15.1^{b}
MMMB(75%-25%)	263.41^{d}	11.43^{c}	35.00^{c}	7.33^{b}	11.5^{a}	4.13^{b}	11.87^{b}

M: Maize; B: Bean; NPP: number of pods per plant; NSP: number of seeds per pod: PL: pod length: SL: seed length; SW: seed width; HSW: hundred seed weight; SY: seed yield.

Table 4. Mean comparison of yield and yield components of maize in intercropping ratios.

Planting ratio (B:bean -M:maize)	GY (kg ha^{-1})	HSW (g)	NGE	NEP	NGR	NRE
MBBB(25%-75%)	3892^{d}	46.63^{b}	753.68^{a}	2.3^{a}	48.83^{ab}	15.13^{b}
MMBB(50%-50%)	10456^{c}	66.66^{a}	741.3^{b}	2.13^{ab}	49.3^{a}	14.6^{c}
MMMB(75%-25%)	13044^{a}	50^{b}	690.5^{c}	2^{b}	49.96^{a}	15^{b}
MMMM(100%-0%)	11920^{b}	36.51^{c}	582.36^{d}	1.66^{c}	43.1^{b}	15.91^{a}

M: Maize; B: Bean; NRE: number of rows per ear: NGR: number of grains per row; NEP: number of ears per plant; NGE: number of grains per ear: HSW: hundred grain weight; GY: grain yield.

different intercropping ratios are indicated in Table 4. Three rows of maize and one row of bean intercropping ratio recorded significantly higher grain yield (13044 kg ha^{-1}). Among different intercropping systems, maize in sole cropping, Maize + bean (2:2) and Maize + bean (1:3) recorded lowest seed yield of 11920, 10456 and 3892 kg ha^{-1}, respectively. Among the intercropping treatments, maize + bean intercropping (2:2) recorded significantly higher hundred grain weight in maize (66.66 g) over rest of the treatments. Significantly lower hundred grain weight in maize (36.51 g) was recorded in sole maize cropping. The intercropping of Maize + bean (1:3) recorded significantly higher number of grains per ear over the other treatment combinations. Significantly lower number of grains per ear was observed in sole maize cropping system. Maize + bean (1:3) recorded significantly higher number of ears per plant (2.3) over rest of the treatment combinations. Maize in sole cropping recorded significantly lower umber of ears per plant (1.66) compared to the other intercropping ratios. Among the treatment combinations, 3:1, 2:2 and 1:3 (maize: bean) intercropping recorded significantly higher number of grains per row in maize (49.96, 49.3 and 48.83, respectively). At the same time, the highest number of rows per ear (15.91) was recorded for maize in sole cropping.

Competitive indices

The highest bean actual seed yield (1334.67 kg ha^{-1}) was obtained from 1:3 (maize: bean) planting ratio and the lowest one was from 3 maize: 1 bean (Table 5). The highest grain yield of maize was obtained from 3:1 (maize: bean) mixture, while the lowest one was from 1 maize: 3 bean mixture. The comparison of actual and expected values of bean yield indicated that actual yield were higher than expected one, in 1:3 (maize: bean) cropping treatment and lower in the other

Table 5. Actual and expected yield of bean intercropping with maize.

Planting ratio (B:bean -M:maize)	Expected yield (kg ha^{-1})	Actual yield (kg ha^{-1})	Actual yield: Expected yield
MBBB(25%-75%)	1254.263	1334.67	+6.41
MMBB(50%-50%)	836.175	702.50	-15.99
MMMB(75%-25%)	418.0875	263.41	-37.00

M: Maize; B: Bean;

Table 6. Actual and expected yield of maize in intercropping with bean.

Planting ratio (B:bean -M:maize)	Expected yield	Actual yield	Actual yield: Expected yield
MBBB(25%-75%)	2980	3892	+30.60
MMBB(50%-50%)	5960	10456	+75.44
MMMB(75%-25%)	8940	13044	+45.91

M: Maize; B: Bean;

Table 7. Effect of planting ratios on intercropping efficiency of bean-maize.

Planting ratio (B:bean -M:maize)	LER_{bean}	LER_{maize}	LER	RCC bean	RCC maize	Total RCC	CRmaize	CRbean
MBBB(25%-75%)	0.80	0.27	1.08	1.31	1.16	1.54	1.01	0.95
MMBB(50%-50%)	0.42	0.75	1.17	0.72	3.02	2.19	1.79	0.56
MMMB(75%-25%)	0.16	0.94	1.09	0.56	4.96	2.79	1.98	0.51

LER: Land Equivalent Ratios; RCC: Relative Crowding Coefficient; CR: Competitive ratio.

intercropping ratios (Table 5). This comparison indicated that actual yield of maize were higher than expected value in the all of the intercropping ratios (Table 6).

Partial LER of bean reduced as the proportion of maize increased in mix-proportions (Table 7). The partial LER_{bean} values were higher than 0.5 in the 3:1 rows (Bean: maize) mixtures. However, the partial LER_{maize} was higher than 0.5 in all planting ratios except of 1 maize: 3 bean. The LER of the intercrops varied from 1.08 to 1.17. The lowest value of LER was recorded from 1:3 (maize: bean) cropping system. The highest value of LER was obtained in combination of one row of bean between three rows of maize.

The total RCC was much higher than one in the all of the intercropping systems, which indicating there is a yield advantage. The highest RCC value (2.79) was obtained in 3 maize: 1 bean intercropping combination, while the lowest one (1.54) was recorded in 1:3 (maize: bean) ratios. The lowest value of RCC for bean (0.56) were observed in 3:1 (maize: bean) ratio, that indicating competitive ratio were high for bean in this intercropping system. Therefore, this intercropping ratio is not effectiveness for bean; while in 1:3 (maize: bean) ratios, intercropping can be competence for bean according its RCC is greater than 1.

Competitive ratio (CR) of maize and bean populations under different intercropping ratios was computed and the results were indicated in Table 7. Intercropped maize had higher competitive ratios in all planting patterns. Among the different row ratios of bean and maize intercropping, 1:3 (bean: maize) ratio indicated the lowest value of competitive ratio (0.51) for bean and highest value (1.98) for maize. These results recommended that among intercropping systems of bean and maize, the 1:3 (bean: maize) intercropping ratio were a better competitor in comparison to other planting patterns. The maize population strongly competed over bean in this row ratio intercropping system. But the bean population strongly competed over maize in 3:1 (bean: maize) rows ratio.

Discussion

One of the main advantages of intercropping is an increase in yield per area of land. The land equivalent ratio (LER) was developed to compare yields of mono-cropped and intercropped fields and provides an accurate assessment of the biological efficiency of the intercropping situation. The partial LERs in the all of maize–bean intercropping systems were less than one, the total LER were higher than one in all of the intercropping combinations. For example in 2:2 (maize: bean) intercropping ratio, intercropped beans produce 0.42 the yield of sole beans and the intercropped maize produce 0.75 of the yield of monocropped maize. When added together, the partial LERs create a total LER of 1.17, which means that 17% more land in the monocultures is required than that in the intercropping for producing same yield (Willey 1985). The trade-off between increasing the yield of suppressing species and decreasing that of the suppressed species has three possible outcomes for intercropping systems, including yield advantage (LER > 1), yield disadvantage (LER < 1), and the intermediate result (LER = 1) (Vandermeer 1989). These findings indicate that intercropping improved total land productivity as supported by greater LER. Therefore, the maize–bean intercropping system could improve land-use efficiency considerably. Most of the actual yield of maize was higher than expected, whereas the bean gave only more yield than expected under 1:3 (maize: bean) row ratio intercropping. It shown that the relative crowding coefficient (RCC) of the maize was greater than 1 in all the treatments, indicating yield advantage compared with their monoculture due to reciprocal cooperation. In this experiment, the higher values of LER and RCC to unity indicated crop complementarities in bean–maize intercropping and greater yield advantage. This corroborated the findings of Willey (1979) and Reddy & Willey (1981).

The CR was grater than unity for maize in the all of the studied combinations and lower to one for bean. The CR value of bean was less than maize, indicating that bean in the intercropping system is less competitive than maize. This clearly indicates that maize were more competitive. According to Willey & Rao (1980), CR gives a better measure of competitive ability of the crops and can prove a better index as compared with RCC. The findings of present study due to LER, RCC and CR shows an advantage in yield compared with sole crops and proposes that bean in the intercropping system is less competitive than maize.

Grain yields of the two crops in the intercropping were less than those in the monocultures in all of the intercropping combinations, except for 3:1 (maize: bean) ratio. The reduction in yield due to intercropping was more pronounced in bean as compared to maize because of higher requirement of moisture and nutrients of bean than maize. Total yield of maize–bean intercrop was also greater than sole bean yield, but it was similar or lower than that of sole maize, except of 3:1 (maize: bean) ratio. In this combination treatment, the yield of maize in intercropping was higher than sole maize. Similar results were reported by Aggarwal & Sidhu (1988) that indicated that yields of cereal–legume intercrops have been found to be less than those of the sole cereal. Albrizio & Steduto (2005) concluded that comparisons based on grain yield per unit area between monocropping and intercropping of maize and soybean is biased since these species differ in radiation use efficiency (i.e. C3 vs. C4) and grain composition, therefore in the amount of grain produced per unit energy and reduced carbon (Andrade 1995).

Seed yield of sole bean (1672.35 kg ha^{-1}) were higher than their intercropping system. The highest seed yield of the sole cropped bean might be attributed due to more vigorous growth with favorable space, sunlight, air and nutrient availability or less interspecific competition (Chang & Shibles 1985; Willey 1990; Helenius & Jokinen 1994). These results are supported well by the findings of Morgado & Willey (2008), Tsubo et al (2005), Tsubo & Walker (2002) and Yilmaz et al (2008). Agegnehu et al (2006) and Xu et al (2008) concluded in maize–bean intercropping crops in an intercropping mixture is a common phenomenon. In this experiment, there was also significant variation of seed yield among the intercropping ratios of maize–bean in comparison to monocropping.

Conclusions

This study provides an understanding on the eco-physiological processes affecting yield determination in two intercrops. The LER were greater than 1 in all of intercropping system, indicating that the intercropping favors the growth and yield of the both species.. Intercropping bean and maize increased LER to values exceeding 1, indicating yield advantage in this study. Bean did not benefit from intercropping to the same degree as maize. However, growing bean between maize rows (1:3) could produce additional yield in the intercropping system without jeopardizing the yield of maize. Seed yield of bean intercropped with maize was reduced due to suppressive effect of fodder. It is concluded that maize and bean intercropping systems do have a substantial yield advantage compared to single crop systems.

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